

G × E × C: genotype-by-environment (x community) interactions in insect breeding

Workshop and Management Committee meeting · Novi Sad, Serbia · 19–21 May 2026

1. About the meeting

The meeting brought together several Insect-IMP working groups to explore how genotype-by-environment (G × E) (x community C) interactions affect key areas of insect breeding and rearing. Across three days, invited talks and discussions covered general examples of G × E in insects, the role of the microbiome and diet, phenotype definition and measurement, how to model and account for G × E in genetic evaluation, and how to take it into account in breeding and rearing. The programme also included an excursion to an insect pilot farm and closed with a meeting of the Insect-IMP Management Committee.

Key messages

- G × E is poorly understood in the insect-rearing community, and terms are often used inconsistently. A shared vocabulary is needed.
- There is more hidden genetic variation than we know of – in black soldier fly and other farmed insects – while natural populations remain little studied.
- We do not truly understand what is a standard environment and which environmental variables influence production. A good start would be to define standardised diets, which offer a common reference for comparing strains under comparable conditions.
- Generalists vs. specialists, breeders need to define their breeding goal and decide whether they want to breed for insects that perform well across a range of environment or that do superb in a single well-defined environment

2. Session summaries

Day 1

The opening discussion highlighted that the definition of G × E is poorly understood in the insect-rearing community, in the same way as breeding itself. Vocabulary is frequently used without a clear understanding of what the terms mean. There is also a lack of basic understanding of how genetic diversity interacts with the production environment, partly because rearing in closed or controlled systems leads to the assumption that fixing environmental variables is sufficient.

Day 1, morning - General examples of G × E in insects

Chair: Gertje Petersen

Tom Generalovic – *Variability in the black soldier fly*

Populations are more strongly stratified than currently recognised. Little effort goes into studying naturally occurring populations and varieties, mainly because of the cost. This applies to black soldier fly, but also to crickets, which have been bred in the community for a long time and face disease issues, particularly viruses.

Maria Boukouvala – *Unveiling the Khapra beetle *Trogoderma granarium*: biology, behaviour and management of a global quarantine pest*

Breeding for success means looking for small changes and improvements, whereas when you're trying to disrupt, as in pest insects, control looks for large disruptions and failures in a system. This contrasting perspective is useful for thinking about G × E: when new strains are used under controlled conditions, it would be valuable to also observe their performance in their natural habitat, as is routinely done for pest insects.

Kemal Karabag – *CRISPR-based gene silencing for *Varroa* resistance in honey bees and its implications for host-parasite G × E interactions*

The talk presented a sensible application of CRISPR. Although less directly linked to G × E, it exposed differences in applications and regulations across regions.

Day 1, afternoon - Microbiome and feeding

Chair: Roel Meyermans

Veyssel Bay – *Pathogen-driven microbiome modulation: the impact of *Theileria* infection on vector microbial communities*

Using the tick microbiome as an example, the talk showed that there are large gaps in our knowledge of host-parasite interactions and of interactions within multi-species communities. In Central Europe, much of this knowledge comes from research on pests, which forms a separate community from insect production. These communities need to be bridged, as production researchers have not yet learned which questions to ask.

Lotte Froninckx – *Repeated feeding trials with black soldier fly lines on varied diets: setup and data processing challenges*

Black soldier fly has general nutritional requirements that cannot be avoided, such as essential amino acids. At the same time, there are clear differences between genetic lines and in heterosis when lines are crossed. This links back to Tom Generalovic's talk: there is considerable cryptic variation, and not only in black soldier fly.

Freek IJdema – *The persistent influence of host lineage on the gut microbiomes of black soldier fly and yellow mealworm*

The talk extended Lotte Froninckx's findings.

Marco Tejeda – *The role of standardised diet in the control for $G \times E$ interactions of BSF*

A standardised black soldier fly diet makes it possible to set up a semi-controlled environment in which individual components can be changed one at a time. Because the diet is agar-based, there is no need to add moisture, which removes another variable. The industry needs insects that are adapted to multiple substrates, or that can adapt to multiple environments. A standard diet can be used to characterise and evaluate different strains under comparable conditions.

Action point: a ring test for performance of different strains (for BSF)

Participants proposed setting up a ring test for performance testing of different black soldier fly strains, and connecting with the groups already working on standardised diets. The test would run in stages:

1. **Validate the standardised diet.** If neonates of the same material are distributed to different labs, do they all perform the same?
2. **If not, run a full $G \times E$ experiment**, exchanging material between partners and identifying which environmental variables cause the differences. This multi-stage trial could also show whether distinct ecotypes exist.

Day 2, morning – Excursion to the Insect Pilot Farm

Participants visited an insect pilot farm, which gave a practical view of production conditions.

Day 2, afternoon – Overcoming $G \times E$ in phenotype definition and measurement

Chair: Mert Kükrer

Seth Murray – *Phenomics as a novel way of overcoming / capturing $G \times E$ effects*

In plants, $G \times E$ is a major part of breeding efforts, because the environment cannot be managed to the same degree as for animals. Mass phenotyping may not capture the same level of detail as inspecting individuals. However, using the whole data pool and the correlations between those data and the output can give an accuracy comparable to, or even better than, classical genetic evaluation. This is phenomic prediction: defining the phenome as a whole and focusing on the result rather than on a specific trait. Insects are most likely still far from implementing this, but the talk underlined the need for batch phenotyping. Two open questions emerged:

- Should we breed for generalists or for specialists?
- Should we collect more granular information on fewer individuals, or less granular information on more individuals? We are unlikely to be able to have both.

Daniel Tolhurst – *Leveraging genotype by environment interaction for improving selection and crossing decisions in plant and animal breeding*

Understanding $G \times E$ in actual production settings across different climatic regions shows that part of the interaction ($G \times E \times C$) depends on regional requirements. Decisions may be made by the people who buy the end product, or may depend on the processing equipment. These are questions that have nothing to do with genetics but may have everything to do with the outcome. Two points were highlighted:

- **Breeding for the future:** traits that may become important later, for example if EU legislation on food waste changes.
- **Leveraging environmental variation:** selecting for specific climates so that production does not need adjustment there, for example dry climates in the Middle East and Africa, while taking cultural preferences into account.

Frank Ssemakula – *Spectroscopic and hyperspectral-imaging based phenotyping approaches for nutritional composition in live BSF larvae*

The European insect sector focuses on producing clean products rather than on producing large amounts of protein to support food security. This raises a big question: should we produce clean or produce massively? Europe can learn from production outside Europe. Who is our end consumer, what is our end product, and could we bridge one end consumer to the other?

Day 3, morning – Modelling $G \times E$ and accounting for it in genetic evaluation

Chairs: Jana Obsteter, Gertje Petersen

The final session opened with a summary of the previous two days.

Kishor Bommalingegowda – *Genetic parameters and genotype-by-diet interactions for growth traits in Australian black soldier fly larvae: implications for selective breeding*

The talk presented insect breeding as proper animal breeding, applying established quantitative-genetic methods to estimate genetic parameters and genotype-by-diet interactions in black soldier fly.

The workshop closed with a general discussion, followed in the afternoon by the meeting of the Insect-IMP Management Committee.