EIP-AGRI Focus Group

Sustainable ways to reduce pesticides in pome and stone fruit production

Mini Paper 5

funded by European Commission

Plant Genetic to contribute to pesticide reduction

Towards an ideal genetic program to get closer to the resilient orchard

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Context and challenges

European pome and stone fruit horticulture currently faces the challenge of optimizing systems to respond to economic (quantity and production costs), environmental (low input, reduction of chemicals, resilience to climate stresses and climate changes) and societal (Genetically Modified GM- and chemical-free crops, nutritional issues) demands. These challenges are compounded by shifts in consumer demand, reduction in available resources (such as water, pesticides or workers) required for farming, climate change, and governmental policies.

To move to a more sustainable agricultural system, reductions in pesticide applications within pome and stone fruits will require the development of innovative concepts. These concepts will need to be integrated throughout the entire horticultural industry, from tree breeding to fruit sales. In this context, genetic resistance to pests and pathogens is a primary tool to reduce damages linked to pests and disease and to ensure the adequation between new agro-ecological practices, a reduction of pesticide use, while providing a high quality fruit that is still demanded by the consumer.

Nearly all pome and stone fruit orchards contain two distinct genetic partners, the rootstock and the scion (Figure 1).

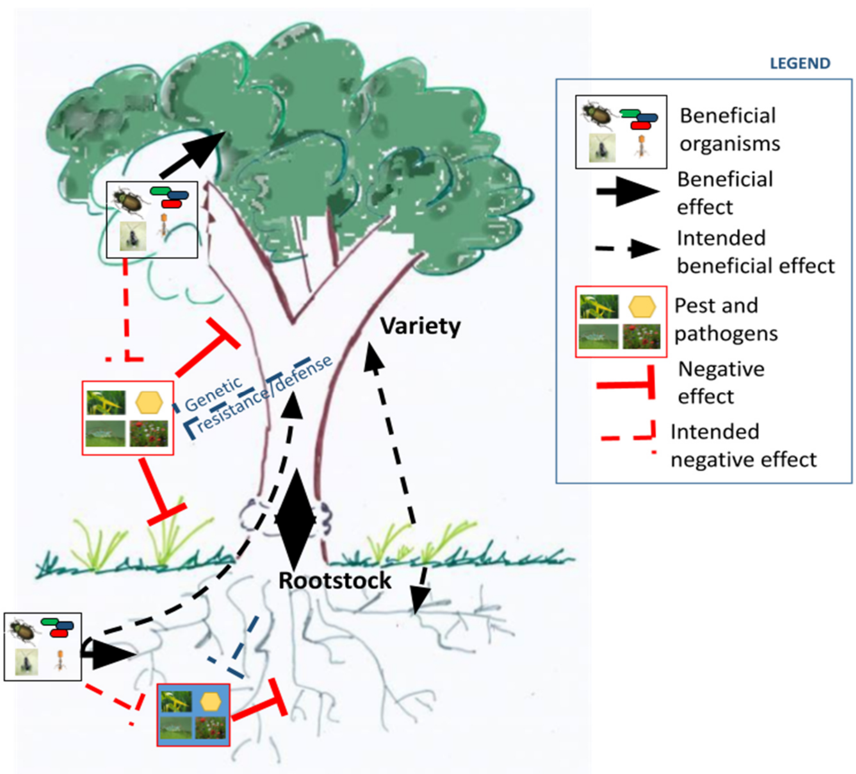

Figure 1. Representation of interactions between beneficials, pests, pathogens and the fruit trees that are actually or should be taken into account for breeding programs.

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Cultivars, or more commonly called varieties, are the fruit-producing part of the tree and selected for fruit characteristics and resistance (to foliar and flower diseases, fruit pests, and post-harvest rots). Cultivars are often grafted onto rootstocks which have differing genetic and phenotypic features. Rootstocks are selected for their lower susceptibility to root diseases and nematode parasitism, climate change, drought and for their intrinsic horticultural characteristics such as vigor conferred to the scion. The decision to combine one particular scion with a specific rootstock is made before the orchard is established, following current consumer or grower requests and environmental conditions. This decision is critical as it often has a long term effect (10+ years) on the success of the orchard. Ideally, this decision should rely on unbiased, research based information from locally established field trials to account for the varying conditions across the EU.

Although rootstocks and cultivars are the foundation of a successful orchard, the development of new rootstocks and new cultivars takes time. A traditional belief is that it takes 20 to 30 years to demonstrate that a rootstock or cultivar is acceptable within a given production area. This is roughly one generation of orchard life. Unfortunately, the constant and rapid evolution of climate, consumer demands, public funding and policies do not currently provide this long of a timeline. Additionally, multiple private breeding programs compete aggressively for limited market share, often promoting and releasing cultivars and rootstocks before the perceived traits are thoroughly determined. Therefore, to fully utilize rootstocks and cultivars as a means to reduce pesticide use, new resources, tools, and techniques will have to be integrated into the breeding programs to provide more timely, site specific tools.

Developing more effective breeding programs across the EU will be a challenging task. The quality of breeding programs across the various member states vary. Many of these have been chronically underfunded or are in the process of closing research activity. Each of these breeding programs have differing germplasms available to work with to address localized challenges. Additionally, the limited funding has often led to minimal collaboration between public and private breeding programs, leading to a gradual degradation and loss of perceived public value.

To redevelop these programs, some basic steps may be considered. A network of breeders across all stone and pome fruits should be established, providing a database of parent material available. This is important as the systemic use and characterization of genetic resources is the foundation of any breeding effort. Once public breeding programs are characterized, the effort should be extended to private breeding programs to grow the database. This step is fundamental as knowing what genetic material is available for use is critical to identifying traits that can reduce pesticide use.

Once the various sources of germplasm have been identified, they will need to be characterized. Consistent molecular markers should be applied across all germplasm to identify potential mechanisms of resistance. Once traits are identified, breeding techniques will be able to quickly integrate these mechanisms of resistance into new varieties, providing a more rapid development of new rootstocks and cultivars.

The challenges with rootstocks and cultivars are not limited to breeding. After the identification of valuable genetic accessions, an European-wide testing should be implemented allowing to assess the new cultivars and rootstocks in a variety of growing conditions that represent most of the situations encountered in EU. These projects should be established in multiple environments, in grower fields or research centers to make sure many types of modern farming practices are being applied, and to integrate both the farmer's and researcher's perspective into the research. This does not only hold true for the selection of genetic resistance but also with respect to quality of the agricultural products and farming economic sustainability.

There are several examples from which this type of program can be implemented, including the European plum rootstock trials (**https://www.ishs.org/ishs-article/734_16**) and the NC-140 multi-state apple rootstock trials conducted in the United States of America (**https://apples.extension.org/apple-rootstock-testing-and-nc-140/**). Both of these programs have been successful in integrating modern techniques, open collaboration, and site specific grower trials in their work.

Using genetics for pesticide reduction: ideas of solution to widen or implement

Farmers have been using differing cultivars and rootstocks to reduce pesticide use for centuries because it is widely known that differing cultivars and rootstocks have differing levels of resistance to various pathogens. For example, within apple rootstocks, the Malling series of apple rootstocks are more susceptible to crown rot and fire blight than the Geneva series.

With research, it is easier now to have cultivars or rootstocks with real resistance or tolerance (as far as they have been already identified, which is unfortunately not the case for each pest and pathogen) combined with great agronomic performance.

Case study: Resistance of apple trees to apple scab (*Venturia inaequalis*)

During the 70s and 80s, varieties with gene Vf had been developed and launched on the market. This gene has been targeted for its specific resistance to apple scab. Those varieties had a monogenic resistance to Venturia inaequalis. (Vanessa SOUFFLET-FRESLON, 2008).

As soon as 1989, circumvention of this resistance appeared in several European countries (Parisi et al . 2004). This loss of efficacy of gene Vf in only 10 years shows the vulnerability of monogenic resistance selection.

Since then, several breeding programs led to some other resistant varieties but still based on the same type of resistance. We can cite Florina® Querina, Ariane®, Antarès® Dalinbel, Choupette® Dalinette, Story® Inored. They were launched on the market in the 20s. Circumvention of resistance on those varieties has already been noted in several areas of production and it appears faster if there is no special management of the apple disease. Indeed, to prevent the risk of circumvention of resistance, prophylaxis measures and treatments on the major primary contamination are essential. Those varieties are still very useful in organic orchards or conventional orchards because they allow a reduction of TFI (Indicator for Treatment Frequency).

In France, a study has been led in the Ecophyto program on the variety Ariane in a conventional program. It was combined with different levers as leaves crushing or light chemical program to reduce the inoculum and protect against the risk of circumvention. In this context, fungicides had been reduced by 50%. (Ecophytopic)

However development of polygenic resistance is in study and this would permit a durable genetic resistance.

In a European context, this might be more than necessary to clearly identify which cultivars or rootstocks are suitable according to strains. Within cultivars, there are several examples including the Spanish breeding program targeting resistance to one single plum pox virus (PPV) strain (the D strain) solely because it is the only one present on the territory (P. Martínez-Gómez, F. Dicenta, W. E. Weber, 2008). Conversely, those new varieties are not particularly adapted to growing in other European areas where other strains, sometimes more virulent than the D strain, are spreading.

In previous years, varieties and rootstocks evaluation were essentially focused on their agro-economical potential, which means maximum production in quantity and visually bigger, colourful and no defaults fruits. The susceptibility to diseases or pests of fruit trees was easily solved with pesticides. However, the current

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context of pesticides ban and the European goal of pesticides reduction force to adapt the protocols of plant materials evaluation. Criteria of selection have to be prioritized according to these changes. Even though traditional breeding programs are long term and time intensive, modern techniques have changed the breeding process. Modern breeding techniques could reduce the development time of rootstocks and cultivars. The following steps are an example of the ideal breeding program to achieve reduction of pesticide uses in orchards (Figure 2).

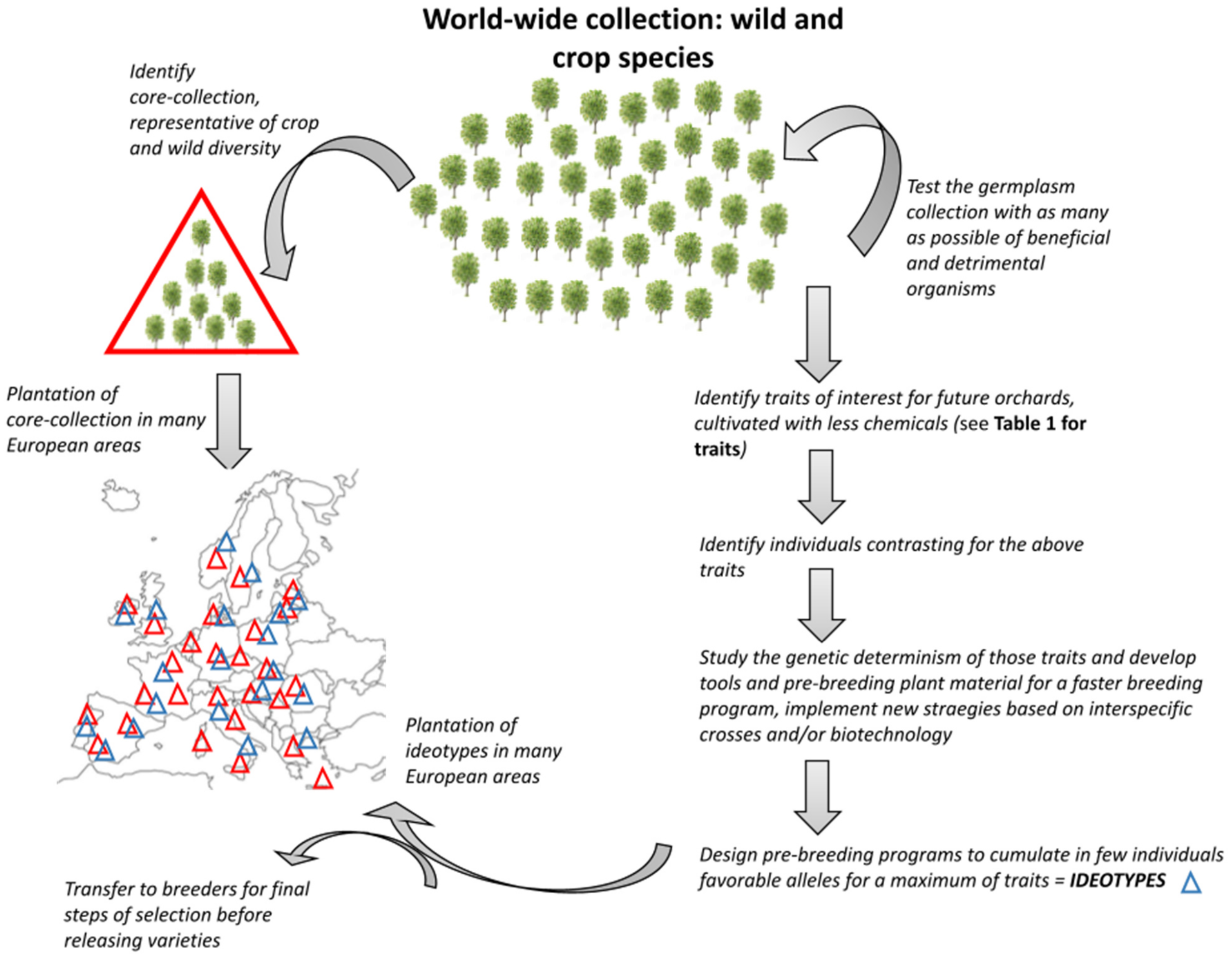

Figure 2. Ideal European breeding program.

1. Enlarge the diversity of the plant material used in breeding programmes and implement a multi-trait approach

There is little chance that varieties of interest which have not been bred to be resistant or tolerant will behave nicely in pesticide-free cultivation conditions. The capacity of a variety to respond to its chemical-free environment will mostly depend on its genetic potential to 'tolerate' local biotic and abiotic conditions. As depicted in Figure 2, breeding programs should first increase the genetic and phenotypic diversity used in their programs and then develop 'prototypes', usually named 'ideotypes', that will be then tested in a variety of environments presenting a large panel of sanitary risks situations.

The prerequisite to such a program is the access to wild and crop germplasm collections that would include wild, undomesticated relatives, landraces and ancient cultivars. This access is rather dependent on the country and the fruit species. While wild germplasm is available in Europe for Malus and Pyrus species, this is not the case for many more species still endemic outside of Europe (peach, apricot, kiwi fruit , citrus etc..). Following the signature of the Nagoya protocol by most of the countries holding such unique germplasm, European breeders have to rely on pre-existing collections like the ARS-USDA germplasm repositories and collections of institutes affiliated to the European Cooperative Programme for Plant Genetic Resources (ECPGR, https://www.ecpgr.cgiar.org/). In the second case, attention should be given to enlarging European gene banks to more unique and diverse plant material, over the sole survey of domesticated material for genetic and functional diversity (see example of world-wide fruit tree collection, Wu et al, 2018 for Citrus ; Groppi et al, 2021 for apricot).

The second requisite is the implementation of a multi-trait approach that will start with the screening step and will end with the combination of traits related to pest/pathogen resistance, fruit quality and production, tree management and cultivation. Ideally, it should consider adding resistance to endemic and emerging pests and diseases, and evaluate these for market requirements. In a context of agro-ecological conditions of fruit tree cultivation, new traits have to be included in such diversity survey programs such as plant-plant associations, intra- and inter-specific mixtures in the orchards etc… (Table 1).

	Trait to enhance fruit tree plant health		**Trait to reduce pest and pathogen risk**
T1	Fruit tree-companion plant association (reducing competition)	T5	Genetic resistance
T2	Adaptation to intercropping	T6	Rootstock properties
T3	Scion/rootstock compatibility	T7	Fruit tree architecture
T4	Responsiveness to substances or VOCs (Volatile Organic Compound) that induce plant resistance	T8	Better host for beneficials that occupy the same ecological niche as pest species
		T9	Phenology (escape pest/pathogen impact by changes in life traits)

Table 1. List of traits of interest to select for a better behaviour of trees towards pests and diseases.

2. New technologies in breeding program to fasten the selection

New breeding programs should integrate new genetic and breeding tools and methods, including MAS (marker assisted selection), genomic selection and fasTrack breeding approaches (see ex. here https://ucanr.edu/sites/fastrack/, Petri et al, 2018) in order to shorten the time needed to bring to the market pesticide-free, resilient fruit crops.

When no diversity is available in the crop or related species or if no resistance to one specific pest or pathogen is identified within the gene banks, new biotechnological approaches are possible alternative solutions. This includes genome editing that will target susceptibility, host gene(s), RNA interference, lower susceptibility transmitted by rootstocks and so on. Another avenue of study is the contribution of the plant microbiome to a better resilience of the orchards and this topic is still poorly understood.

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Case study: project RésiDiv of Gafl/INRAE of Avignon

The RésiDiv project, which is just starting, aims to acquire key knowledge on fruit trees resilience and identify the mains composant of resilience in low pesticides conditions. The purpose is also to identify ideotypes with important resilience composants which are necessary components to breed the future variety for more sustainable orchards. It will be achieved by exploiting a multisite experimental device of core-collection of peaches and apricots. It will require new protocols to caracterise sensibility traits to pests or diseases and new methodologies for multivariate analysis of data. Adding new integrated variables reflecting the tree's health will permit to identify resilience variables, to evaluate their heritability and to propose new selection tools with genetic markers.

https://www6.paca.inrae.fr/gafl/Partenariats-et-projets/Projets-nationaux/ResiDiv-2022-2026

3. Evaluate with a multidisciplinary EU breeder/researcher/farmer networks

The ultimate requirement of 'ideal' breeding programs is the organization of a multi-site experimentation testing, Europe-wide. For this purpose, private and public breeders could make use of the EUFRIN network (**https://eufrin.eu/frontpage**) among other institutional and private possibilities, with the extensive financial support of the European commission. This might also require participatory testing with low-inputs cultivation and across multiple production areas, in many more contrasted environments, EU-wide.

Current cultivars evaluation consists in assessing yield, size of fruits and gustative or nutritional quality. Some aside observations on general sensibility or tolerance are done but in a normal pesticides use context. It may be evaluated in different localisations but in any way, it lacks observations on resilience to pests and diseases.

Case study : project Sensivar of French experimental stations

In France, the current steps for the evaluation is to implement varieties from fruit breeders in different localisations and to evaluate in the first 5 years their agronomic potential. Recently, another step has been added and consists of planting interesting varieties in non-treated orchards where the pests or diseases susceptibility and tolerance will be observed. Different French experimental stations participate in this program. A particular accent is made on curl leaves disease (*Taphrina deformans*) on peaches. For example, 30 varieties of peaches and nectarines have been planted between 2018 and 2020 and their disease attack is assessed and then comparison is made with the most resistant variety we know of, Benedicte® Meydicte cov. First results shows that only one variety (ROYAL MAID® Zai718P) is as resistant as the reference and few others (NAJIPOP cov, NECTAPOM ® Nectana cov, NECTASWEET ® Nectarnovala cov, IPS 727-09 and PAJENY cov) are a very low infestation.
In this condition, in a few years, varieties can already be pre-selected according to their agronomic interest which is obviously still very important but also for their behavior regarding pests and diseases. Some varieties can already be set aside for farmers of organic orchards or those with strict specifications.

https://www6.paca.inrae.fr/gafl/Partenariats-et-projets/Projets-nationaux/SENSIVAR

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Gaps or limits to anticipate

The above ambitions give rise to gaps or limits that should be taken into consideration carefully:

1. Necessity of long-term European funding projects

As mentioned above, research on genetics requires different steps and each one of them requires several years to complete. Therefore, long-term funding projects are needed, in particular in perennial fruit tree species. Actually, funding is given mostly by each country and for a way shorter time (3 to 5 years). It is not appropriate for genetics research and limits the possibility of improvement.
Since breeding programs are relevant to both local and EU-wide farmers, one possible solution is for the EU to provide long-term, 20 year grants that require matching from the participating country. This will help leverage EU funds, maximizing opportunities.

2. World-wide genetic diversity and equal access to plant material within EU

Some rootstocks show better results in some areas than others. It can be linked to the climate difference or the soil type. Therefore, if a rootstock shows good behavior somewhere, it can be useful to develop it in nurseries. However, probably for profitability reasons, nurseries will not propose a large choice especially of rootstocks depending on the area. This practice does not help to adapt the tree to its environmental conditions and make it less susceptible to pests or diseases.
This assessment is made at a national level but it is also true at the European level where some varieties or rootstock are not available in one country while it is in another one.
It still brings to the same remark that an uniformisation at an EU level is necessary.
Competition between private and public breeders: some are importing varieties from other parts of the world with good agronomic qualities but not adapted to European conditions and no resistance to European pests and diseases while public organisms work on developing resistant varieties. Rules might have to be implemented so that we can favor varieties adapted to the achievement of pesticides reduction.

3. Deploying new resistant varieties and limit breaking of the resistance mechanisms

Once a resistant or tolerant variety is developed, it requires a specific practice from the grower to maintain the resistance in time and in space. Indeed, it seems obvious that spreading pesticides will not be necessary on resistant varieties but this is an incorrect idea. Inoculum has to be contained so that generation of pests or diseases do not quickly circumvent the resistance. The example of apple scab resistant varieties that broke is not to be reproduced over and over again. Thus, here are some recommendation that should be implemented by the grower to make the resistance sustainable :

- Use less pesticide but still few treatment well positioned according to the cycle of development of the pests or diseases (use models and monitoring to help positioning the treatments)
- Control or reduce the inoculum with efficient-proved biocontrol products
- Manage the pests and diseases conditions with orchards management such as trained trees, green pruning, prophylaxis measures, landscape management…
- Control the biotic and abiotic risks to limit the inoculum through system approach with companion plants, biodiversity development, mixture of crops of multiple intra and inter-specific fruit trees

In general, genetic resistance deployment could be coupled with cultivation practices such as the ones described in mini paper 3.

4. Good communication with the public opinion

When talking about genetic selection, it is quite easy to alert the media and the public opinion because it is wrongly associated with GMO’s practices. Having too little knowledge about the different genetic selection techniques and their impacts, they can make the most of this subject to get a bad reception from consumers and maybe then force governments to ban those techniques.

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This would be essential to implement a good communication system between the research sector and the public opinion, to build a better comprehensive relation. It will also be useful to reestablish a friendly and comprehensive relation between consumers and farmers.

Conclusion

Improvement of European breeding programs is necessary to achieve the goal of pesticides reduction in pome and stone fruits orchards. It has to go through a harmonization of programs within European countries first, with implementation of large collections from world-wide to enlarge the genetic diversity in cultivated varieties and search for multiple resistance. Breeding techniques have evolved and should permit to fasten the process of creating a variety both resistant and agronomically interesting. It also needs a further control of resistance breakout and possible resistance of existing varieties to new arriving diseases or pests (through sentinel blocks). Links between breeders, experimenters and farmers should be reinforced to better adapt plant materials to each kind of climate, soil characteristics and local strains of diseases.
The above ambition requires long-term funding projects together with paradigm changes in the agricultural production sectors as well as within the markets to valorize more diversified and naturally resistant products. At the research level, it requires high throughput methodologies to improve the screening, characterization and use of the biodiversity on the phenotypic and genotypic level. Those boundaries allow identifying links with the other minipapers as follows:

- Mini Paper 1: Precision spraying of pesticides when the risk for pest and pathogen outbreak is too high
- Mini Paper 2: Use of agro-ecological practices and beneficial organisms to limit the spread of inoculum
- Mini Paper 3: Use of those complementary, alternative measures of cultivation to deploy resistant varieties.
- Mini Paper 4: Promotion of a more diversified farming system to the farmers in complement to genetic resistance
- Mini Paper 6: Use of alternative bio technological measures to re-enforce and complement the genetic solutions

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French project Sensivar : https://www6.paca.inrae.fr/gafl/Partenariats-et-projets/Projets-nationaux/SENSIVAR

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