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Reviewed Paper

# The European Organic Fruit Breeding Network Initiative: A collaborative framework for developing more robust and resilient cultivars better adapted to organic farming

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## Abstract

*Most fruit tree cultivars currently available to European organic growers were not bred or selected under organic conditions. As a result, they are often not well adapted and lack the robustness and resilience required to perform under low-input organic farming systems (liOFS). There is therefore an urgent need to implement liOFS-based evaluation approaches and to establish dedicated breeding programmes in which cultivars are developed and evaluated under organic management, with selection focused on long-term tolerance to pests, diseases, and climatic stresses.*

*Given the complexity and long time frame of fruit tree breeding, this challenge can only be effectively addressed through a more coordinated and collaborative European effort. To this end, the European Organic Fruit Breeding and Breeding for Organic Farming Network was established under the Horizon Europe project InnOBreed to foster cooperation among breeders, researchers, evaluators, curators, and growers engaged in developing fruit tree cultivars that are more robust, resilient, and better adapted to organic production systems.*

*The network is governed by a charter which defines common principles and rules for cooperation, governance, and plant material exchange. It promotes participatory breeding approaches, transparency, and equitable access to genetic resources. Plant material exchange - covering genetic resources, pre-breeding, and elite material - is organized annually through an "Exchange platform" and regulated by the FAO Standard Material Transfer Agreement to ensure traceability and legal compliance.*

*Harmonized phenotyping protocols developed within the InnOBreed project facilitate data sharing across multiple test sites. This multi-site approach also accelerates the acquisition of robust, comparable data and supports faster yet reliable cultivar evaluation and selection.*

*By pooling genetic resources, expertise, and evaluation efforts across Europe, the European Organic Fruit Breeding and Breeding for Organic Farming Network aims to accelerate the development of more robust fruit cultivars that combine resilience and quality, thereby fostering the development and long-term sustainability of organic fruit production systems.*

**Keywords:** Organic breeding, Participatory breeding, Collaborative breeding, Fruit tree genetic resources, Plant material exchange.

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## Introduction

Organic agricultural land dedicated to permanent crops (fruit trees and berries, olive groves and vineyards) continues to expand in the European Union, with a cumulative growth of 83.9% over the period 2014–2023, reaching 2.3 million hectares in 2023 and representing about 18.8% of the total permanent crops area (Willer et al., 2025).
Although this trend is clearly positive, the current rate of expansion remains insufficient to reach the European Green Deal and Farm to Fork objectives of 25% agricultural land under organic management by 2030. For temperate fruit trees specifically, organic area increased by about 11.7% between 2014 and 2023 but still accounts for only a limited share (9.8%) of the total temperate fruit production area in the EU (Willer et al., 2025). This moderate growth underscores both the potential and the vulnerability of organic fruit production systems, and highlights the need to better support organic fruit growers by alleviating key technical and economic constraints that currently limit the conversion and expansion of orchards under organic management.

Beyond this quantitative expansion, organic farming is increasingly recognised not only as a response to rising consumer demand but also as a key driver of sustainability and agroecological transition. Organic agriculture contributes significantly to biodiversity conservation, soil restoration, and the reduction of chemical pollution, while enhancing ecosystem services and long-term soil fertility (Reganold and Wachter, 2016).
Organic producers nevertheless face multiple converging pressures. They are expected to further reduce their reliance on plant protection products, while coping with increasing climatic variability, the emergence or resurgence of pests and diseases, and persistent economic uncertainty (Osorio-Marín et al., 2024). In this context, enhancing the resilience of fruit production systems and increasing the availability of cultivars and rootstocks more adapted to organic and low-input conditions become key priorities for sustaining and expanding organic fruit growing in Europe.

However, most crop cultivars currently used in organic production have been selected under high-input conventional conditions and often perform poorly under organic management (Lammerts Van Bueren et al., 2011). Breeding programmes must therefore explicitly target traits such as (i) broader genetic bases, (ii) improved tolerance to biotic stress, (iii) enhanced resilience to abiotic stress, (iv) higher nutritional quality, and (v) improved nutrient-use efficiency. This need is particularly acute for perennial crops such as fruit tree species, where breeding cycles are longer and adaptability to local environments is critical.

Given the long timelines and resource demands of fruit breeding programmes, collaborative approaches at local, national and international scales are of utmost importance. Sharing experiences, plant material, data, and field evaluations across countries allows partners to accelerate selection cycles and exploit genotype-by-environment (GxE) and genotype-by-management (GxM) interactions. Such cooperation requires a clear framework for germplasm exchange and collective evaluation procedures and protocols.

In this context, the establishment of a structured *European Organic Fruit Breeding and Breeding for Organic Farming Network* offers a strategic opportunity. By harmonising protocols, ensuring fair plant material exchange, and fostering participatory evaluation across environments, such a network could substantially accelerate the development of cultivars that are better suited to organic and low-input systems.
To address this issue, the Horizon Europe project InnOBreed (Innovative Organic Fruit Breeding and Uses) established the *European Organic Fruit Breeding and Breeding for*

*Organic Farming Network*. This network provides a collaborative framework for developing, evaluating, and exchanging fruit tree genetic resources specifically more adapted to organic systems. The network is supported by a jointly developed charter that outlines its vision, governance and operational principles, including participatory breeding, transparency, and fair access to plant material and data.

**Vision and objectives of the Network**

Within the framework of the EU InnOBreed project, a network concept was developed through a participatory process involving partners from research institutes, universities, SMEs and NGOs across Europe. During this process, it became clear that partners operate under diverse institutional constraints and follow different breeding philosophies.

Some key partners are already implementing organic plant breeding, as defined before (IFOAM 2017, Nuijten et al., 2017, Messmer et al., 2025) meaning that the entire breeding process and all steps — including the management of parental plants used as female parents in crosses — are taking place under certified organic conditions and even more in unsprayed conditions during seedlings stages. One of the rationales is that parental plants grown under organic management may exhibit — and potentially transmit — traits that are particularly relevant for performance under organic conditions. Although the stability and heritability of such environmentally induced epigenetic marks remain under investigation, recent studies suggest that epigenetic variation could contribute to breeding cultivars with improved resilience to environmental stress (Lempe et al., 2022). Environmental stresses such as drought, temperature fluctuations or pathogen pressure can induce epigenetic modifications that influence gene expression and potentially affect traits relevant for adaptation (Kaya et al., 2024; Peer et al., 2025; Wang et al., 2025).

Although the stability and heritability of these stress-induced epigenetic marks remain uncertain in perennial fruit crops, the possibility that some of these modifications persist or influence progeny performance provides an additional rationale for maintaining parental plants under organic, stress-exposed conditions. Organic breeding may therefore capture environmentally induced phenotypic and epigenetic variation that better reflects the challenges encountered in low-input systems.

Other partners, however, share the goal of developing cultivars better adapted to organic farming but face practical, technical or administrative constraints that prevent them from implementing the full breeding cycle under certified organic conditions. For example, certain breeding centres are unable to maintain their genetic resources and crossing parents under organic management without losing 5–10% of their accessions, particularly when rare or disease-susceptible genotypes are involved (J.-M. Audergon, 2025, INRAE Avignon, France, pers. comm.; T. B. Toldam-Andersen, 2025, PLEN-UCPH, Denmark, pers. comm.). In these cases, parental collections may display essential traits for organic systems but cannot be preserved entirely under organic conditions without unacceptable genetic erosion.

Some partners also participate through participatory breeding schemes involving private growers or small structures whose fields or gardens, although unsprayed, are not formally certified organic. In addition, some breeding programmes take place on plots that are either in conversion or not yet eligible for organic certification due to land-use history or institutional constraints.

The European Organic Fruit Breeding Network aims to be inclusive, supporting institutions and partners committed to organic breeding while acknowledging the diversity of operational

constraints across Europe. Its objective is to facilitate a progressive transition towards more sustainable breeding practices, to make optimal use of available genetic resources, and to strengthen collective capacity to deliver cultivars truly adapted to organic and low-input farming systems.

Therefore, to accommodate this diversity of situations and opinions while maintaining scientific collaboration and transparency, the network recognises two complementary breeding approaches:

- Organic Plant Breeding (OPB)

OPB requires fully certified organic management from the maintenance of parental plants and the crossing phase to seedling production, selection and evaluation.

- Breeding for Organic Farming (BfOF)

BfOF allows certain breeding steps (e.g. parental plant maintenance, early crossing or juvenile stages) to occur under conventional conditions (Nuijten et al., 2017; Messmer et al., 2025), provided that selection and final evaluation are conducted under organic management, ideally under certified organic conditions when feasible.
Both approaches are aligned with IFOAM, ECO-PB and European regulation (EU) 2018/848 positions, i.e. they exclude genetic engineering and new genomic techniques (NGTs), as well as other breeding techniques involving direct technical intervention at the level of isolated cells or DNA (e.g. protoplast fusion, transgenesis, cisgenesis and targeted genome editing such as CRISPR-Cas, etc.).

**Conditions of collaboration**
Several partners — although strongly interested in participating in the network — face internal constraints linked to the organisations in which they work (research institutes, private breeding companies or universities). As a result, they cannot formally or legally commit to complying with a fully prescriptive charter. For this reason, the network and its Charter are not legally binding. Their purpose is instead to provide a shared framework that facilitates the exchange of knowledge, genetic resources (including pre-breeding and elite materials), evaluation data and access to trial sites.
The network aims to foster bilateral or multilateral collaborations between partners who are aligned on specific objectives (e.g. a fruit species, a target trait or a breeding approach). The precise terms of these collaborations remain outside the scope of the network and must be negotiated directly between the partners involved, according to their institutional and legal constraints.

By design, the network and the Charter have no regulatory or contractual ambition; rather, they serve as a platform for sharing visions, experiences and strategic objectives, and for progressively strengthening Europe’s collective capacity in Organic Breeding and Breeding for Organic Farming.

**Principles of plant material exchange: the annual exchange platform**
A harmonised framework for plant material exchange was established, based on the Food and Agriculture Organization of the United Nations (FAO) Standard Material Transfer Agreement (SMTA) under the International Treaty on Plant Genetic Resources for Food and

Agriculture (ITPGRFA), and in compliance with the access and benefit-sharing rules of the Nagoya Protocol. An annual “Exchange Platform” coordinates the offer and demand of seeds, budwood, pollen and young trees among network members. All exchanges comply with EU phytosanitary regulations and require appropriate traceability documentation (e.g. EU Plant Passport).

To keep the network active and dynamic, an annual Exchange Platform meeting is organised in December, initially as an online event and potentially as a physical or hybrid meeting in the future. During this meeting, partners are invited to present their ongoing breeding objectives, including target species, traits and population types (genetic resources, pre-breeding material, advanced selections). The meeting also provides an opportunity to jointly identify priority traits by species in order to guide future exchanges and collaborative evaluations.

The aim of the Exchange Platform is not to oblige partners to disclose or share their entire collections or all their genetic material, but rather to foster constructive and voluntary exchanges. To this end, a shared template is used in which partners can specify their needs in terms of plant material (e.g. species, target traits, type of material requested) as well as the material they are willing to offer (e.g.: seeds populations from controlled crosses or open pollination). Other partners can freely respond to these requests by proposing accessions or selections that match the desired profile, while providing transparent information on both the strengths (e.g. disease tolerance, fruit quality) and known weaknesses or limitations of the proposed material.

In practice, the network supports the exchange of five main categories of plant material: pollen, seeds, budwood and grafted trees or seedlings. Pollen exchange, in particular, allows partners to perform controlled crosses without maintaining all parental genotypes at the same location and involves relatively low phytosanitary risk, whereas seeds, scion wood and trees enable the establishment of segregating populations and clonal trials for multi-site evaluation under organic or low-input conditions.

This structured yet flexible mechanism is designed to facilitate targeted, trust-based exchanges, while respecting institutional constraints and intellectual property rules. It supports the overarching goal of the network: to mobilise the diversity of fruit tree genetic resources available in Europe and to channel them towards breeding objectives that are relevant for organic and low-input production systems.

**Common evaluation of FTGR, pre-breeding and breeding material**

One of the main objectives of the network is to facilitate the collaborative evaluation of fruit tree genetic resources (FTGR), pre-breeding populations and advanced breeding material under organic and low-input conditions. To this end, common phenotyping protocols have been developed based on the descriptors of the European Cooperative Programme for Plant Genetic Resources (ECPGR), which were recently harmonised, amended and complemented within the InnOBreed project. These descriptor lists cover key traits relevant to organic fruit production, including disease and pest tolerance, tree vigour and architecture, bearing regularity, fruit quality and storability, as well as phenology and responses to abiotic stress.

The use of shared descriptors and harmonised protocols allows data generated in different countries and pedoclimatic conditions to be directly comparable and aggregated across sites

and years. Partners are encouraged to record their observations using common data templates, which facilitates subsequent meta-analyses and the identification of promising accessions or breeding lines for organic and low-input systems. In this way, the network promotes not only the exchange of plant material but also the exchange of evaluation data, thereby increasing the collective value of each trial and enhancing the efficiency of existing FTGR and breeding efforts. Finally, this coordinated multi-site approach will strengthen our ability to assess the adaptive capacity of exchanged material under contrasting growing conditions and, on a voluntary basis, to derive additional indicators such as chilling and heat requirements or climatic and bioagressors risk cartography.

## Conclusion

The *European Organic Fruit Breeding and Breeding for Organic Farming Network* formalises collaboration among European partners and provides a transnational framework dedicated to organic and low-input fruit breeding. It ensures that all breeding material exchanged or co-developed within the network follows transparent, ethical, and traceable procedures. It articulates a shared vision for governance, plant material exchange and evaluation, while leaving sufficient flexibility for partners to establish their own bilateral or multilateral agreements according to their specific constraints and objectives. By structuring cooperation and making germplasm and data exchange more predictable, the Network is expected to enhance the efficiency and impact of existing breeding efforts and to attract additional partners over time.

The institutions, organisations and individuals who share this vision and wish to be associated with the further development of the Network are listed below:
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