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"OekoapfelForward": New strategies for codling moth resistance management and fungicide reduction in organic apple production

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Abstract

Nearly 20 years of monitoring revealed progressing resistance of Cydia pomonella *(codling moth) field populations towards Cydia pomonella granulovirus (CpGV) products in organic pome fruit production. Hence, there is urgent need to optimize strategies for the CpGV application to further reduce the pressure for resistance development. In the recently started joint project, "OekoapfelForward", we evaluate newly discovered virus isolates on resistant* C. pomonella *strains and their robustness towards changing weather patterns due to climate change. This contribution provides an overview of the main objectives in "OekoapfelForward" to improve resistance management and pesticide reduction for organic pome fruit production.*

Keywords: Codling moth, granulovirus, resistance management, fungicides, climate change

Cydia pomonella resistance towards CpGV

Organic apple production faces significant challenges in managing pests and diseases while adhering to strict organic regulations. Among the most damaging pests is the codling moth (CM, *Cydia pomonella*) and the combined use of mating disruption with Cydia pomonella granulovirus (CpGV) applications are the most important measures of the control strategy. However, the emergence of resistance in CM populations to CpGV products poses a significant risk to their long-term effectiveness and potential economic losses for growers. Before alternative CpGV isolates became available, the development of resistance had been primarily attributed to the repeated and exclusive use of CpGV products containing the same virus isolate, which exerted strong selection pressure on CM populations. Seven phylogenetic lines of CpGV isolates (genome groups A-G) are known (Eberle et al., 2009; Gebhardt *et al*.; 2014; Wennmann *et al*.; 2017, Fan *et al*., 2020ab). Genetic analyses and resistance testing revealed three different types of resistance in CM (type I-III) differing in their mode of inheritance and resistance mechanism (Asser-Kaiser *et al*., 2007; Jehle *et al*., 2017; Sauer *et al*., 2017ab). While CpGV of genome group E (isolate CpGV-S) can overcome resistance type I (against group A, isolate CpGV-M), nowadays only CpGV products containing genome group B (isolate CpGV-E2) effectively control CM population expressing resistance types II-III against virus isolates of genome groups A, D, and E. However, first reports from Italy and France of insufficient CM control with genome group B CpGV are raising concern of emergence of a new resistance type, without new potential resistance-breaking virus isolates at hand (Siegwart *et al*., 2020).

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Status quo in the development of CpGV-resistance in German *C. pomonella* populations

Since the first records of CM populations resistant to commercial CpGV products in Germany in 2004, extensive resistance monitoring was conducted in different regions in Germany (Fritsch *et al*., 2005; Schmitt *et al*., 2013). Codling moth infestation in organic orchards with suspicious populations was assessed and further analysed in resistance biotests (Schulze-Bopp *et al*. 2013). Altogether, in spring 2022, 64 CM populations resistant to CpGV products containing single virus isolates as well as mixtures (genome group A and E, i.e. CpGV-M and –S; genome group E and B, i.e. CpGV-S and –E2; Gebhardt *et al*. 2014) were known in Germany (Fritsch *et al*., 2022). In the years 2022 and 2023, two new CM populations resistant to CpGV products containing genome group A and E (isolates CpGV-M and –S, resistance type II) were found.

However, the number of new resistant populations is decreasing since 2020. In the years 2022 and 2023 only two new populations were discovered being resistant although several suspicious populations were tested (Table 1). Hence, the pace of resistance development decelerated.

Although resistance was mainly restricted to genome groups A and E in the past years, hints on lowered efficacy of the resistance-breaking genome group B CpGV (CpGV-E2) with sole emergency registration in Germany have made further monitoring and testing of new virus isolates from other genome groups important cornerstones in this project.

Table 1: Occurrence of CpGV resistance in organic apple growing in Germany 2004 – 2023, verified in laboratory bioassays with L1 larvae by LC_{50} estimation or resistance testing (exposure to 5.8 x 10^4 OB/ml) and/or direct testing of L2-L4 larvae extracted from apples (exposure to 2 x 10^5 OB/ml).

Year		Verified Resistance		Total
		Type I Genome group A)	Type II (Genome group E)	
2004 - 2009		22	2	24
2010 - 2016		-	14	14
2017 - 2019		-	17	17
2020 - 2021			9	9
2022 – 2023			2	2
2004 - 2023		**22**	**44**	**66**

Stability of CpGV isolates towards changing climate conditions

In recent years, effects of climate change became more evident with extreme weather conditions. Heavy precipitation events are increasingly occurring during the summer months, alternately with longer drought periods with strong UV exposure. On the other hand, global warming results in higher risk of additional generations of regional CM populations, requiring modified CpGV treatments for efficient CM control (Samietz *et al*., 2015). Significant changes in the traditional weather pattern can have a significant impact on the effectiveness of CpGV application. Since heavy downpours occur more frequently, it is necessary to test the extent such weather events wash off the viral spray deposit on apples. Furthermore, increased sunlight is a limiting factor for virus stability, degradation, and long-term efficacy of CpGV products. Hence, a quantification of the efficacy reduction in correlation with UV solar radiation is needed. Both topics will be analysed in laboratory and

field studies in this project. Experiments on climatic factors influencing virus stability are carried out in a climate simulator under standardized conditions. Furthermore, methods will be developed to quantify these influencing factors under field conditions by measuring virus activity after corresponding weather events in correlation with virus application time and rate. These data will help elaborating more accurate treatment schedules and improving CpGV product formulations for changing requirements to a transforming climate.

Developing strategies for reducing the frequency of CpGV applications in the second CM generation

In recent years, CpGV applications have been recommended during the complete hatching period of CM larvae in orchards with already resistant CM populations, even though supplementary mating disruption was applied to reduce pest pressure. The project aims to reduce the number of applications for plant protection in late summer to reduce the risk for resistance development. Additionally, an overall reduction of fungicide application is aimed in organic apple production. Fungicide application and CM control are timely connected and hence, only a simultaneous reduction of both is economically reasonable for growers.

In 2023, the infestation level of the first generation of CM was monitored in all orchards with resistant populations. The aim was to identify potentials to reduce or skip further CpGV applications for the second generation without the risk of an increase of the infestation rate. The monitoring in Southern Germany of the orchards with populations resistant to CpGV Type I showed in 2023 a sufficient reduction of infestation rates to a very low level. However, many orchards have untreated big apple or pear trees in close proximity from which the infestation can spread to nearby commercial orchards. Depending on the situation, the whole orchard or only the tree rows at the border have to be treated with CpGV during the hatching period of the second generation to prevent an increase of infestation pressure in these commercial orchards in the following year. This strategy presents a high risk for new resistance development, though. To evaluate if the immigration can be reduced, commercial puffers for mating disruption were mounted to big untreated trees at the borders of commercial orchards, but there was no evidence of a sufficient reduction of infestation rates. In a second approach, exclusion netting at the border of the commercial orchards adiacent to big untreated trees to prevent immigration of mated CM females into the orchards will be tested.

The monitoring in the Lower Elbe region of the orchards with populations resistant to CpGV Type I showed in 2023 that infestation rates in the orchards applying the new CpGV isolate was low but in 2023 the second generation was not relevant.

Conclusion

The project “OekoapfelForward” aims to find solutions for applied research questions regarding effective and targeted codling moth control in congruence with reduced pesticide application for enhancing biodiversity and crop yield in a transforming environment.

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References

Asser-Kaiser, S., Fritsch, E., Undorf-Spahn, K., Kienzle, J., Eberle, K. E., Gund, N. A., Reineke, A., Zebitz, C. P. W., Heckel, D. G., Huber, J., Jehle, J. A. (2007). Rapid emergence of baculovirus resistance in codling moth due to dominant, sex-linked inheritance. *Science* **318**, 1916-1918.

Eberle, K. E., Sayed, S., Rezapanah, M., Shojai-Estabragh, S., Jehle, J. A. (2009). Diversity and evolution of Cydia pomonella granulovirus (CpGV). *Journal of General Virology* **90**, 662-671.

Fan, J.; Wennmann, J.T.; Wang, D.; Jehle, J.A. (2020a). Novel diversity and virulence patterns found in new isolates of Cydia pomonella granulovirus from China. *Applied and Environmental Microbiology* **86(2)**. DOI**:** 10.1128/AEM.02000-19.

Fan, J.; Wennmann, J.T.; Wang, D.; Jehle, J.A. (2020b). Single nucleotide polymorphism (SNP) frequencies and distribution reveal complex genetic composition of seven novel natural isolates of Cydia pomonella granulovirus. *Virology* **541**. DOI: 10.1016/j.virol.2019.11.016.

Fritsch, E., Undorf-Spahn, K., Kienzle, J., Zebitz, C.P.W. & Huber, J. (2005). Apfelwickler-Granulovirus: Erste Hinweise auf Unterschiede in der Empfindlichkeit lokaler Apfelwickler-Populationen. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes* **57**, 29-34.

Fritsch, E., Undorf-Spahn, K., Kienzle, J., Zimmer, J., Benduhn, B., Adolphi, C., Zebitz, C.P.W., Jehle, J.A. (2022) Virulence management of codling moth resistance to Cydia pomonella granulovirus (CpGV) in organic fruit growing in Germany. Proceedings of the 20th International Conference on Organic Fruit-Growing, online 2022.02.21-23. Ed. FOEKO e.V. 2022: 159-161.

Gebhardt, M.M.; Eberle, K.E.; Radtke, P.; Jehle, J.A. (2014). Baculovirus resistance in codling moth is virus isolate-dependent and the consequence of a mutation in viral gene pe38. Proc. Natl. Acad. Sci. USA 111, 5711–15716.

Jehle, J.A., Schulze-Bopp, S., Undorf-Spahn, K., Fritsch, E. (2017): Evidence for a second type of resistance against Cydia pomonella granulovirus in field populations of codling moths. *Applied and Environmental Microbiology* **83(2)**: e02330-16.

Samietz, J., Stoeckli, S., Hirschi, M., Spirig, C., Höhn, H., Calanca, P. and Rotach, M. (2015). Modelling the impact of climate change on sustainable management of the codling moth (Cydia pomonella) as key pest in apple. *Acta Horticulturae* **1068**, 35-42. DOI: 10.17660/ActaHortic.2015.1068.3

Sauer, A., Fritsch, E., Undorf-Spahn, K., Nguyen, P., Marec, F., Heckel, D., Jehle, J.A. (2017a). Novel resistance to Cydia pomonella granulovirus (CpGV) in codling moth shows autosomal and dominant inheritance and confers cross-resistance to different CpGV genome groups. *PLoS ONE* **12(6)**: e0179157.

Sauer, A.J., Schulze-Bopp, S., Fritsch, E., Undorf-Spahn, K., Jehle, J.A. (2017b). A third type of resistance to Cydia pomonella granulovirus in codling moths shows a mixed Z-linked and autosomal inheritance pattern. *Applied Environmental Microbiol* **83**:e01036-17.

Schmitt A, Bisutti IL, Ladurner E, Benuzzi M, Sauphanor B, Kienzle J, Zingg D, Undorf-Spahn K, Fritsch E, Huber J, Jehle JA (2013) The occurrence and distribution of resistance of codling moth to *Cydia pomonella* granulovirus in Europe. *Journal of Applied Entomology* **137 (9)**:641-649.

Schulze-Bopp, S.; Jehle, J. A. (2013). Development of a direct test of baculovirus resistance in wild codling moth populations. *Journal of Applied Entomology* **137**, 153-160.

Siegwart, M.; Maugin, S.; Besse, S.; Lopez-Ferber, M.; Hinsberger, A.; Gauffre, B. (2020). Le carpocapse des pommes résiste au virus de la granulose. *Phytoma* **738**, 45–50.

Wennmann, J.T.; Radtke, P.; Eberle, K.E.; Gueli Alletti, G.; Jehle, J.A. (2017). Deciphering single nucleotide polymorphisms and evolutionary trends in isolates of Cydia pomonella granulovirus. *Viruses* **9(8)**, 227. DOI: 10.3390/v9080227.

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