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## Implementing the systems-based breeding approach: Experiences and lessons learned from the European Union LIVESEED project

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### Abstract

Organic breeders must meet many requirements when developing cultivars to satisfy demand for high yield, good quality, resource efficiency and climate robustness, cultural and ethical acceptability, and the provision of ecosystem services. Given

the current and future climatic, agronomic, economic, and socio-cultural challenges, resilience can only be efficiently achieved through concerted actions. The concept of systems-based breeding integrates the strengths of different breeding

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orientations and provides a perspective where breeders can initiate developments toward ecologically and societally resilient crop production that address six sustainability targets, including (1) food security, safety and quality; (2) food and seed sovereignty; (3) social justice; (4) agrobiodiversity; (5) ecosystem services; and (6) climate robustness. In this paper we present five supportive pillars for implementing the concept of systems-based breeding, based on experiences obtained during the European Union (EU) project LIVESEED from 2017 to 2021, and including results from prior related projects and literature on innovation systems and systems change. The five supportive pillars we have identified are (1) increasing social awareness and reflection, (2) developing alternative financing approaches, (3) promoting the development of appropriate breeding methodologies and methods, (4) applying integrative interdisciplinary and transdisciplinary learning in education, and (5) fostering facilitation for connecting these processes. These five supportive pillars are all necessary for fostering sustainable transformative change in complex systems, such as organic plant breeding. Based on workshop outcomes, we find that the main impediments to a wider embrace of a more holistic perspective on organic breeding are the current strong focus on short-term profits and EU law and regulations. Increasing social awareness, alternative financing models, new breeding methods, and multi-actor approaches are necessary for broadening breeding approaches.

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#### Keywords

plant breeding strategies, novel approaches, societal resilience, ecological resilience, sustainable seed systems, innovation systems, social awareness

#### Introduction

Plant breeding is not only a technical activity for improving plants, but also a social construction that can be addressed through a variety of breeding approaches (Table 1). Our thinking about this employed a holistic perspective on social construction that builds on Lammerts van Bueren et al. (2018), who analyzed several challenges to ecological and societal resilience given the current and future climatic, agronomic, economic, and social environment. They argued that social construction can only be properly addressed by concerted action and the inclusion of multiple perspectives on sustainable food systems (Figure 1). Polarization can easily arise between approaches to agriculture when systems like low-input and high-input approaches favor contrasting methods and goals (Struik & Kuiper, 2017). This is also true for hard and soft systems thinking: in hard systems thinking, the system exists independently from the observer and can be analyzed, understood, and developed if given a clear goal, while in soft systems thinking, a system is understood by the involved actors in different ways given their different perspectives (see Rölöng, 1992).

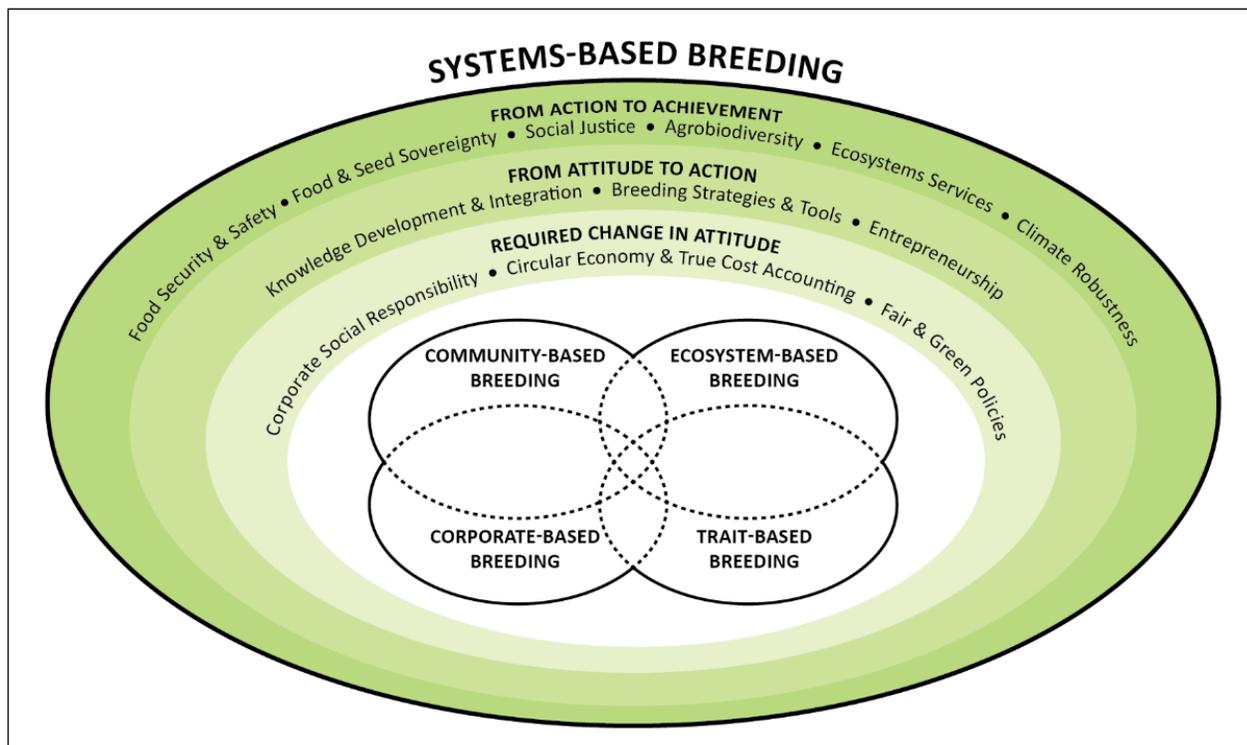
To avoid polarized discussions of plant breeding stances, a scheme developed by Bawden (2010) describing four paradigmatic orientations was used as analytical framework (Lammerts van Bueren et al., 2018). This scheme consists of two axes wherein the x-axis positions relativism versus objectivism and the y-axis plots holism versus reductionism (see Table 1 for a glossary of terms and concepts). The scheme makes the tensions that can be found in any society or group explicit, contrasting decision-making between the individual and society (the x-axis) and between the heart and the head (y-axis). The four paradigmatic breeding orientations identified using this schema include community-based, ecosystem-based, trait-based, and corporate-based. Each stance embraces a different mindset, style of thought, values, and economic models (Lammerts van Bueren et al., 2018).

**Table 1. Glossary of Terms and Concepts**

Category	Term or concept	Short explanation
Scientific perspectives	Objectivism	There is a permanent reality that can be known rationally.
	Relativism	Reality can never be completely known.
	Holism	There is an irreducible wholeness of nature and other living systems.
	Reductionism	Systems can be separated and subdivided into subsystems in a hierarchical manner.
Breeding approaches	Community-based breeding	A style of thought that combines holism and subjectivism. It aims to develop collaborative breeding networks and organizations involving a range of chain players at local or regional level, thereby respecting diverse cultural values and societal pluriformity.
	Ecosystem-based breeding	Starts from an ecological perspective and is a style of thought that combines holism and objectivism analyzing general patterns in ecology and aiming at developing varieties adapted to ecological conditions at regional level.
	Trait-based breeding	A style of thought that combines objectivism with reductionism, resulting in a mechanistic view of how plants grow, by subdividing complex traits into smaller, manageable (heritable) components and by better understanding how these components contribute to plant traits.
	Corporate-based breeding	A style of thought that combines subjectivism and reductionism. It assumes that the truth and knowledge on what is best are relative and are up to the individual or corporate organization.

Adapted from Lammerts van Bueren et al., 2018.

**Figure 1. The Systems-Based Breeding Approach, with the Aim of Integrating the Strengths of the Four Breeding Orientations, to Meet Socio-Economic, Environmental, Climatic, Agronomic, and Ethical Values**



Source: Lammerts van Bueren et al., 2018.

Each orientation has significant impact and value, but no single orientation alone will achieve all six of the sustainability targets listed above that compose systems-based breeding (Lammerts van Bueren et al., 2018). Following that each orientation has a different style of thought, these six sustainability targets can be understood in different ways. This can be done by applying overarching systems thinking as a driver to integrate the strengths of the four different breeding orientations and to provide a perspective where breeders can begin developing ecologically and societally resilient crop production.

Each of the four paradigmatic orientations has advantages and disadvantages, and none of them alone can be the only solution to meet the identified goals. Ideally, we need a balance among these four paradigmatic orientations. Today, plant breeding is dominated by corporate and trait-based breeding approaches, represented among others by large international seed companies (Lammerts van Bueren et al., 2018). To develop truly systems-based breeding, we need to stimulate additional types of breeding, such as farmer-led breeding or locally oriented breeding through community-based and ecosystem-based orientations (Chable et al., 2020).

In the current institutional, socio-economic,

and political context of plant breeding in the Global North, it may not be easy to get a good balance between the four breeding orientations in conventional agriculture. In mainstream plant breeding, developments prioritize scale enlargement, more protection through patents, and more high-tech breeding methods as well as increased use of genomic techniques. Given the many vested interests of various types of companies (not only in plant breeding but also in processing, plant protection, and agricultural trade), we can speak of so-called lock-ins (Vanloqueren & Baret, 2009). These can only be solved if all parties in a value chain are prepared to act at the same time.

Assuming that the parties in organic agriculture aim to use a more holistic approach, we expect a greater potential to achieve a good balance between the four orientations. The four principles of care, ecology, health, and fairness, as identified by the International Federation of Organic Agriculture Movements (IFOAM) (Box 1), show that the organic sector considers both agroecological and socio-cultural aspects important to achieve sustainable agricultural systems. In that respect, organic agriculture could provide a model for the way forward for agriculture in general. Unfortunately, the organic principles provide no simple recipe to follow. The way forward is to stimulate various pro-

**Box 1. The Transdisciplinary Research Networks Involved in the EU-Funded Project LIVESEED (Boosting organic seed and plant breeding across Europe)**

To foster an increase in organic seed and breeding, the LIVESEED project used a multi-actor approach. This means that in various research and breeding activities, other value-chain actors were involved, building on transdisciplinary experiences developed in other EU projects such as DIVERSIFOOD (Embedding crop diversity and networking for local high quality food systems) and SOLIBAM (Strategies for Organic and Low-input Integrated Breeding and Management) (Chable et al., 2020; Ortolani et al., 2017). Depending on the activity, farmers, traders, processors, researchers, policymakers, and citizens were involved. As such, LIVESEED can be considered a transdisciplinary and participatory research network that drew upon the research networks of the involved project partners.

By conducting research on organic seed and breeding, LIVESEED aimed to contribute to more sustainable food and farming systems that maximize social and environmental goods related to (a) health, (b) fairness, and (c) care, following the descriptions of IFOAM:

- Health: Enhancing the health of soils, plants, humans, and the planet is considered indivisible.
- Fairness: Building relationships that foster collaboration in breeding and access to seeds.
- Care: Maintaining and fostering crop diversity, so it is accessible to future generations.
- Ecology: Working within living ecological systems, meaning that production is to be based on ecological processes.

cesses of change with different stakeholders at various levels simultaneously (Bos et al., 2009). Before actual change can be achieved, necessary actions need to be identified first, for which change in attitude is often a prerequisite (Figure 1). By stimulating community-based and ecosystems-based orientations, we can foster a larger diversity in breeding approaches and change the currently dominant linear value-chain thinking into more circular and systems thinking. At the same time, change in policy-making is considered to be crucial for fostering a fertile ground for systems-based breeding. Policy-makers can be crucial in developing a balance in concurrently maintaining diversity in breeding approaches and ensuring common ground on a level playing field.

In this paper, we present five supportive pillars for operationalizing the concept of systems-based breeding with a focus on organic agriculture, based on our experiences and activities in the EU LIVESEED project (see Box 1). In various workshops where the systems-based breeding approach was discussed, it was made clear by the participants that in order to implement a systems approach to breeding, further operationalization of the concept was needed. In that context we have developed five supportive pillars.

## Material and Methods

The concept of the systems-based breeding approach was discussed with organic breeding practitioners and with actors in the value chain in several project workshops and meetings held from 2018 to 2021 using the framework of LIVESEED (see Box 1). Participants in these workshops worked for, among others, breeding companies, informal breeding initiatives, seed companies, non-governmental organizations (NGOs), universities, and independent research institutes. All were involved in the topic of organic breeding. Five international workshops were open to a wider audience. The sustainability targets as described by Lammerts van Bueren et al. (2018) were used as entry point to guide the discussions of the various workshops. Some workshops sought to gain insights into the role other value chain actors can play in the implementation of holistic organic breeding. Other workshops allowed for reflection and distillation of

crucial steps various actors could take to implement the concept of system-based breeding. This analysis was complemented with new insights based on other LIVESEED project outcomes as described by Chable et al. (2021), Mendes-Moreira et al. (2021), Nuijten et al. (2020), Rodríguez-Burruezo et al. (2020), and Rodríguez-Burruezo et al. (2021). Additional insights were obtained from other research projects in which the authors have been involved in, such as the EU DIVERSIFOOD project.

## Results and Discussion

Synthesis of the workshop results with information from other LIVESEED activities, other research projects, and the literature led to several conclusions. Based on the workshop results, we identified three supportive pillars: (1) increase social awareness and reflection, (2) develop alternative financing approaches, and (3) develop appropriate breeding methods. Based on other projects and literature, we have identified two additional supportive pillars needed to foster the integration and interlinking of the processes part of the first three supportive pillars. The fourth pillar is to (4) apply integrative interdisciplinary and transdisciplinary learning in education, which is needed to better anchor the integration of social and natural science thinking in daily practice. For example, having alternative breeding methods can support processes of social awareness, and clarifying the social aspects of breeding techniques can support the development of new breeding methods. The fifth supportive pillar is to (5) foster facilitation, which is needed to foster the integration and interlinking of the various processes at societal level. Below the five supportive pillars are described.

### *Supportive Pillar Number 1: Increase Social Awareness and Reflection*

A lesson learned from the workshops was that the group processes create awareness on the importance for openness for other values, diversity, and thought styles. At the workshop in Witzenhausen, Germany, on February 21, 2018, practitioners were asked to reflect on how they are currently managing their breeding and how they could adjust their breeding practices in the future, including the

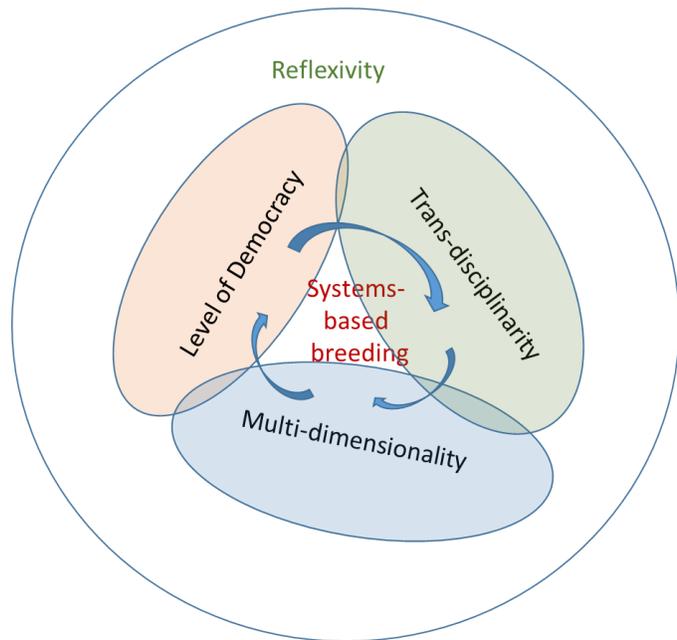
socio-cultural and ethical aspects (Nuijten, 2019). This workshop showed that a first step is a self-evaluation of their own breeding activities according to the 12 key elements using a spider diagram. A second step is group reflection, as the discussions will then deepen understanding and allow better internalization of the concepts.

To achieve changes in attitudes, continuous dialogue at various levels is necessary. The workshop in April 2019 with two Swiss biodynamic breeding companies, Sativa and GZPK, showed that the sustainability targets can be used for reflection and open dialogue. This reflection process can gain value when it is done repeatedly and regularly, as the process can be considered like peeling an onion to come to the essence of the organization in its ecological and societal context. With the first cycle of reflection, the obvious elements are discussed. During the next cycle of the reflection process, the less obvious issues emerge and can be challenged. If the targets are clear, they can be used as benchmarks and implemented in the strategy of the organization.

To foster processes of social awareness, a framework for multi-actor research developed in the DIVERSIFOOD project can be helpful (Rossi et al., 2019). The main elements of this framework are transdisciplinarity, democracy, and multidimensionality that are connected in an ongoing process of reflexivity (Figure 2). In the context of systems-based breeding, this means connecting and/or integrating different perspectives and knowledge fields of the four paradigmatic orientations in breeding (community-based, corporate-based, ecosystem-based, and trait-based) in an open and transparent way that allows a wide range of actors to be involved (breeders, farmers, scientists, and other actors in the food system). Guidelines that need to be considered to allow open communication include (1) proposing one's ideas to others instead of trying to convince them, (2) having an open attitude and respect toward others, (3) adopting ideas and practices that do not violate the principles and morals of the other actors involved, and (4) being open to a continuous process of reflection. Rossi et

## Figure 2. Overarching Framework

This shows that systems-based breeding has multiple dimensions, different actors involved, different knowledge fields, and that there is a constant process of re-iteration, resulting concurrently in a process of reflection.



Source: Adapted from Rossi et al. (2019).

al. (2019) concluded that every multi-actor research project may have its own approach adapted to the specific context, depending on its goals, people involved, their perspectives, timeline, and resources. Likewise, implementation of the systems-based breeding approach will be different depending on the institutional, socio-cultural, and agro-ecological specificities of every context.

Another outcome of the DIVERSIFOOD project was the identification of useful building blocks, such as common will, common vocabulary, trust, transparency, facilitation, resources, and well-adapted distribution of the work (Serpoly-Besson, 2018). These building blocks are all important for the successful implementation of the systems-based breeding approach. A common will is important, as confusion and disagreement inevitably will arise at any point in the process. Related to a common will is a “common sense of urgency,” but a common will is proactive in following one's ideals, whereas a common sense of urgency is

reacting to urgent problems. A common vocabulary is important to allow efficient, clear, and transparent communication among a diversity of actors with diverse backgrounds. The common vocabulary may develop over time and will support trust, transparency, and facilitation, which are interrelated and can reinforce each other. Trust, transparency, and facilitation allow everybody involved in the process to clearly share their ideas, fears, and hopes. As a result, all actors involved clearly understand their own position regarding the orientations of the others, where the connections are, and what the (potential) tensions are. Translating this to the process of the systems-based approach is that instead of superimposing a new homogenous perspective, a common approach is developed that allows room for small differences in the perspectives of all individuals involved. Lastly, the availability of resources and a well-adapted distribution of the work are important to make the systems-based approach work in practice, beyond the level of discussion, which it usually starts with.

To induce change (e.g., a paradigm shift or a broadening or connecting of paradigms), all actors in the system need to be involved (Chable et al., 2020; Ito, 2018), and change must be made at various levels simultaneously (Bos et al., 2009), individual and system levels (and perhaps other levels). Although it seems counterintuitive, it has been demonstrated that people can shift their mindset in less than a second (Meadows, 1999), through arts as well as other means (Ito, 2018). However, a kind of “fertile ground” is still needed for mindset shifts, feeding the common sense of urgency: the involved actors need to have a more or less conscious feeling of running into limits. The current context with various crises at hand such as climate change, nitrogen pollution, and loss of biodiversity can speed up an individual’s processes of change.

Meadows (1999) showed that not only actors need to change, but also the hardware of a system as well. Hence, a societal mind shift will usually only happen slowly. As multiple change is needed at multiple levels and to be achieved in diverse ways, a range of positive reflection tools is needed, as different people will be inspired by different approaches. Rossi et al. (2019) identified reflection at individual and group levels as especially impor-

tant to foster awareness and mind shift (Figure 2).

Being able to transcend paradigms is the most effective way to induce sustainable change, since no one specific paradigm is considered the best; people can have multiple perspectives to solve a particular question or issue (Bawden, 2010; Bos et al., 2009; Meadows, 1999). The paradigmatic framework by Bawden (2010), on which the systems-based approach is based, can help explain the differences between the decision-making processes and social dynamics that are related to each of the paradigmatic orientations (Figure 3). As explained by Lammerts van Bueren et al. (2018), to date the two lower quadrants dominate in many western societies. However, each of the four quadrants has advantages and disadvantages in terms of decision-making and social dynamics, and hence, more balance in approaches is required.

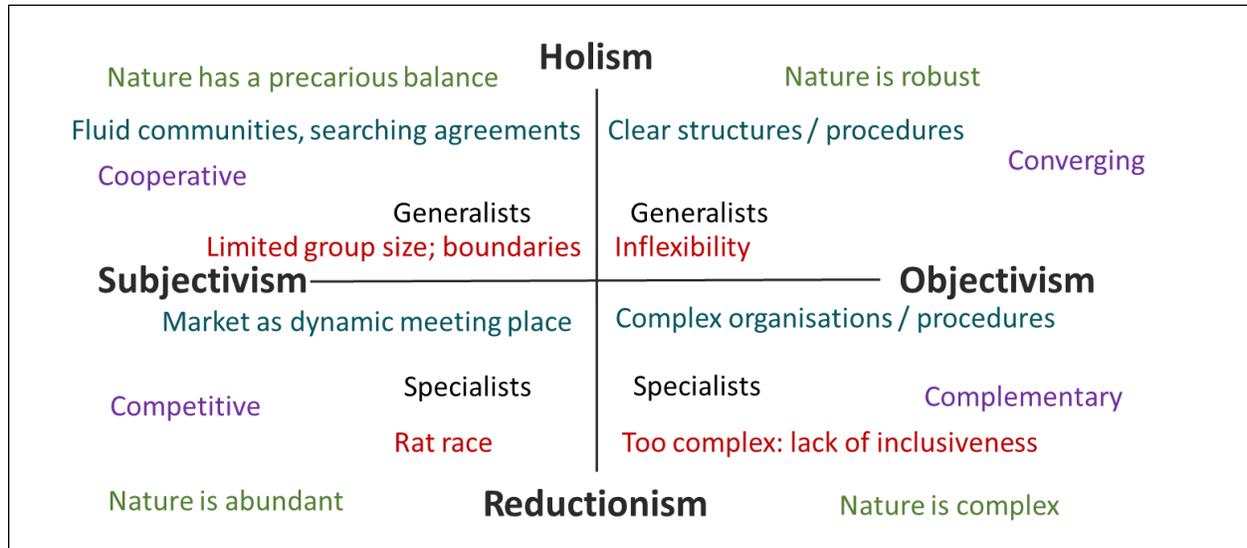
When it comes to breeding, change is not the sole responsibility of breeding practitioners. Government, value chain actors, and citizens also have a role to play. For citizens to take their responsibility, it is necessary to set up virtual and physical platforms—such as workshops, markets, and field visits—where citizens can meet and feel involved in this environment. As breeding has become distant from daily life and difficult to understand for many citizens, it is important to create more awareness and distribute information about today’s breeding practices and let citizens experience the results and processes of breeding, such as through taste tests and field visits (e.g., Rodríguez-Burruezo et al., 2020, 2021).

### ***Supportive Pillar Number 2: Develop Alternative Financing Approaches***

In the dominant breeding approach in Europe, breeding efforts need to be financed through seed sales. For organic agriculture, however, a broad portfolio of crops and varieties is needed to create resilience in the cropping systems which cannot be recovered through seed sales. The current EU seed regulations require a high uniformity of varieties in order for them to be distinguishable from other varieties and to be stable in their appearance. Such varieties can be protected by breeders’ rights, which ensure monopoly of sales and which in turn allow the financing of future breeding. Many small-

**Figure 3. Keywords Describing the Social Decision-Making Processes Related to Each of the Four Paradigmatic Orientations**

Key: **Black:** focus; **Green:** perspective on nature; **Purple:** tendency of human relationships; **Blue:** resulting positive aspects; **Red:** potential disadvantages



scale organic breeders prefer to work with more diversity within their varieties as it contributes to better adaptability and stability of the crop performance in the field. But complex registration processes based on EU regulations complicate the activities of small breeders working with landraces, traditional varieties, and populations. Adding to that, compared to the breeders' rights often applied for in Europe whereby breeders can still use each other's varieties for further breeding, the patenting of natural traits hampers the exchange of breeding material and the maintenance of a broad genetic base for food security.

At the workshop in Witzenhausen, Germany, the most-mentioned obstacles for new breeding approaches were "law and regulations," "short-term profit," and "long-term funding," while solutions were seen in "collaboration in breeding," "market reorganization," and "knowledge sharing" (Nuijten, 2019). Together these solutions describe a common idea for organizing breeding in a different way, with more collaboration in the value chain and broader forms of funding plant breeding. At a LIVESEED workshop connected to the DIVERSIFOOD final congress (December 12, 2018), participants emphasized that the financing

of plant breeding needs to be changed. It is not possible to organize breeding in a different way if the financing remains unchanged. In the LIVESEED workshop at Biofach of February 21, 2019, participants emphasized that changes in relationships within the value chain and in education curricula are needed as well. At the second annual meeting of LIVESEED (May 15, 2019), workshop participants mentioned that it is important to realize and understand exactly how breeding, including its financing, has altered over the last 50 years.

Hence, a second essential element to implement the systems-based breeding approach is a larger diversity in funding approaches. Currently, the dominant approach to fund breeding (the mainstream model) is through seed sales by commercial enterprises. However, economic efficiency (based on a limited portfolio with a large spread) is not the same as ecological efficiency (based on a diverse portfolio adapted to different ecological and/or cultural conditions), and so it will not work for all breeding approaches, such as community-based and ecosystem-based breeding. As described by Nuijten et al. (2020), other financial models are needed to finance organic breeding when consider-

ing the IFOAM principles. The following existing alternative financing strategies were identified to sustain organic plant breeding: (1) public funding, (2) funding through private foundations, (3) open-source seed approaches, and (4) small-scale value-chain collaborations.

So far, the reach of these alternative financing strategies is limited, and other funding schemes are needed for the benefit for society. In response, Winter et al. (2021) propose another strategy: a so-called cross-sector pool funding strategy in which all value chain partners in the organic sector jointly invest in organic breeding and, hence, collectively secure the integrity of the future organic product supply. They have identified four success factors: a long-term commitment, a pool fund for organic cultivar development, awareness-raising on the importance of breeding, and an elevated level of transparency in the process. This approach also builds on a consensus in the organic sector that seed sales should cover the costs for seed production. However, the breeding activity can be considered part of managing the cultural heritage and the commons, and thus should receive financial support from the government and/or the value chain.

In any case, to foster processes of change, regular dialog with actors in the value chain and public authorities is needed. Another potential strategy is to involve citizens in funding as well, as they can be reached with appropriate labeling and other techniques.

### ***Supportive Pillar Number 3: Develop Appropriate Breeding Methodologies and Methods***

Whereas mainstream breeding methods have been developed in the context of corporate-based and trait-based breeding, the development of breeding methodologies and methods for community-based and ecosystem-based breeding has been limited until today. At the workshop in Witzenhausen, Germany, it was concluded that alternative breeding approaches imply more collaboration in breeding (e.g., with an active role of farmers and other value chain actors) and breeding for diversity (e.g., populations, intercropping, and agroforestry systems). Specific examples included the biodynamic vegetable breeding initiative

Kultursaat in Germany, the biodynamic vegetable breeding company Sativa in Switzerland, the organic potato breeding project BIOIMPULS in the Netherlands, and collaboration of INRAE (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement) with Réseau Semences Paysannes on cereals in France (Nuijten, 2019).

In the western world, potential breeding approaches, such as participatory and multi-actor approaches, have been explored over recent decades. These approaches have in common that they aim to consider the local agro-ecological and socio-cultural contexts as much as possible. Instead of minimizing Genotype x Environment (GxE) interaction, the logic is to maximize GxE interaction, profiting from local adaptation (Ceccarelli, 1989). Lessons learned in EU projects like SOLIBAM, DIVERSIFOOD, and LIVESEED show how to integrate the different socio-economic contexts of the various European countries in the breeding practice, resulting in optimized Genotype x Environment x Society interactions with advantages such as improved yield stability and resilience (Nuijten et al., 2020). LIVESEED results underline that improving resilience in agricultural systems is not only based on improving specific plant traits, but also on dynamic relationships between plants (Mendes-Moreira et al., 2021); between plants and their environment, in particular the soil (Chable et al., 2021); and between plants and people (Rodríguez-Burruezo et al., 2021). Participatory and multi-actor approaches can integrate the benefits of these diverse types of relationships to improve yield stability, product quality, and resilience through

- On-farm cultivar testing, in which other actors in the food system are also directly involved,
- Optimizing cultivar mixtures to local contexts,
- Developing cultivar mixtures and populations with local actors,
- Designing crop mixtures adapted to local contexts (e.g., intercropping),
- Joint learning about resilience in complex systems (such as agroforestry systems), and

- Joint learning about plant-soil interactions through so-called Living Labs.

When it comes to developing breeding networks, a range of factors need to be considered. Rodríguez-Burruezo et al. (2020) observed that these factors can differ based on the existing building blocks for the breeding network to be developed. Based on the experiences with five representative crops (apple, cabbage, tomato, wheat, and white lupin) these factors were subdivided into two main categories organized according to socio-economic and organizationally related factors, and plant- and crop-related factors (Table 2).

LIVESEED Deliverable 3.6 (Mendes-Moreira et al., 2021) provided the following practical aspects and guidelines to consider for breeding for more diversity:

- Screening germplasm for its performance in complex systems
- Methods to search for the best combinations
- Ways to increase diversity level and performance
- Improvement of various strategies for weed competition

- Improvement of disease tolerance and resistance
- Comparisons of breeding strategies: strengths and weaknesses
- Methods for involvement of the value chain: multi-actor approaches

It may be apparent that the guidelines are different for annual and perennial crop mixtures, organic heterogeneous material, and agroforestry systems. In terms of breeding for improved resilience, nutrient-use efficiency, water-use efficiency, or drought tolerance, the use of a gene pool more diverse than current modern varieties is essential, as old landraces and ecotypes have evolved under less intensive and more stressful conditions (Nuijten et al., 2020). Methodological approaches should not only consider evaluation of the above-ground parts of the plant in response to stress conditions but pay more attention to the below-ground parts, as the root and soil interaction is essential. Chable et al. (2021) describe several ways in which plant roots and soil interact in detail. Good plant-soil interaction supports plant resilience by improving nutrient use and disease tolerance. Hence, when it comes to resistance breeding, organic breeding should consider this along with other

**Table 2. Factors Important for Developing Breeding Networks**

Factors with a social, economic, cultural, organizational, and/or regulatory nature	Plant- or crop-related factors
<ul style="list-style-type: none"> <li>■ Trust-building among partners</li> <li>■ Type of actors involved (level of congruency between skills and knowledge)</li> <li>■ Group size and diversity in backgrounds</li> <li>■ Exchange of material (limited, free, etc.)</li> <li>■ Scale and/or economic importance of the crop</li> <li>■ Funding resources</li> <li>■ Timeline (congruency in time of activities)</li> <li>■ Exchange of knowledge (facilitator can play a key role)</li> <li>■ Involvement of other value chain actors (facilitator can stimulate this)</li> </ul>	<ul style="list-style-type: none"> <li>■ Goal and/or focus (variety improvement and/or specific traits)</li> <li>■ Crop type (reproduction system, annual or biannual crop, rate of reproduction)</li> <li>■ Crop-specific related knowledge: The current state of knowledge on breeding</li> <li>■ Type of germplasm tested (population, breeding lines, varieties, etc.)</li> <li>■ Breeding approach (focused on homogeneous varieties, populations, etc.)</li> <li>■ Possibility of combining, integrating, and/or connecting different approaches</li> <li>■ Availability of methods for testing (visual, lab analysis, etc.)</li> <li>■ Evaluation: Set-up of design, level of participation, sharing of templates</li> </ul>

From Rodríguez-Burruezo et al., 2020.

approaches to improve plant health and integrate into fair social and economic models (Nuijten et al., 2020). Weed tolerance, likewise, should be considered from a holistic perspective. These results of the LIVESEED project also underline the compliance of breeding methods with the organic principles and values as outlined by IFOAM.

Instead of trying to develop a single approach, the results of the EU project LIVESEED described by Chable et al. (2021), Mendes-Moreira et al. (2021), Nuijten et al. (2020), Rodríguez-Burruezo et al. (2020, 2021) all call for the development of guidelines for breeders, researchers, and farmers to develop tailor-made breeding approaches adapted to the specificities of the crop, agro-ecological context, climate conditions, and socio-economic and cultural contexts.

The higher the diversity in breeding approaches and the more initiatives, the more agrobiodiversity can be maintained and bred for, which is also important to make agriculture more climate-robust and resilient. In addition, diversity in breeding approaches and initiatives will foster the development and maintenance of diversity in knowledge, and it will help reinforce what seeds are: they are not only commodities but are also culture and part of common heritage.

#### ***Supportive Pillar Number 4: Apply Integrative Interdisciplinary and Transdisciplinary Learning in Education***

Our experiences are that many practitioners realize the importance of integrating different perspectives, methods, and ways of working together only at a later stage in life. As systems-based approaches require skills and knowledge from various disciplines, training in interdisciplinary and transdisciplinary thinking will help young people to learn to look at problems and questions with a broad, holistic perspective. However, teaching at interdisciplinary and transdisciplinary levels is not common (Spelt et al., 2009).

It is also important that the underlying meaning and reasoning of the four basic principles of organic agriculture (ecology, fairness, care, and health; see Box 1) become part of educational curricula. For example, looking at the concept of health, an essential aspect is to enhance robustness

to prevent illness. This is not only for people, but also for plants, soils, and ecosystems. Hence, the principle of health is interrelated with the principle of ecology (Nuijten et al. 2017). The implications for systems-based breeding are significant: it means we need to critically reflect when resistance breeding is at stake and when it requires improving general plant robustness and microbe-mediated disease tolerance, for example.

It also means that educational curricula should address the diverse types of visions of society as described by Bawden (2010). For example, it is important to stress that a balance is required between competition and cooperation (see Figure 3). Also, basic principles of social interaction should be addressed, such as having an open mind and being respectful of other ideas, proposing one's ideas to others instead of trying to force them on others, and practicing self-reflection and group reflection, as described by Rossi et al. (2019). It is important that young people are supported to find their actual role in life and live true to themselves. Building and maintaining a balance in common ground and diversity in ideas needs to become a widespread practice and needs to be in our daily consciousness. This implies that we need critical historical, epistemological, and ontological reflections on plant breeding science (Chable et al., 2020, 2021). The current dominant visions of plant breeding have been developed in parallel and contributed to the current dominance of an industrial vision of agriculture, and therefore of our food systems and our concept of health. Recent research on plant-soil interactions as described by Chable et al. (2021) shows that other approaches to breeding and agriculture have much potential to develop ecosystem resilience through organic breeding and organic agriculture.

#### ***Supportive Pillar Number 5: Foster Facilitation***

The above makes clear that plant breeding is not only a technical activity but also a social activity (Chable et al., 2020, Lammerts van Bueren et al., 2018, Osman et al., 2016). The development of appropriate breeding approaches, methodologies, and methods suited to organic agriculture are not possible without co-construction among a broad range of actors, such as breeders, farmers, proces-

sors, traders, and other chain actors. Politicians also have a key role in shaping plant breeding, as demonstrated by Kloppenburg (2005).

Earlier, it was suggested that so-called knowledge brokers can play a key role in the transfer of knowledge (Klerkx & Leeuwis, 2009). It is important that breeders and other actors are aware of new insights on breeding, agronomy, economics, regulations, and other important aspects. Over the past decades, awareness has increased that the active involvement of all sorts of value chain actors in research and crop development is important, as all can contribute to the development of innovations (Klerkx et al., 2012). The role of good facilitation is especially important when different paradigmatic perspectives and their related ontologies and epistemologies come together. For example, knowledge can develop in a structured way, but it can also emerge through interaction (Bawden, 2010). Facilitation may need to be organized at various levels, depending on the goals and questions that exist. While in some situations, a particular entity (person or organization) has the role of facilitator, facilitation can be done by various actors (Serpoly-Besson, 2018). Rotating facilitation can be useful to maintain awareness of the importance of good facilitation among stakeholders. At an overarching level, government can play a key role in maintaining a good balance and dynamism in common ground and a diversity in approaches.

## Conclusion

In this paper we argue that plant breeding is not only a technical activity but also a social activity. The concept of systems-based breeding aims to

integrate the strengths of different breeding orientations. It provides a perspective where breeders can be initiators of developments toward a sustainable agri-food system based on an ecologically and societally resilient crop production. Five supportive pillars for implementing this concept include (1) increasing social awareness and reflection, (2) developing alternative financing approaches, (3) promoting the development of appropriate breeding methodologies and methods, (4) applying integrative interdisciplinary and transdisciplinary learning in education and (5) fostering facilitation for connecting these processes.

We argue that a multitude of breeding approaches that rests on these pillars is needed to contribute to agro-ecological and societal resilience. Multi-actor approaches are essential to involve farmers, processors, traders, and other value-chain actors in plant breeding. Among the discussed five supportive pillars, we think the financing models of breeding are the least developed and need more elaboration, since they are a precondition to diversify breeding approaches. Another future challenge important for diversification is the transition from the focus on short-term market profits toward long-term ecological and societal sustainability. This transformation also includes law and regulations in the EU regarding complex and inflexible variety registration processes to foster a diversity of activities of small breeders. 

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