Policy and stakeholder recommendations to boost organic seed & breeding sector

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LIVESEED team at meeting in Zelechow, Poland, May 2019

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Executive summary

The use of a broad portfolio of cultivars and crops adapted to specific climatic, soil, and farming conditions are key for more sustainable agriculture. The goal of the Horizon 2020 project LIVESEED is to improve the performance of the organic sector by boosting organic seed and plant breeding activities across Europe. In a concerted action of 50 partners covering different disciplines and actors along the seed value chain all relevant aspects from organic seed market transparency and policy, organic cultivar testing and registration, organic seed health, novel breeding concepts aiming for higher diversity as well as socio-economic modelling of organic seed production are addressed. Here we summarize key results and innovations that allow boosting of organic seed and plant breeding. LIVESEED for the first time identified the use and market potential of organic seed for major crops and highlighted the importance of more harmonized and stricter implementation of derogation rules for non-organic seed supported by improved interactive national databases and an EU wide router database. Recommendations were made for the characterization and registration of new cultivar types with higher level of genetic diversity as now defined in the new EU Organic Regulation (2018/848). Novel strategies for seed health and frugal on-farm cultivar testing networks were explored to allow farmers an informed choice of most suited cultivars. A systems-based breeding concept including also social aspects in order to achieve the UN Sustainability Development Goals (SDGs) was developed and breeding strategies to improve resilience of crops by improved diversity (e.g., cultivar mixtures, dynamic populations, composite cross populations, crop mixtures, agroforestry) were explored as well as the importance of root and seed microbe interactions. Phenotypic screening and genetic marker tools have been developed for major crops and the perception of novel breeding techniques were explored among organic consumers.

After a synopsis of the main outcomes of LIVESEED (Chapter 1), we present in more detail the evidence based recommendations and actionable next steps to improve availability of high quality organic seed of cultivars suited for organic production with respect to:

- regulatory and policy measures on production, use, and transparency of organic seed (Chapter 2, WP1);
- measures enabling release and marketing of organic heterogeneous material and organic varieties suited for organic production as well as frugal models for on-farm cultivar testing supporting farmer's choice (Chapter 3, WP2.1);
- a holistic organic seed health and quality strategy and upscaling seed production (Chapter 4, WP2.3);
- boosting and harnessing innovations of organic plant breeding (Chapter 5, WP3);
- socio-economic aspects to achieve a viable organic seed supply chain and consumer trust (Chapter 6, WP4).

These recommendations discussed and validated with stakeholders and policy makers at different events resulted in a roadmap towards 100% organic seed of suitable cultivars by January 2036 (Fig. 1) and recommendations for the different target groups (Fig. 2).

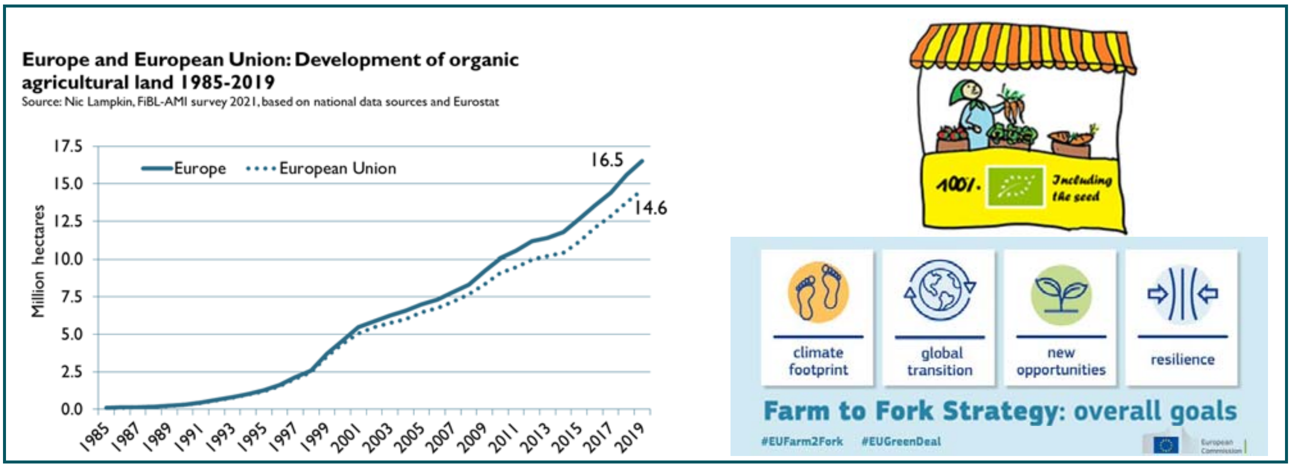

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Figure 1: A roadmap towards 100% organic seed of adjusted cultivars in Europe

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Figure 2: Recommendations for key stakeholders and policy makers to reach 100% organic seed of adjusted cultivars in Europe

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1. Synopsis of LIVESEED (D6.2, WP6)

1.1 Background and research approach

LIVESEED is based on the concept that cultivars adapted to the unique conditions inherent in organic systems are the key for eco-functional intensification and realization of the full potential of organic agriculture in Europe. Innovations facilitating breeding, registration, organic seed production of a wide range of cultivars and crops will ensure sustainable and resilient food production of organic and low-input agricultural systems, thereby, increasing their competitiveness. However, presently organic production still relies to a very large extent on homogeneous cultivars developed for and under conventional farming systems of limited number of crops, seldom tested under organic farming practice in the different pedo-climatic regions of Europe, while organic and participatory breeding initiatives are slowly emerging (Fig. 3). Although it is mandatory to use organic plant reproductive material in organic agriculture (EC No 834/2007), this has not been achieved for a single crop species across Europe in the last decades. In most EU Member States, there is a lack of high-quality organic seeds or the amount of such seed is limited, and farmers are therefore, request derogations to use conventional untreated seeds instead (Fig. 3). These derogations, however, in line with the new EU Organic Regulation (Regulation (EU) 2018/848 enter into force on 1st January 2022), will be phased out by the end of 2035, therefore the market and all stakeholders in the organic sector must prepare to tackle the problems around the production and availability of organic seed.

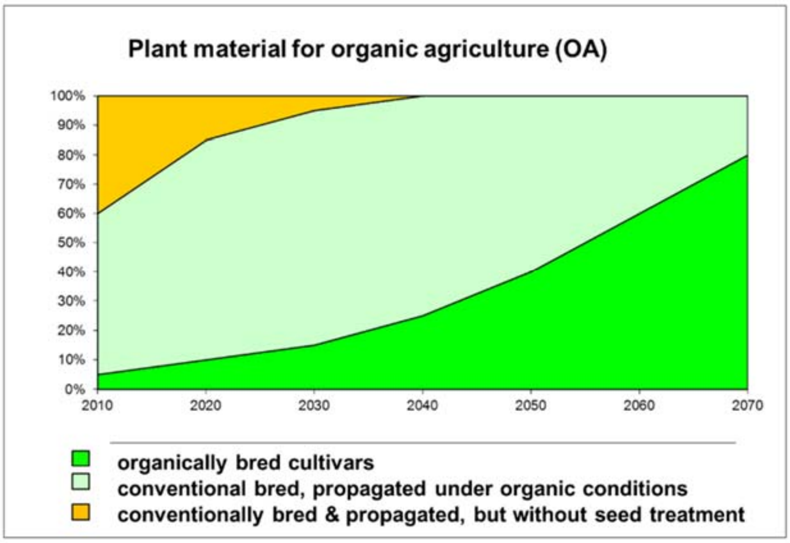

Figure 3: Schematic time line to reach the goal of 100% organically propagated seed of suitable cultivars (light green) in short term and to foster cultivars specifically bred for organic farming systems (bright green) in the long term

Moreover, the demand for high quality seed of a large portfolio of resilient cultivars adjusted for organic and other sustainable farming systems will increase rapidly, considering the ambitious targets of the European Union's Farm to Fork strategy to reduce fertilizer losses and pesticide inputs by 50%, and to upscale organic managed farm land from 8.1% in 2019 to 25% by 2030. At the same time, farmers need to cope with increasing challenges of climate change, emerging pest and diseases, and diversified market demands. This highlights the urgent need to invest in breeding of new cultivars and cultivar types with improved resilience for many crops species, improved cultivar testing systems and upscaling of high-quality organic seed production. Therefore, the LIVESEED project has addressed the issues around the lack of organic seed of suitable cultivars in a holistic way from factor analysis and market potential of organic seed, policy implementation and interventions striving to achieve 100% organic seed, to new concepts and approaches of organic breeding, novel cultivar types, cultivar testing networks, innovative seed health strategy, and co-creation of knowledge in organic seed production including farm saved seed.

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LIVESEED aimed to improve the sustainability, performance, and competitiveness of the organic sector by (i) boosting organic seed production, (ii) developing novel breeding approaches to increase the choice of cultivars of various crop species adapted to organic and low-input agriculture for different pedo-climatic conditions in Europe, and by harmonizing the implementation of the European regulations in relation to organic seed. In order to achieve this goal, LIVESEED targeted all dimensions that impact the use of organic seed from breeding to seed availability (breeding approaches, cultivar testing, seed multiplication, the use of organic seed databases) and addressed institutional, legal, technical, scientific, and socio-economic barriers of organic seed availability. LIVESEED covered the five main crop categories: legumes, vegetables, fruit trees, cereals and fodder crops, considering diverse cropping systems across Europe (including mixed cropping and agroforestry). LIVESEED generated locally adapted innovative solutions that are immediately applicable and adjusted to the needs of the project end-users (breeders, farmers, seed producers, retailers, traders, certifiers and regulators) in the different EU countries.

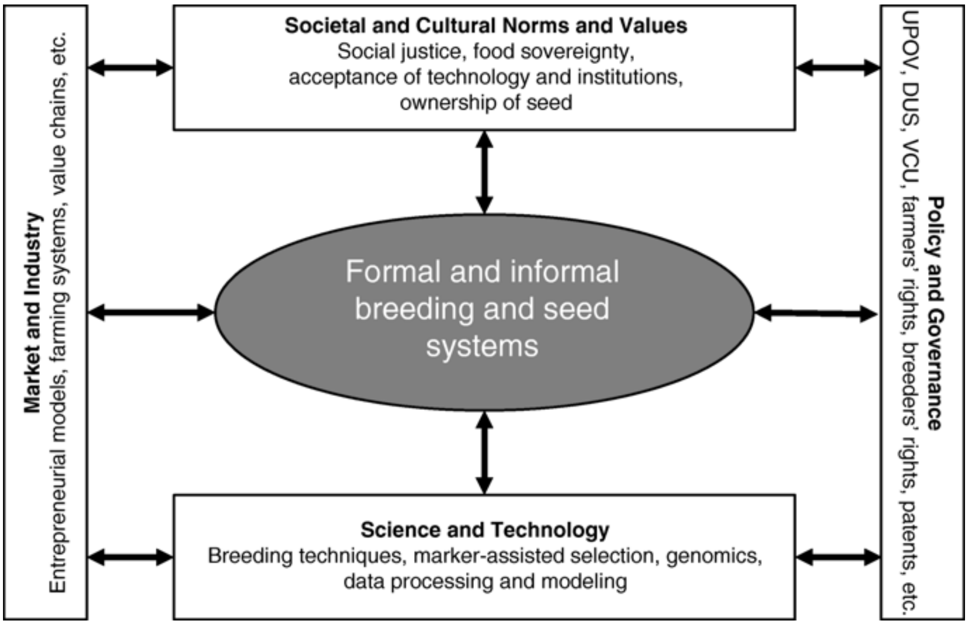

Figure 4: Roles and positioning of the organic breeding and seed systems within their technical, economic, institutional and cultural context derived from Lammerts van Bueren et al. 2018

To boost the organic seed and breeding sectors LIVESEED addressed the different dimensions (scientific innovations, organic and seed regulations, societal norms and marketing situation) which have a great impact on the development of formal and informal seed systems (Fig. 4).
The main objectives were addressed in different Workpackages:

WP1: Provide a level playing field regarding the use of organic seed across Europe by (i) analysing the determinants of the current production and use of organic seed, (ii) identifying breeding gaps of crops and sub-crops where suited cultivars are missing, (iii) increasing transparency of the EU organic seed market, (iv) improving the implementation of legislative requirements in close collaboration with national authorities in EU Member States, and (v) developing missing national databases together with an EU-wide router database tool for seed suppliers.

WP2: Increase the volume and quality of organic seeds derived from cultivars suited for organic farming by (i) developing and improving efficiency of cultivar testing models under organic farming for the identification of suited cultivars, (ii) developing adjusted protocols for 'Distinctiveness, Uniformity, Stability'

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(DUS) and 'Value for Cultivation and Use' (VCU) examination suited for the official variety registration of open pollinated varieties and new descriptors for marketing of heterogeneous population, (iii) sharing of knowledge and training on smart practices for organic seed multiplication across countries, and (iv) investigating novel seed health strategies and technologies focusing on the vitality of organic seed.

WP3: Accelerate the breeding process and adoption of new cultivars by (i) developing novel and holistic breeding concepts and approaches, from trait based to system based breeding, (ii) delivering new breeding tools based on better scientific understanding of the biological basis of crop resilience and product quality, plant-plant, and plant-microbe interactions, (iii) strengthening small breeding initiatives and stimulating collaboration among actors to close breeding gaps for the five main crop categories: legumes, cereals, vegetables, fruit trees and fodder crops, and (iv) identifying key factors for successful breeding initiatives.

WP4: Improve the competitiveness of the organic seed sector by (i) identifying gaps and bottlenecks in the market development of organic seeds and breeding through stakeholder consultations, (ii) analysing the organic seed market supply chain, (iii) developing business and governance models including all actors of the supply chain (breeders, seed producers, farmers, processors, retailers and consumers, (iv) performing case studies on the socio-economic impact of upscaling organic seed and (iv) studying consumer attitudes to the use of new breeding techniques.

WP5: Enhance greater uptake of organic seed by (i) knowledge sharing and disseminating of LIVESEED results (i) building the capacity of breeders, seed producers, farmers, retailers, researchers, and other actors of the food value chain through training and networking, and (iii) raising awareness of policy-makers regarding the importance of using organically bred seeds in organic farming.

WP6: Foster seed and breeding related innovation in the organic sector by (i) coordinating and ensuring scientific exchange between WP1 to WP5, the stakeholder platform and other related projects (e.g., ECOBREED, BRESOV, ReMIX, Diversify, INVITE), (ii) fostering strong collaboration between academic and non-academic actors along the food value chain including competent authorities and policy makers and (iii) synthesising project results and developing joint-up recommendations.

For a broad and fast implementation across Europe the multi-actor and action research approach ('learning by doing') has been vital for the LIVESEED project. Therefore the LIVESEED consortium represents an inter- and multidisciplinary European partnership involving 50 organisations from 17 EU countries and Switzerland, including researchers, breeders, seed companies, organic associations, retailers, certification bodies, examination offices. Knowledge creation has been supported by 145 registered European and international stakeholders including farmers, seed companies, policy makers, national authorities, and examination offices (Fig. 5). Combining scientific and practical knowledge enabled the consortium to generate innovative solutions adapted to the needs of end-users and the different pedo-climatic and socioeconomic contexts. Final impacts are improved breeding efficiency and greater choice and uptake of organic seeds derived from cultivars with high resilience for optimising organic and low-input agriculture strengthening sustainable food production in Europe.

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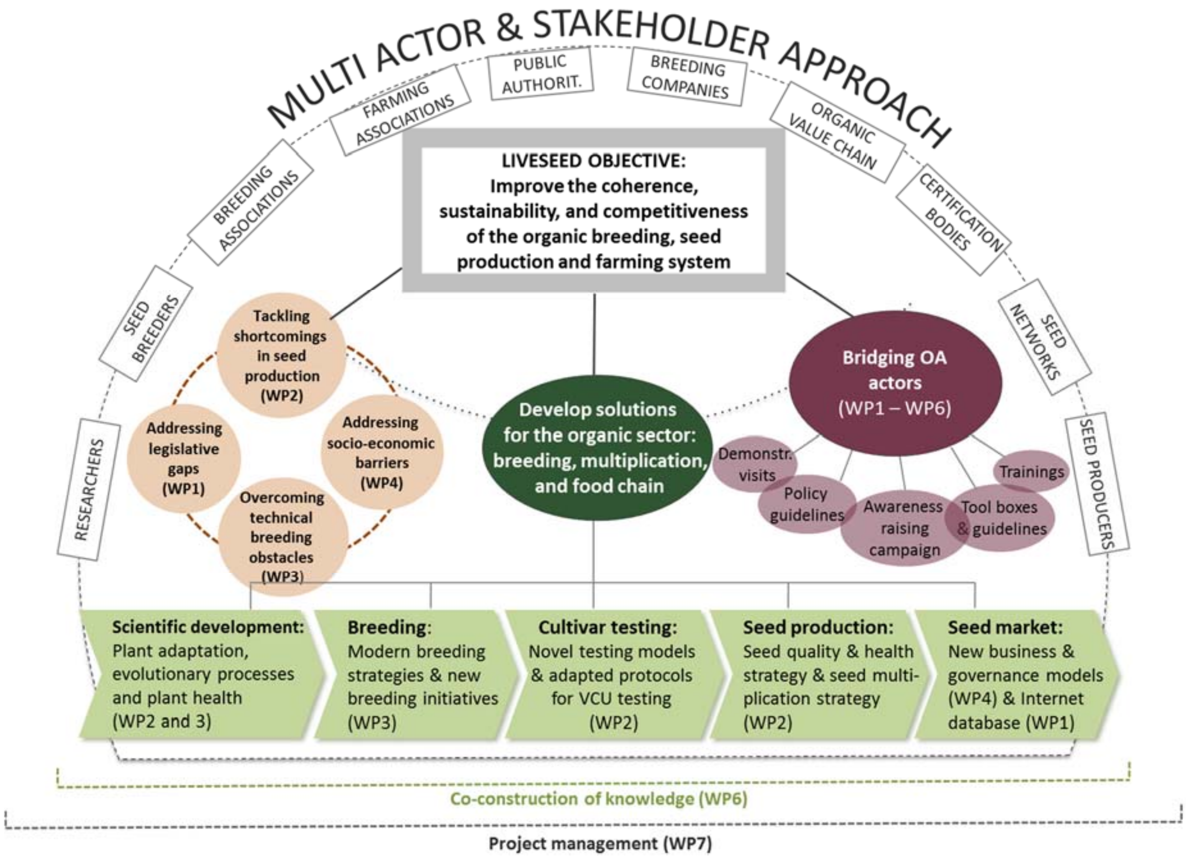

Figure 5: Multi-actor project approach of LIVESEED

This cooperation among actors has been crucial to (i) understand the existing bottlenecks related to the low use of the organic seed and (ii) co-develop solutions adapted to the needs of the project end-users (market-oriented approach). Furthermore, it allowed innovation through co-construction of knowledge and knowledge sharing, which is vital to guarantee a broader application of breeding and seed production strategies suited for organic production. Business plans for the exploitation of key results have been developed by the LIVESEED partners supported by the Horizon Results Booster service.

Definitions used in LIVESEED

Cultivar: comprises registered varieties, landraces, populations, composite cross populations, dynamic populations, organic heterogeneous material etc.

Organic Plant Breeding (OPB): Organic cultivars are obtained by an organic plant breeding program as defined by the IFOAM International norms of 2014. All breeding steps from crossing till final selections take place under organic conditions and the applied breeding techniques are in accordance with the techniques listed in the Annex of the position paper of IFOAM International for organic breeding from November 2017. Moreover, cultivars derived from OPB shall also not be patented. For more details see ECO-PB position paper 2013.

Breeding for Organic (BfO): are more product oriented and have a special focus on the breeding goals which are specific for organic agriculture (e.g. tolerance against seed-borne diseases, weed tolerance, nutrient use efficiency), they do not use critical breeding techniques and selection occurred at least partially under organic conditions.

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Definition in the new Organic Regulation (EU 2018/848)
Organic heterogeneous Material: Article 3 (18): 'organic heterogeneous material' means a plant grouping within a single botanical taxon of the lowest known rank which:
(a) presents common phenotypic characteristics; (b) is characterised by a high level of genetic and phenotypic diversity between individual reproductive units, so that that plant grouping is represented by the material as a whole, and not by a small number of units; (c) is not a variety within the meaning of Article 5(2) of Council Regulation (EC) No 2100/94 (1); (d) is not a mixture of varieties; and (e) has been produced in accordance with this Regulation

Organic varieties suited for organic production: Article 3 (19): 'organic variety suitable for organic production' means a variety as defined in Article 5(2) of Regulation (EC) No 2100/94 which:
(a) is characterised by a high level of genetic and phenotypical diversity between individual reproductive units; and (b) results from organic breeding activities referred to in point 1.8.4 of Part I of Annex II to this Regulation
Annex II: 1.8.4.: For the production of organic varieties suitable for organic production, the organic breeding activities shall be conducted under organic conditions and shall focus on enhancement of genetic diversity, reliance on natural reproductive ability, as well as agronomic performance, disease resistance and adaptation to diverse local soil and climate conditions. All multiplication practices except meristem culture shall be carried out under certified organic management.

1.2 Highlights and key results of LIVESEED

Main outcomes of LIVESEED are:
Increased knowledge of the organic seed market with first data on potential demand of organic seeds in Europe based on land area and sowing density, and status quo of share of organic certified seed, farm saved seed and non-organic seed for target crops in different European countries (Solfanelli et al. 2019, 2020, 2021). About 800 larger and smaller seed businesses (breeders and traders) as well as farmers multiply organic seed crops are involved in organic seed production, covering only half of the potential demand. There are considerable differences in the level of availability of organic seed between arable, vegetable and forage crops and between geographic regions with an accumulation of organic seed suppliers in Central Europe (Solfanelli et al. 2021). Major factors influencing demand and supply of major crops from the perspective of (i) farmers (Orsini et al. 2019a. 2020), and (ii) seed suppliers were identified (Solfanelli et al. 2019, 2021).

National organic seed databases differed very much in their functionalities, ease to use, completeness, and update frequency (Solfanelli et al. 2019, 2021). Interactive databases with frequent update directly by seed companies are highly recommended. A Europe-wide survey revealed that only a quarter of all seed suppliers list their organic seed offer in national databases and seed supply is often only listed in their country-owns national seed database even though organic seed might also be exported to other EU Member States.

The EU-wide router database for organic seed to feed into national databases was designed as a back-end database that allows information exchange between seed suppliers and representatives of national competent authorities, which addresses their basic requirements and needs (Fig. 6). The beta version of the router database was validated by the users, adjusted in 2020 and translation in 22 national languages of the EU Member States, and finally launched in March 2021 https://www.seeds4organic.eu/rdb (Schäfer and Gatzert 2020a). Several trainings of end users (seed suppliers, national authorities) were conducted in 2021 (Schäfer and Gatzert 2020b,c). A business plan for long term financing of the EU-wide router database beyond

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LIVESEED was developed and forwarded to the EU commission. Besides a reliable financing strategy, it is important to gain a high uptake of the database by actors of the organic seed supply chain and national authority representatives.

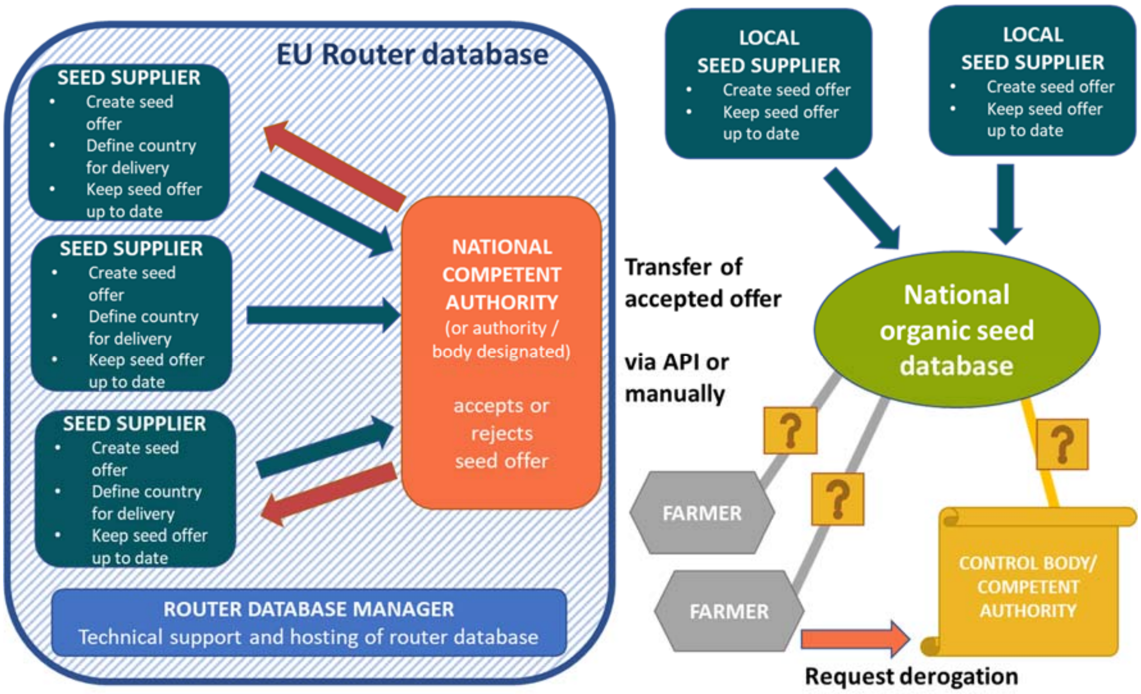

Figure 6 Back-end design of EU-wider router database

In-depth analysis to overcome political bottlenecks and derived regulatory and policy measures to increase the production and use of organic seed were revealed during national vistis, national and European workshops and expert interviews. Policy recommendations on the implementation of the rules for organic seed in the present and upcoming Organic Regulation (Raaijmakers and Schäfer 2019) and best practices for implementing Organic Regulation with respect to organic seed (Fuss et al. 2020) were published and disseminated to European, national and regional authorities. The organic seed declaration as conceptual framework to gain stakeholder involvement and active participation in expert groups has been tested and implemented in 10 EU Member States with weak organic seed market. It reach high acceptance by the participants resulting in the commitment of a diverse range of concrete action points which also allows monitoring of the progress (Raaijmakers et al. 2019, Sommer et al. 2021). For seed companies stricter derogation rules for non-organic seed within the next 5 years and research on market transparency and economics are key to invest into organic seed production, while farmers have a high demand for locally adapted cultivars (Solfanelli et al. 2021). Different incentives for farmers are needed to increase use and production of organic seed (Raaijmakers et al. 2020). Due to the large number of national and European seed workshops, surveys, expert interviews and presentations LIVESEED raised the awareness and urgency to improve and harmonize the organic seed sector across Europe. Installation of national seed expert groups, national organic cultivar trials, improved organic seed databases, improved derotagion reports (Annex 1), national lists for non-derogation crops or subcrops, and development of a stepwise roadmap and monitoring scheme are important corner stones for the achievement of 100% organic seed of adapted cultivars. The phasing out of derogations by the end of 2035 and national non-derogation lists has already been implemented in the new Organic Regulation (EU 2018/848). Moreover, in-conversion seed shall be used in case of shortage of organically produced seed, instead of untreated conventional seed.

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Organic cultivar testing protocols and models were developed for (i) characterization of heterogeneous populations and notification of organic heterogeneous material, (ii) release of organic varieties adjusted for organic production, (iii) post-release on-farm cultivar testing under organic conditions. Organic cultivar trials are an important information for farmers to make the best choice for their farming environment. However, until 2011 seed can only be commercialized if the cultivar has been officially released and is listed in the national or European catalogue. Precondition of the release of a variety is that it is distinct, uniform and stable (DUS testing), and in addition for arable crops, the new variety need to pass nationally defined thresholds on Value for Cultivation and Use (VCU testing). Based on an interviews in 15 EU countries in 2018/19, only six countries (Germany, Austria, Denmark, France, Latvia, Switzerland) allow official registration under organic VCU testing of few crops (Kovacs and Pedersen, 2019). In the other countries or for other arable crops, cultivars can only be released if they pass VCU testing under conventional conditions. This causes a severe bottleneck, as on one side organic bred cultivars may not pass the conventional VCU thresholds, and on the other side released cultivars might not be adapted to organic farming conditions. Moreover, organic breeders aiming for open pollinated cultivars that can be multiplied by farmers often face problems to achieve sufficient uniformity in the DUS testing, as the remaining genetic diversity is essential to avoid inbreeding depression.

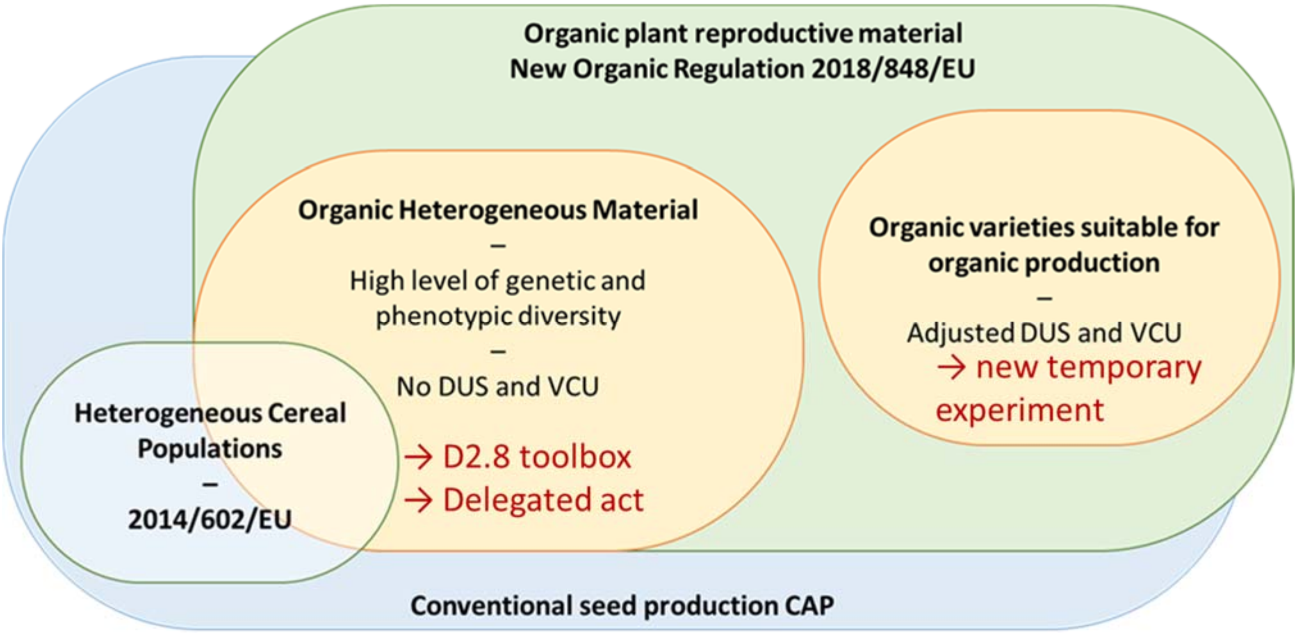

Figure 7: Characterization of novel cultivar types defined in the new Organic Regulation (EU 2018/848) for details see Costanzo et al. 2019 and Pedersen et al. 2021)

To allow for greater within-cultivar diversity the Organic Regulation (EU 2018/848) has defined two new cultivar types: (i) organic heterogeneous material and (ii) organic varieties adjusted for organic production (Fig. 7). To support the implementation and elaboration of the delegated acts LIVESEED developed respective guidelines. Firstly, we analysed the running temporary experiment on marketing seed of **heterogeneous populations of wheat, barley, oats and maize (2014/150/EU)** from 2014 till 2021 (Costanzo et al. 2018). Heterogeneous populations and OHM are designed for high genetic diversity to allow for compensation, and thus for adaptation and genetic evolution to stressful environments. OHM have a broader definition than organic varieties and encompass all crop species. LIVESEED developed a case by **case toolbox of 5 elements**

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for identification and description of OHM for notification, which is required before commercialization of organic seed derived from OHM from 2022 onwards. This includes discloser of parental lines, crossing and selection scheme, selection environments, and characteristic traits if applicable (Costanzo et al. 2019). Secondly, we developed guidelines and recommendations on improving testing procedures for organic varieties and inputs for the **implementation of the 7-year temporary experiment planned on organic varieties** starting in 2022. This includes adjusted and less stringent DUS testing and VCU testing under organic conditions (Pedersen et al. 2021). Concrete proposals for adjusted DUS protocols for carrot and kohlrabi have been submitted to DG Sante and further protocols are under progress (Annex 2).

Based on the overview of existing post-release variety trials under organic farming in 15 EU countries with respect to setup, organizational and financing model, and dissemination of results (Kovacs and Pedersen 2019) and several workshops and webinars, organisational models and tools for **cost-efficient decentralized on-farm testing networks supported by citizen science tools** were developed to improve interaction between actors, exchange of information and improved reliability of results (Rey et al. 2021). This will improve and foster on-farm organic cultivar trials in the future and help farmers to identify the best suited cultivars for their purpose.

Increased awareness of seed quality specifications in the organic sector through the inventory of seed health and seed quality related issues in European organic farming, with in-depth analysis and propositions of solutions that have been developed for the two cases: wheat (*Tilletia caries*) and carrot (*Alternaria leaf blight*) and side projects on white lupin, Lucerne and potato. Development of **an integrated strategy to optimise organic seed health and quality**, reinforced by the setup of a professional network on organic seed production across Europe, with more than 40 practitioners, from different parts of Europe and more than 20 success stories, expert interviews, technical and/or innovation fact-sheets, and videos (Rey et al. 2020, Groot et al. 2020).

Collection of smart practices related to organic seed production were made available to large group of farmers on Organic Farm Knowledge, success stories on organic seed production and networks established during the cross-visits in order to train the trainer will help to upscale organic seed production (Rey et al. 2020).

Innovative approaches of organic plant breeding as a results of extensive experiences and cross-fertilization of diverse actors within the organic sector, based on holistic concepts for organic plant breeding and criteria for success. Mapping of organic breeding initiatives (Nuijten et al. 2019b), development of systems-based breeding concept and innovative organic breeding approaches (Lammerts et al. 2018, Nuijten et al. 2019a, 2020).

Implementation of breeding for diversity for development of organic cultivar mixtures, composite cross and dynamic population (intra-species diversity within cultivar) and **for developing material suitable for annual cereal – legume mixtures, perennial lucerne-grass mixtures**, and feasibility study for breeding for **agroforestry systems** in different geographic regions. Comparison of different designs, selection strategies statistical tools, elucidating plant x plant and plant x plant x environment interactions (Mendes Moreira et al. 2021).

Improved understanding on plant microbe interaction and holobiont based breeding strategies for (i) seed vigour and (ii) resistance against soil-borne pathogen complexes with a focus on plant – root microbe interactions in pea and maize (Wille et al. 2018, 2020, Hohmann et al. 2020, Ares et al. 2021, Chable et al. 2019, 2021).

Development of phenotypic screening tools and molecular markers for tolerance against (i) complex soil borne diseases in pea, (ii) smut resistance in wheat, (iii) anthracnose, calcinoses and alkaloid content in lupines (Rodriguez et al. 2020, 2021, Alkemade et al. 2021). Service can be provided to companies for caloresporometry as assessing resilience towards stress during germination phase.

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New European breeding networks supporting small organic breeders and seed producers with five demonstrative case studies: (i) white lupine, (ii) cell fusion free brassica vegetables, (iii) winter wheat, (iv) Mediterranean tomato (Fig. 8), and (v) a European organic apple breeding network linking wholesalers' activities (Rodriguez et al. 2020, 2021), what will continue beyond LIVESEED project.

Tomato PPB-social activities with general public and consumers´ evaluations. Posters for announcements of activities in summers 2018 and 2019 in Valencia (left and right) and consumers evaluations in Mercado de los Toruños (Puerto de Santa María, Cádiz, August 2018, La Verde Coop selling point)

Tomato PPB activities in Italy. Locations of farms (left) and groups or evaluators coordinated by RSR and Arcoiris

Figure 8. Tomato participatory trials and social activities in Italy and Spain.

Improved breeding populations and cultivars selected for and under organic farming conditions for notification as OHM or registration as organic variety of (i) wheat and barley mixtures, (ii) cereal (wheat, barley, triticale, oat) - legume (pea, lupin, faba bean, vetch), and (iii) grass-lucerne mixtures; (iv) maize and tomato under agroforestry conditions, (v) pea with high tolerance against soil-borne diseases; (vi) smut resistant winter wheat, (vii) cell fusion free broccoli, cauliflower and kohlrabi, (viii) resilient lupines, (ix) locally adapted and tasty tomato as well as (x) pretested candidate apple cultivars ready for registration for organic farming (Mendes Moreira et al. 2021, Rodriguez et al. 2021).

Actor based modelling allowed to predict various interventions for improvement and upscaling of organic breeding and seed markets was developed for carrots in Germany, durum wheat in Italy and perennial ryegras in the UK including all chain actors. As a first step, the seed and breeding value chains of three organic crops per crop sector were analysed with regard to their typical actors, organic seed and cultivar use and production, including bottlenecks and success factors for increasing the latter. For each case different scenarios for technical innovations (insect resistant carrots, promotion of OHM, higher nitrogen use efficiency) and policy (stepwise phasing out of derogation), public or private interventions (premium price for organic seed, subsidies for organic seed /organic cultivars, promotion of farm saved seed, pool funding for breeding open pollinated cultivars by the organic value chain) were analyses. Sufficient time is needed for upscaling as well as allocation of financing resources before derogations for non-organic seed are completely phased out. Voluntary measures to incentivise farmers to start using or increase current use of organic seed in order to obtain 100% organic seed use by 2036 is also advisable. This is especially important when considering the steady growth of the organic sector and ambitious policy goals such as the farm to fork

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strategy. This is the first study that simulates future policy scenarios for the organic seed and breeding sector taking the economic situation of the entire chain into account and investigating into three important crop country cases in Europe. A useful extension of the chosen method would be the inclusion of external costs and benefits along the seed and breeding value chain for organic agriculture. This could e.g. demonstrate the advantages of breeding or seed innovations in a more holistic manner (Winter et al. 2021).

Increased understanding of organic consumer attitudes to the use of new breeding techniques across different European countries. Organic consumers are very sceptical against new breeding techniques and dependency of farmers from hybrids (Dudinskya et al. 2021). Awareness on the benefits of organic plant breeding and organic seed use for organic and low-external input farming was raised through many events for farmers, breeders, seed companies, processors, traders and consumers. Several promotion videos were designed for practitioners and the public.

1.3 Common vision on organic plant breeding and organic seed health

LIVESEED partners developed together with stakeholders a common vision on systems-based breeding. The starting point is the definition of organic plant breeding respecting plants as living organisms based on the four IFOAM principles of care, ecology, fairness, and health, conducting all breeding steps under organic farming conditions, and respecting crossing barriers, refraining from cell fusion and genetic engineering (ECO-PB 2012). Organic breeding aims to develop stable yielding, healthy, nutritious, resilient, resource-efficient cultivars that are climate-robust, culturally acceptable and contribute to ecosystem services. To achieve these goals a wide range of aspects, such as socio-economic, environmental, climatic and ethical factors as well as innovations in agroecology, agrobiodiversity, soil fertility, pest and disease management and social aspects like integration and participation of different stakeholders, distribution of risk and decision power, IP rights, etc. need to be considered simultaneously. The systems-based breeding concept proposes to connect different perspectives of community-based breeding, ecosystem-based breeding, trait-based breeding, and corporate-based breeding that currently co-exist, in order to achieve social justice, food quality, security and safety, food and seed sovereignty, agro-biodiversity, ecosystem services, and climate robustness. This involves change of attitudes (corporate social responsibility, circular economy and true cost accounting, fair and green policy) and action resulting into knowledge development and integration, breeding strategies and tools and entrepreneurship (Lammerts van Bueren et al. 2018).

The common vision contains a **broader perspectives on organic breeding** describes (i) incorporating cultural and ethical aspects in breeding, (ii) perspectives on the use of Intellectual Property Rights (IPR), (iii) collaborative approaches, (iv) breeding for diversity based on agro-ecological principles, (v) innovative ways of financing organic breeding, **innovative breeding strategies** related to (vi) trade-offs between resilience, yield and quality, (vii) breeding for complex cropping systems, (viii) balances plant – microbe interaction, and **specific breeding tools for organic** addressing (ix) direct versus indirect selection for nutrient and water use efficiency, (x) use and efficiency of molecular tools, marker assisted selection and genomic prediction, (xi) inheritance of resistance to seed and soil borne diseases, (xii) breeding for integrated weed management, (xiii) challenges of rootstock and scion organic fruit breeding, and (xiv) decentralized participatory breeding based on dynamic management of evolutionary populations (Nuijten et al. 2020).

In order to translate these principles into the practice of organic breeding, the first step is to describe, understand and reflect upon various types of relationships, between technologies and working methods, between microbes and plants, between people, and between people and plants and technologies. Together these fourteen topics describe and showcase how organic breeding can use and contribute to a holistic perspective in successful ways, that innovations in organic breeding are well connected with innovations in other knowledge fields such as agro-ecology, micro-biology, soil fertility, weed and disease management, sociology and economy (e.g. re-arrangements of the market) and law and governance

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(such as developments on intellectual property rights). To foster processes of change, policymaking is very important.

1.4 Research gaps and next actionable steps to boost organic seed and plant breeding

Based on the results and outcomes of LIVESEED on policy, technical, scientific, and socio-economic level, the upcoming new Organic Regulation (EU 2018/848) and the goals outlined in the EU commission Farm to Fork and Biodiversity Strategies we identified further gaps and next action points till 2030.

Breeders

- Initiate and extend organic breeding programs
- Join forces with farmers, value chain actors and public bodies to develop participatory organic breeding for short value chains
- Building alliance with other breeders and recruit young breeders
- Extend number of crops
- Initiate breeding programs for increased diversity (cultivar mixtures, OHM, mixed species)
- Conduct selection under organic conditions
- Explore breeding for increased functional biodiversity & novel screening tools (remote sensing, MAS)
- Participate in official experiment on adjusted DUS and VCU testing starting in 2022
- Notify the OHM at national authorities to facilitate commercialization and spread of the seed

Researchers

- Explore genetic resources of large number of crops
- Investigate resilience of new cultivar types with increased genetic diversity
- Improve efficiency of decentralized on-farm cultivar testing, apply citizen science tools and adjusted statistical analysis, facilitate testing network, train the trainer
- Analyse trade-off between resilience and food quality
- Reach out to local value chain to create demand for novel crops and define breeding goals for specific products and processing
- Involve farmers, value chain actors and consumers in participatory research
- Elucidate plant-microbiome interaction for organic breeding and seed production
- Explore breeding for root traits to combat abiotic stress
- Research on seed health and vigour, holistic seed strategy as well as seed treatments
- Investigate effect of cultivation method on seed microbiome and seed health and vigour
- Analyse environmental and societal impact of organic cultivars
- Develop adequate risk assessment protocols and detection methods for novel genomic techniques

Farmers / Advisors / Organic associations

- Choose organic seed
- Test new cultivars and cultivar types and new crops / cropping systems under local on-farm organic conditions
- Explore market potential for neglected crops and speciality products
- Facilitate organic on farm testing networks
- Engage in national seed expert groups
- Develop list of cultivars adapted to organic production in respective country / region
- Initiate and participate in research and breeding projects
- Increase agrobiodiversity in space and time (crop rotation, mixed cropping, diversity within cultivar)
- Improve quality of organic seed production following seed health strategy

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- Develop business plan to start organic seed entrepreneurship
- Reach out to local value chain

Seed producers

- Explore market potential for organic seed
- Provide data on organic seed production
- Train organic farmers in seed production for upscaling
- Provide premium price for organic seed production
- Add organic seed offers in national and/or EU router database and update frequently
- Provide information on performance of cultivar under organic conditions in different countries
- Follow holistic seed health strategy
- Test seed vigour and germination under stressful conditions
- Invest in infrastructure and geographically distinct seed production areas

Policy makers and public authorities

- Harmonize implementation and reporting of derogation for non-organic seed among Member States
- Develop national action plan to reach 100% organic seed, conversion to organic to reach 30% arable land, reduction of synthetic fertilizer and pesticides by 50%
- Implement national expert groups, stricter implementation of rules on organic seed, initiaize national non-derogation lists for crop species or subspecies, develop step by step phasing out of derogations
- improve efficiency and user friendliness of national organic seed database and link them with the EU-wide router database
- Monitoring progress in EU Member States for organic seed use on regular basis and collect data on organic seed production
- Reduce administrative burden for organic farmers and breeders and seed producers
- Allow more flexibility in EU Seed Directives
- Provide subsidies for local organic seed production and rural development
- Incentives for farmers and seed companies to upscale use and supply of organic seed
- Promote high quality production of farm saved seed and provide affordable seed health testing
- Public support for organic seed and breeding research, pre-breeding of minor crops and organic cultivar testing
- Provide objective and thorough risk assessment for seeds derived from novel genomic techniques, make labelling and provision of detection methods mandatory, secure transparency and traceability of novel genomic techniques, secure viability of the organic sector by prevent contamination of genetic resources, breeding material and organic products

National organic seed expert groups

- Represent different stakeholder groups
- Advise the competent authorities on which crops can be placed on the national non-derogation list and which cultivars are adapted and equivalent
- Stimulate research and breeding programs for organic cultivar testing

Seed certifiers / Organic certifiers / examination offices

- Record amounts of organic seed certified
- Assess the percentage of organic certified, organic farm saved seed, and non-organic seed use at farm level
- Get acquainted with organic heterogeneous material and provide resources for new temporary experiment for organic varieties adjusted for organic production (starting in 2022)

Processors and traders

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- Explore diversity of crops for delicious plant-based food
- Adjust processing to raw products
- Accept greater diversity in food shape and quality
- Campaign for organic varieties to maintain integrity of organic food, seed and food sovereignty
- Explore labels and tools to communicate added value of organic breeding, agrobiodiversity, traceability and freedom from genetic engineering
- Join forces with other actors for long-term engagement and pool funding in organic breeding initiatives to secure future organic supply
- Conduct sustainability analysis including true cost accounting, fair cost benefit sharing, circular economy and social responsibility of organic versus conventional seed and cultivars

Consumers

- Get informed about the importance of organic seed and breeding
- Demand diverse local products derived from organic seed and breeding
- Demand labelling information and knowledge on breeding techniques applied
- Support local small scale organic breeding initiatives to support farm saved seed and genetic diversity
- Buy plant-based sustainable produced food

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2. Recommendations on regulatory and policy measures regarding production, use and transparency of organic seed (D1.4, WP1)

2.1. Summary

There is no level playing field regarding production and use of organic seed in the EU. There are huge differences between countries, both in the development of the (organic) seed market, as in the implementation of the regulations on organic seed use. In general, the use of non-organic seed is still very high in most countries. The turnover from organic seed sale increases year by year but so far mainly in central European countries and not for all crops. In the Baltic states and in East and South European countries it was found that a lot of farm-saved seed is used and farmers are often the main producers of (organic) seed.
Since the availability of organic seed on the national seed database is the legal touchstone for granting derogations, it is essential to install user friendly, real time updated seed databases that are connected to the EU Router database. In practise this increases both the offer of organic seed and the number of suppliers. Involving national stakeholders in policymaking motivates them to take action and to contribute in increasing the production and use of organic seed in their country.
Recommendations focus on the establishment of national seed expert groups, including their contribution to roadmaps (per crop) to reach 100% organic seed. In addition, strict derogation rules are essential to create incentives for operators to produce organic seed and a continuous improvement of the database infrastructure remains key to improve transparency and facilitate a functioning derogation system. At the same time, organic breeding and testing of cultivars under organic conditions must be stimulated to increase the availability of organic seed from suitable cultivars.

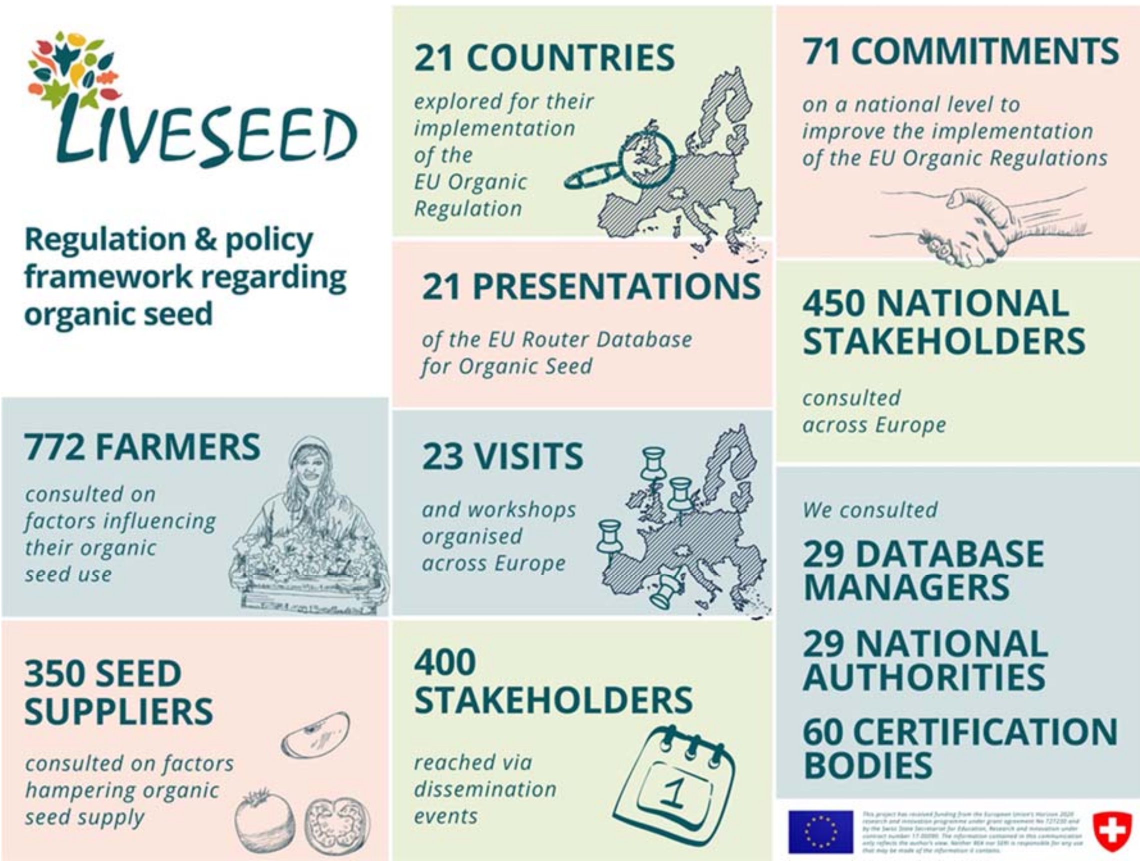

Figure 9: LIVESEED activities to improve transparency and boost production of organic seeds

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2.2. Current realities

Production and use of organic seed

The current production and use of organic seed differ a lot between the EU member states. In the Baltic states and in East and South European countries visited during the LIVESEED project (Raaijmakers et al. 2019) it was found that farmers are often the main producers of (organic) seed. The use of farm saved seed in those countries is generally high, especially for arable crops, and the use of certified seed is often low except for vegetable crops. In several countries there is also a lack of certified seed on the market. Public breeding and research institutes still play an important role there in the production of basic seeds for the main crops. Most countries visited (Bulgaria, Estonia, Greece, Hungary, Italy, Lithuania, Latvia, Poland, Romania, Spain) have few, if any, national seed companies producing organic seed. Most certified organic seed on the market comes either from international seed and trading companies or from specialized farmers (Raaijmakers and Schäfer 2019).

The exact demand and supply of organic seed in the EU remains unknown because of a lack of data. Only few countries collect data on organic seed production on a regular basis like Austria. A seed supplier and breeder survey conducted in LIVESEED (Solfanelli et al. 2019, 2021) revealed that the highest share of organic seed production and trade is in central EU member states (Fig. 10). Thus, in these countries turnover from organic seed sale increases year by year. In Northern, Southern and Eastern EU member states, organic seed sales have increased over time but not at the same pace as the central EU member states. In fact, for some crops and some countries there was no increase in organic seed production and trade as there is no market demand for certified organic seed due to widespread applications of general derogations allowing the use of non-organic, i.e. conventional untreated seed.

Based on the farmer survey conducted in LIVESEED in 20 European countries in 2018/19, the main critical issue reported by farmers was the availability of organic seed for the varieties they need, followed by seed price, whereas seed quality was not reported to be a serious problem. This is true regardless of the crop sector, but it is significantly less pronounced in the countries in Central and Northern Europe, where most organic seed production in Europe takes place (Orsini et al. 2019a, 2020). The percentage of non-organic seed use by farmers varied a lot across countries and crops, and was on average highest in Eastern (59%) and Southern (54%) EU countries and considerably lower in Northern (26%) and Central Europe (37%) and higher for vegetables (61%) and fruits (63%) compared to cereals (31%) and legumes (40%) (Solfanelli et al. 2020, 2021).

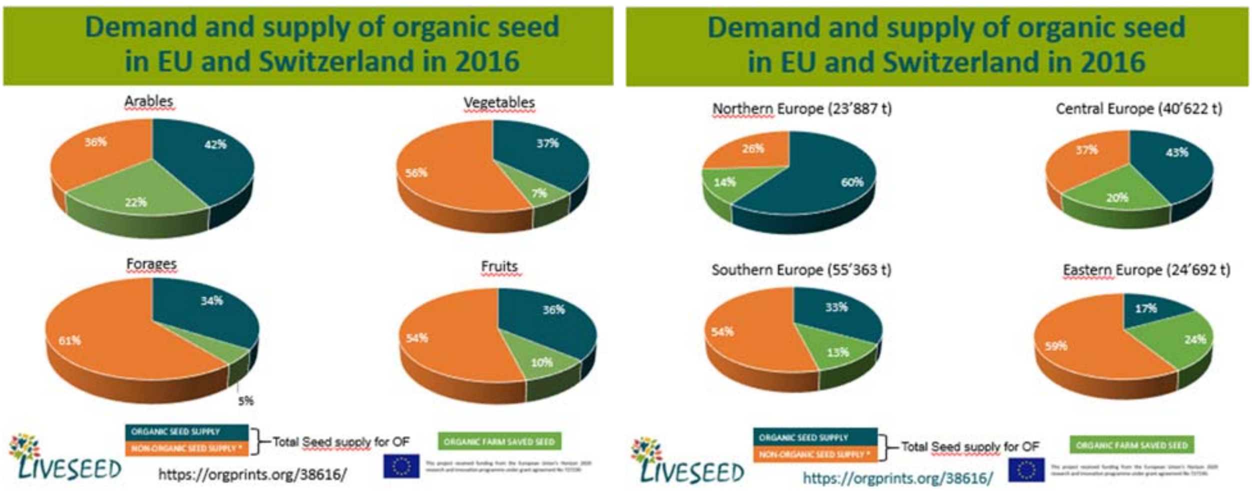

Figure 10 Percentage of organic seed use for selected crops and EU regions in 2019 (Solfanelli et al. 2020)

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Implementation of the regulation

According to the Organic Regulation EC 834/2007 the use of organic seed is obligatory, however derogations can be granted if not sufficient seed is available. In addition, EU Member States need to establish a national organic seed database and rules for derogations. In practise there are large differences in implementation between countries with respect to derogation rules, functionality of organic seed databases and reporting (Fuss et al. 2020, Solfanelli et al. 2019, 2021). There is no level playing field in the EU. In general, the use of organic seed has not improved sufficiently over the last decades and non-organic seed still accounts for almost 50%.

Organic Seed Databases

In many countries across the European Union organic seed databases do not meet the main goal: providing an up-to-date overview of the organic seed available on the market in that country. Often the seed database is not very user friendly and not frequently updated. In addition, the database is often unknown to farmers and difficult to access for (foreign) seed suppliers due to language and administrative barriers. As a consequence, several national databases are nearly empty and seed suppliers prefer to sell their organic seed directly to farmers (Raaijmakers et al. 2019, Solfanelli et al. 2019, 2021). However, some EU Member States do maintain a fully computerized and interactive database that offers a wide range of cultivars, while in other EU Member States a lack of capacity and funding hinders authorities from maintaining well-functioning organic seed databases (Solfanelli et al. 2019).

Rules for derogations

In most EU countries derogations are usually granted when requested, since farmers only need to ask for a certain variety that is not offered on their national seed database. In some countries applying for a derogation involves high administrative costs and the sanctions for not complying with the rules can be high. In several countries farmers do not need to apply for individual derogations, as general derogations are granted for certain crop species. Therefore, the existing derogation reports of the Member States are not comparable and not adequate to estimate the present use of non-organic seed (Raaijmakers and Schäfer 2019, Solfanelli et al. 2021).

Policy measures

Countries where the availability of organic seed is relatively high, have often implemented stricter national derogation rules. So far seven countries (Germany, The Netherlands, Belgium, France, Luxembourg, Sweden, Switzerland-BioSuisse) have implemented a national non-derogation list. For crops (and sub crops) on this list the offer of organic seed is enough to cover the national demand and therefore no derogations are granted, except for experimental trials. Expert groups with relevant stakeholders advise the competent authorities on which crops should be placed on this list.

In some other countries, for instance the Baltic states, the production and use of organic seed is stimulated with subsidies and training for farmers who want to become seed producers (Raaijmakers et al. 2019). Several countries (e.g. Poland, France, Denmark, Germany) set up field trials to increase the information of cultivar performance under organic conditions. This improves the choice of cultivars for the organic farmers.

2.3. Scientific approaches and key results

Improvement of the transparency of the organic seed market

Currently, most of the organic seed on the market in Europe is not listed in national seed databases. Since the availability of organic seed on the database is the legal touchstone for granting derogations, a dysfunctional database can lead to unsubstantiated exemptions allowing the use of conventional seed. To improve this situation, online and real-time updated databases should be implemented with logins for seed suppliers to manage their seed offer directly and frequently. This will increase both the offer of organic seed and the number of suppliers on the database (Solfanelli et al 2019, 2021).

In addition, to increase the transparency of the European organic seed market it is important to allow organic seed suppliers easy access to all 27 EU Member States databases. The new EU-wide Router database

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(www.seeds4organic.eu/rdb), which was developed within the LIVESEED project gives seed suppliers one single login access to all national EU Member State databases (Schäfer and Gatzert 2020).

Validated data to estimate supply and demand

There are currently no official statistics reporting data on supply and demand of organic seed, either at national or EU level. The LIVESEED project estimated the total demand of organic seed for selected crops (tons of seed, number of plants) in the different countries by combining data on the organic land area (obtained by FIBL-CH and Eurostat databases; multiple imputations methodology was used to estimate missing data) with the estimated average crop seeding rate. Subsequently, results of a farmer survey, validated with further expert assessment, were used to estimate the share of the overall potential seed demand which is covered by organic certified seed supply, non-organic untreated seed supply and organic farm-saved seed (Solfanelli et al 2020, 2021). This methodology allowed to estimate for the first time the present use and future demand of organic seed across the EU Member States (Fig. 8).

Increase of stakeholder involvement

Involving stakeholders in policymaking is essential to improve the implementation of the regulation on organic seed use. Once stakeholders are involved, they are more motivated to take action and to contribute themselves to increase the production and use of organic seed in their country. Both national and international workshops provide an important platform for stakeholders to meet and exchange knowledge on smart practices.

To formalize the commitment a covenant describing concrete action points, for instance in the form of *a declaration of organic seed,* can be used. During the LIVESEED project this proved to be a successful approach to realize progress in 9 different EU Member States (Sommer et al. 2021). For an enduring and more structural commitment of stakeholders, the establishment of a national seed expert group with a clear mandate remains necessary (Fuss et al. 2020).

Increase the production and use of organic seed

In the new Organic Regulation (EU) 2018/848 it is foreseen that the derogations for the use of non-organic PRM will end by 2036. At the same time the European Commission's Farm to Fork and Biodiversity strategies aim at a growth of the organic production area from now 8% (2019) up to 25% by 2030. This means in practice that the organic seed production needs to increase about 500 to 600% to cover the demand of all organic farmers for all crops in Europe within one decade.

According to the respondents of the seed supplier survey (Solfanelli et al. 2019, 2021), more research in organic seed production economics, phasing out of derogations and creating a level playing field is the basis for the necessary growth of the organic seed sector. Across the possible actions to boost the use of organic seed in Europe, the ones that the surveyed farmers perceived as most important were "*Improve availability of organic seed for locally adapted varieties*" and "*More effort to breeding programmes for organic farming*" (Orsini et al. 2019, 2020). The results from the functionality of organic seed database analysis (Solfanelli et al. 2019, 2021) and the survey among farmers (Orsini et al 2019) substantiate the expectation that in countries with a stricter derogation policy, there is greater availability and use of organic seed. However, it must be acknowledged that those countries also have a properly functioning organic seed database and a well-developed seed sector. Without these prerequisites in place, strict derogation rules may only result in higher administrative burdens for farmers (Raaijmakers and Schäfer 2019). On the other hand, if derogation for the use conventional seed remains possible irrespective of the availability and suitability of the organic seed offered on the organic seed database, this undermines the investment in organic seed production by seed companies.

A foreseeable challenge is the supply-demand paradox: seed suppliers question whether the current demand justifies scaling up production, while farmers find the supply of organic seed insufficient and ask for derogations for the use of non-organic seed. To avoid this paradox, a step-by-step approach with

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intermediate targets and deadlines (for derogations) per country and crop is necessary, as outlined in the European progress report on organic seed (Sommer et al. 2021).

Incentivise the use of organic seed

Involvement of supply chain actors can help to create non regulatory incentives for farmers to use organic seed. Traders can for instance pre-finance the organic seed for the farmers, pay a premium price for products obtained from organic seed or help farmers to find an adequate supply of organic seed. Pilot studies in 4 countries have shown that besides economic incentives also technical, social, ecological and ethical incentives can be used to increase the use of organic seed (Raaijmakers et al. 2020). For instance, this can be achieved by expanding the range of cultivars adapted to organic and local conditions (ecological incentive) or by improving the seed quality (technical incentive).

2.4. Evidence-based recommendations and actionable next steps

Options and actionable next steps have been extracted from (i) the national workshops in the countries visited, (ii) the North-Western European workshop, (iii) the special workshop on vegetative material and (iv) the LIVESEED European Workshop. This includes evidence on the status quo and best practices that have proven to be effective in a certain context and from which recommendations can be extracted.

- Each national authority should establish at least one **national organic seed expert group** to involve stakeholders in achieving the goal of 100% organic seed. An ideal composition of the national seed expert groups should include organic farmers that are representing other farmers/farmer organisations, seed producers and traders, some crop experts from research institutes, national certification bodies, the organic seed database manager and the competent authority.
- National authorities should implement strict and transparent **derogation rules.** The **non-derogation list** (also referred to as a national Annex) has proven to be an effective approach and will be obligatory from 1. January 2022, the date of application of the New Organic Regulation (EU) 2018/848**.** The list provides more certainty for the seed suppliers in terms of knowledge for future investment. Expert groups should be the platform to discuss, according to clear criteria, what crops or sub-crops can be placed on this list. And in case of insufficient supply of organic seed (in assortment or amount) they can define what steps are needed to meet the demand.
- **International meetings** for knowledge exchange should be promoted. The European Consortium for Organic Plant Breeding can be used as a platform for this.
- Facilitate **structural knowledge exchange between countries** with similar challenges and circumstances, e.g. those countries that have already implemented a national Annex or countries in a certain region. National authorities or the European Commission need to provide some budget to a coordinator to build upon the informal exchange that is already happening among some countries and to formalize this by setting up annual/regular online meetings.
- **Targeted steps to achieve 100% organic seed use** should be included in the national organic action plans. National seed expert groups, in coordination with national authorities, can make a long-term timetable/plan for each crop. This should include intermediate goals to allow a step-by-step approach. Developing a roadmap is essential, as seed companies need targets and deadlines (for phasing out derogations) to know how much they should invest.
- To increase transparency of the organic seed market, national authorities shall provide real-time and fully computerized **national databases** with standardized derogation systems and reports. In order to stimulate the European organic seed sector and reduce trading barriers, the European Commission should provide long-term funding to the **European Router Database.** Furthermore, the European Commission shall promote the use of the European Router Database by national authorities, as the use of the database is not mandatory by the regulation.

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- National authorities and the European Commission should, in coordination with certifiers, improve **data collection** of organic seed supply and demand by, e.g. harmonized derogation reports, lists of species/sub-species on general and no-derogation (template in Annex 1), area of organic seed multiplication per crop and country, farm-saved seed use.
- The role of **farmers as seed producers** is essential to reach the goal of 100% organic seed in Europe. National Authorities need to allocate funds from the CAP Rural Development ('second pillar') to train farmers to become producers of high quality seed and to provide access to relevant infrastructure, for instance seed cleaning machines.
- For **vegetative planting material** a different approach is needed: the national competent authority managing derogations should introduce a pre-ordering deadline for vegetative material, to enable producers to adequately assess market demand and to produce accordingly.
- On-farm cultivar trials under organic conditions are indispensable to develop **recommended lists of cultivars suitable for organic production** in specific regions.
- To address the breeding gap for locally adapted cultivars suited for organic production and markets, **organic breeding programs** should be initiated and supported by public and private funding.

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3. Recommendations on release and marketing of new cultivar types, and on-farm organic cultivar testing (WP2.1)

3.1. Summary

When the foundation has been laid with proper farm management, the choice of cultivars is the next and very important step for the organic farmer to ensure adequate crop productivity and end-product quality.

The use of diversity at different levels is considered important in organic farming for increasing agrobiodiversity and thus system resilience and to minimize the risk of crop failure. Increased agrobiodiversity can be supported by organic breeders providing a portfolio of crops for the farmers to choose from in a diversified crop rotation and developing cultivars with increased level of genetic diversity within the field. The Organic Regulation (EU) 848/2018 introduced two novel cultivar types in the legislation ("Organic Heterogeneous Material (OHM)" and "organic varieties suitable for organic production") with the aim to allow the use of a higher degree of diversity in organic farming.

Based on the experiences of the temporary experiment 2014/150/EU allowing marketing of seed of heterogeneous populations of wheat, barley, oats and maize (Council Directive 66/402/EEC) and heterogeneous populations of other crops, key tools (related to the constitution, the seed traceability, and the description of such populations) for the characterisation of Organic Heterogeneous Material were developed. These guidelines, aimed to compensate for the non-applicability of DUS-based cultivar description, can be used in the notification process which will come into force with the new Organic Regulation in January 2022.

A proposal for a working definition on organic varieties suited for organic production, which includes the aspects of the breeding techniques in the breeding process and parent material, number of years of breeding and selection under organic conditions was defined. In the new Organic Regulation (EU) 2018/848 a seven-year temporary experiment is foreseen to describe the characteristics of organic varieties and to determine the production and marketing conditions of organic varieties. LIVESEED has engaged with stakeholders and policy makers and developed recommendations on adjusted registration procedures (e.g., adjusted DUS and VCU testing criteria) for organic varieties in order to speed up marketing and increase the number of cultivars available for organic farmers. A template for adjusted DUS for carrot and kohlrabi was presented at DG Sante working group in June 2022 (Annex 2).

Beside the limited range of adapted cultivars on the market, organic farmers also face the challenge of limited information on the actual performance of the available cultivars under organic farming. LIVESEED proposes to develop decentralised organic on-farm cultivar trial networks to offer a cost-effective alternative to the expensive on-station post-release cultivar trials which are only funded for few crops in a few countries.

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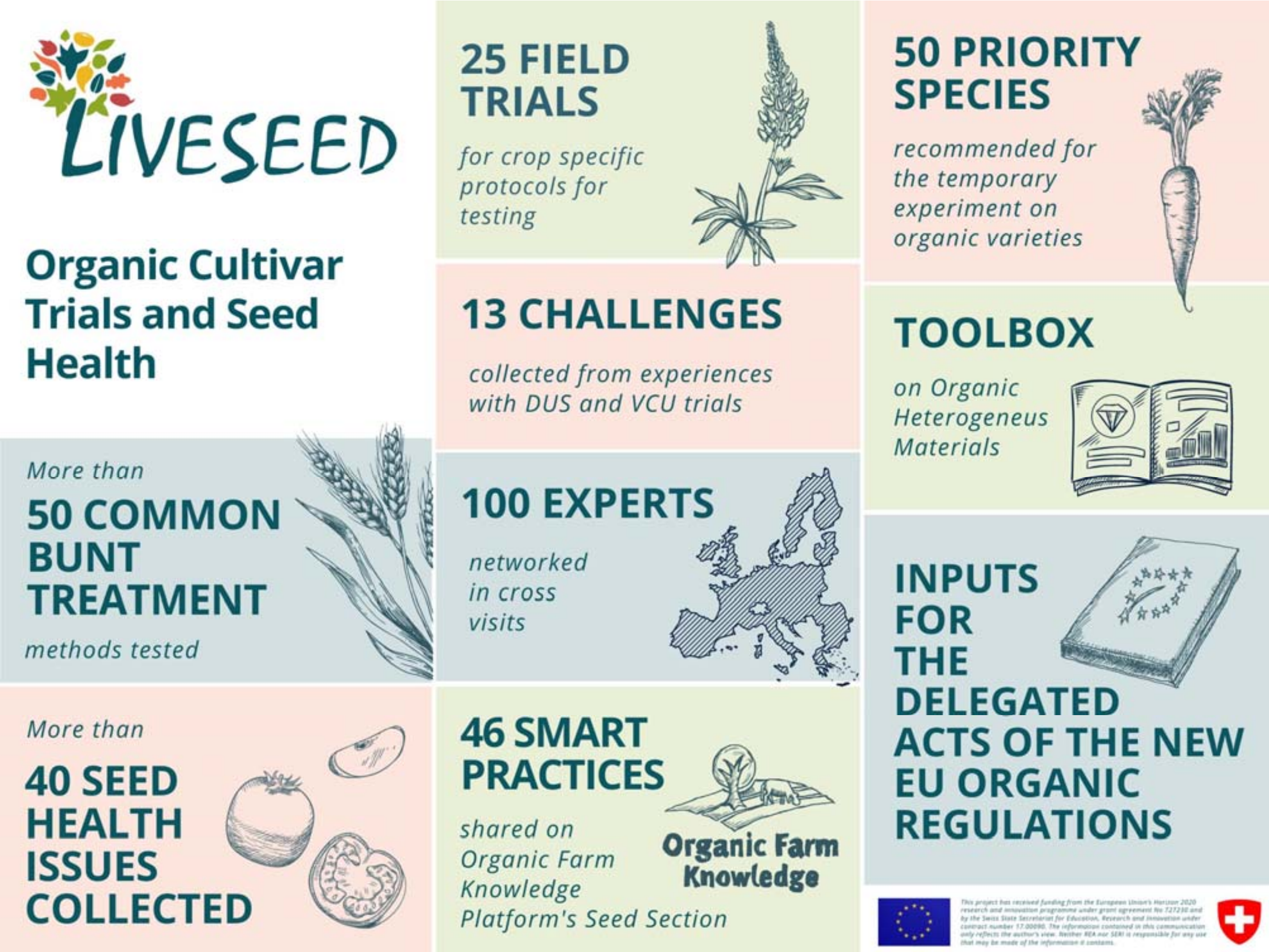

Figure 11: LIVESEED activities to improve organic cultivar trials and develop seed health strategies

3.2. Current realities

New cultivar types

EU Research projects like SOLIBAM, DIVERSIFOOD and LIVESEED have explored the advantage of genetic diversity within cultivars, in particular with regard to organic production, for example to reduce the spread of diseases, to improve resilience against biotic and abiotic stresses, to improve local adaptation and to increase biodiversity. Therefore, plant reproductive material that does not belong to a variety, but rather belongs to a plant grouping within a single botanical taxon with a high level of genetic and phenotypic diversity between individual reproductive units, should be available for use in organic production.

In the new Organic Regulation EU 848/2018 two new cultivar types have been introduced in order to embrace intraspecific diversity from organic breeding and selection: (i) Organic Heterogeneous Material (OHM) and (ii) organic varieties suitable for organic production.

The Organic Heterogeneous Material is intended to be not uniform or stable, and cannot meet the requirements of Distinctness, Uniformity and Stability (DUS) of the existing testing system for variety release. The intention of Organic Heterogeneous Material is the ability to evolve and adapt over time to local growing conditions (Costanzo et al. 2019). The user is guaranteed an identity (based on the geographic origin, parental lines, breeding method, selection sites and history) and a certain seed quality (sanitary, analytical purity and germination).

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Organic varieties suitable for organic production are defined as plant varieties according to EU 2100/94 and thus "considered as a unit with regard to its suitability for being propagated unchanged". Users are thus guaranteed a variety that can be described and whose characteristics of interest are stable over time. When Value for Cultivation and Use (VCU) is relevant for variety release (agricultural crops), performance according to national parameters or indices in most cases assessed under conventional conditions is also guaranteed. The European Commission has introduced a seven-year temporary experiment to work on adjusted DUS and VCU testing criteria for organic varieties in order to facilitate their description and marketing.

Official testing system for variety registration

Registration of a variety is required before seed can be commercialized in any EU country. The breeder can apply either at national or EU level. For all crops, the new variety need to be tested for at least 2 years by examination offices for Distinctness, Uniformity and Stability (DUS) according to species specific CPVO protocols, and, for agricultural crops for the Value for Cultivation and Use (VCU) accessed in multi-location trials over 2-3 years must meet national thresholds. Varieties that have passed DUS (and VCU) can be registered in the official National Variety List and the EU 'Common catalogue of varieties of agricultural plant species', which is a precondition for the marketing of seed.

In the existing testing regime organic breeders face challenges in DUS testing when the level of genetic diversity is too high their cultivars. This is specifically true when open pollinated cultivars are compared with F1 hybrids. Therefore, the temporary experiment aims to allow a higher degree of diversity for organic varieties. In most of the EU member states VCU is conducted only under conventional farming practices, which might not be a good predictor for performance under organic management. Moreover, certain traits that are important for organic farmers like seed-borne diseases or weed competition are not assessed (Kovacs and Pedersen, 2019, Pedersen et al. 2021).

On farm cultivar testing

Expanding the current (very limited) infrastructure and logistics for organic post-registration trials would require large investments which are not justified by the current size of the organic market, even under EU policy support. Besides, on-station trials would be unlikely to provide realistic cultivar information for the varied range of environmental conditions experienced on organic, low input farms.

Organic farming differs substantially from conventional systems, where variability is buffered and controlled by external inputs. As a consequence, cultivars' performance varies across organic sites more widely than across non-organic sites. In order to make a good cultivar choice, for an organic farmer, the information from official cultivar testing on-station, mostly under conventional conditions, is not enough. An organic farmer needs information that applies to the specific agro-environmental context based on the results of on-farm trials. The information currently available to organic farmers on the value of cultivars is highly incomplete.

3.3. Scientific approaches and key results

New cultivar types

With the introduction of genetic diversity into the definition of organic varieties and Organic Heterogeneous Material (OHM), LIVESEED facilitated the discussion among relevant stakeholders and with policy makers about the implications of the demand for homogeneity in the existing registration procedure and at the same time the demand for increased cultivar diversity in organic farming. LIVESEED used the input from the different stakeholders to develop a proposal for a working definition on organic varieties. This includes a discussion on breeding techniques in the breeding process and parent material, number of years under organic management and testing conditions (Pedersen et al. 2021). LIVESEED developed also key tools for the characterisation of Organic Heterogeneous Material (Fig. 12) that can be used in the notification process (Costanzo et al. 2019) and was taken up to large part in the delegated acts in 2021.

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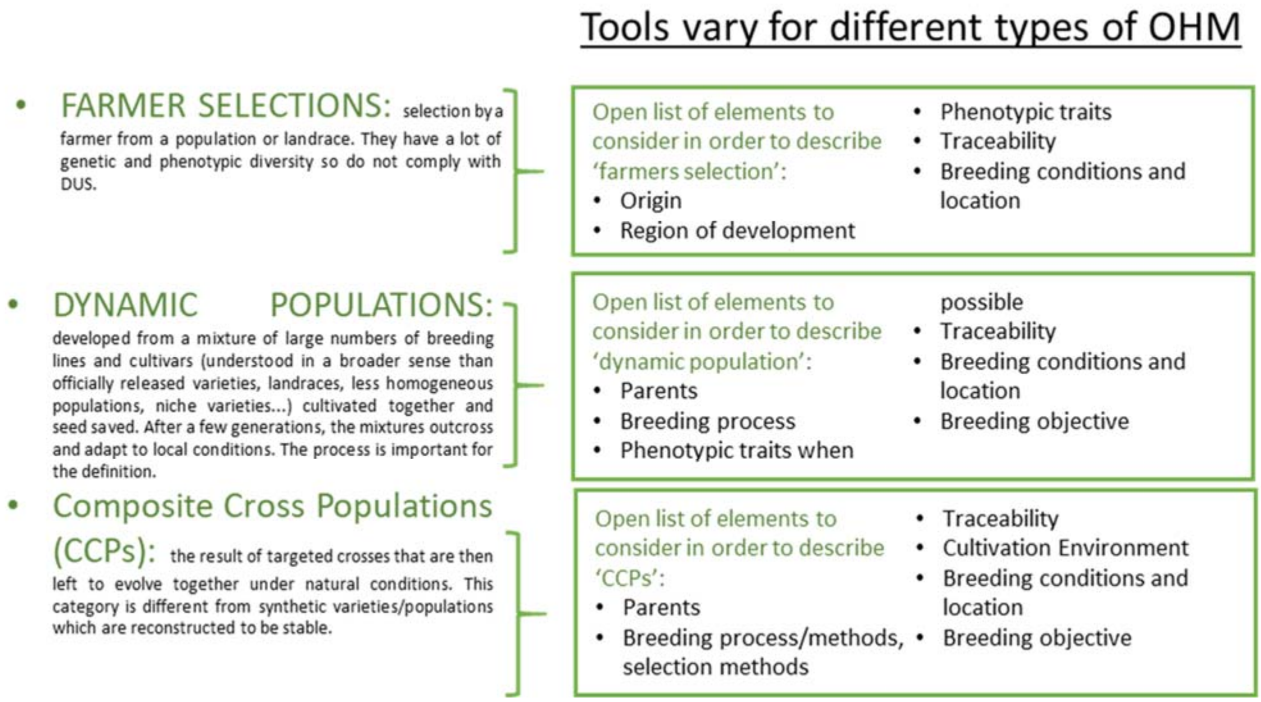

Figure 12: Tools for describing different types of Organic Heterogeneous Material (OHM)

Official testing system for variety registration

Easier release of organic varieties (adjusted DUS) is expected to generate new organic breeding initiatives. LIVESEED has developed templates for adjusted DUS testing for carrot and kohlrabi (Annex 2). Additionally, the possibility for conducting VCU testing under organic farming, with focus on traits of specific interest in organic farming would be an additional incentive for breeders to start breeding for organic adapted cultivars. The derogation from VCU testing should be considered in the case of niche crops in order to limit the cost of registration for cultivars of crops that will be cultivated on a limited area (Pedersen et al. 2021).

On farm cultivar testing

Increased testing efforts for organic cultivar evaluation have an outstanding potential in enabling the success of organic farming and supporting the organic and agroecological transition (Fig. 13). However, currently available resources and infrastructures are not fit for purpose in most European countries and new models need to be designed to address the needs of a rapidly growing organic sector.

Cost-effective, innovative and decentralized models for cultivar evaluation under organic conditions are thus urgently needed. The LIVESEED project offered the opportunity to co-design effective and innovative cultivar evaluation models, applicable even to those European countries with limited or no infrastructure in place.

Such models are based on: (i) on-farm decentralised evaluation, by which a diversity of crops can be tested in a range of real-life conditions and (ii) participatory approaches that make the most of farmers' knowledge of their environmental and value-chain needs and characteristics (Réy et al. 2021). The models recognise that farming encompasses both social and technical dimensions, they therefore include a variety of stakeholders in multi-actor networks. Adequate digital tools are required for collecting data and sharing results within and across network (Abco et al. 2021). A decision tree for adjusted experimental design for non-factorial or non-replicated decentralized cultivar trials with respective open source statistic packages has been developed.

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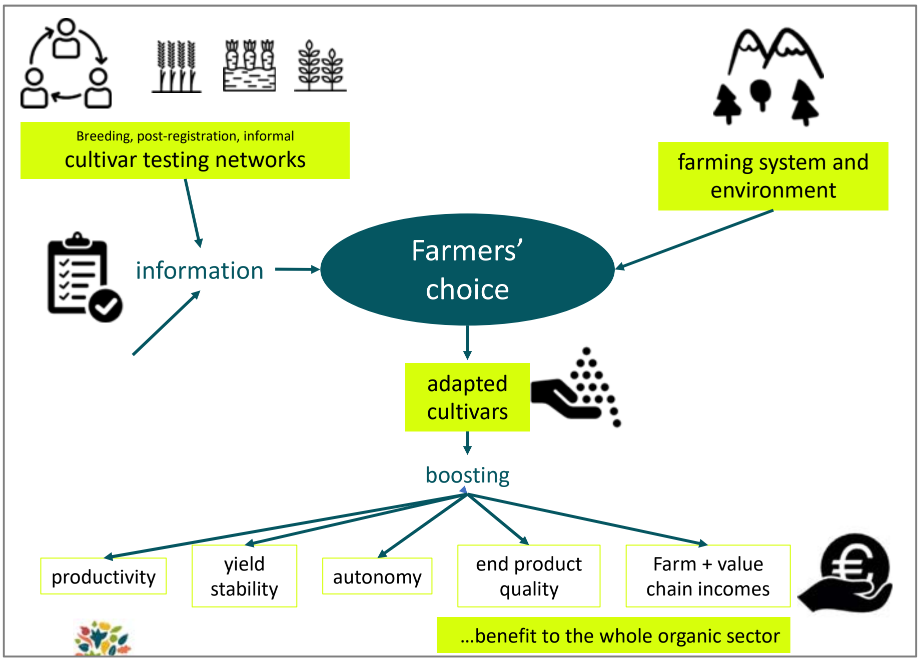

Figure 13: Well organised cultivar testing networks can deliver valuable information to farmers and in the end boost the farm performance and income

3.4. Evidence-based recommendations and actionable next steps

To achieve the transition towards 100% organic seed use of adjusted cultivars and promote organic breeding, the following actions should be implemented:

- Organic varieties should include different variety types with inherently differing levels of genetic diversity ranging from population varieties to hybrids or clones in case of fruit trees.
- All breeding methods applied during the entire breeding process must comply with organic principles as defined in the position paper of IFOAM Organics International 2017 and parent material used for crossing or other origin of organic varieties should not involve cultivars derived from breeding methods that are not allowed in organic farming. Traceability and labelling of varieties derived by genetic engineering techniques should be highly prioritized to avoid contamination. Organic varieties should not be patented.
- Breeding must be conducted under certified organic conditions for a minimum of five years for annual and eight years for biannual and perennial crops to ensure adaptation to organic conditions.
- Adapted DUS trials for relevant genetically diverse cultivar types may apply for organic varieties. The adjusted DUS protocols should allow for more diversity in the cultivar description by dividing DUS characteristics in voluntary and obligatory characteristics and describe all characteristics, but for the acceptance of the organic variety with adapted DUS only the obligatory characteristics - of interest for users - should meet the requirements.
- Testing of VCU (agricultural crops) under organic production must be prioritized and supported in order to value organic breeding achievements in the registration process and, if no possibility exists for organic trial sites, it should also be investigated if conventional trials can be adapted to better describe important traits for organic varieties. Trials can be set up with low input and no pesticides as a first step.
- It should also be discussed in the temporary experiment whether VCU testing can be optional for minor specialized crops for specific purposes. The return on investment for breeders on such cultivars is very low, and it is difficult to finance both VCU and DUS trials for such minor crops.

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- Possibility for testing market acceptance of new cultivars before formal registration are recommended, especially for perennial crops such as apple in which the introduction of a new variety requires a joint effort of the whole value-chain.
- LIVESEED proposed five key tools for characterisation and notification of Organic Heterogeneous Material that can be used in the notification process: (i) origin, (ii) region of cultivation; (iii) breeding methods, in turn divided into constitution, development and multiplication; (iv) phenotypic traits and (v) traceability.
- The notification of Organic Heterogeneous Material should be with low administrative and financial burden for the applicant. To have a smooth introduction in 2022 knowledge exchange between farmers/breeders and national authorities (examination offices, seed certification, seed health inspection) on Organic Heterogeneous Material should be enhanced in the different EU countries.
- Decentralised organic on-farm cultivar trial networks offer a cost effective solution to the limitation of on-station post-release cultivar trials and could play a pivotal role in boosting the organic sector, with targeted investments from both the public and private sectors.
- The integration of digital technologies can facilitate low-cost, highly inclusive and representative cultivar trialing infrastructures, as proven by the existing initiatives (e.g. SeedLinked in USA). Digital tools can be used for collecting data from on-farm cultivar testing by farmers themselves and for analysing and visualising the results of on-farm cultivar testing.
- More research is needed for adjusted experimental design and statistic for non-replicated, non-factorial decentralized cultivar trials taking into account soil properties, farm management and climatic conditions during the trial to make better prediction about the suitability of cultivars under organic farming in certain agro-climate zones.

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4. Recommendations for an integrated strategy to optimise organic seed health and quality and upscaling of production (D2.7, WP2.3)

4.1. Summary

Seed quality is important for seedling establishment - an essential step for crop production. Poor seedling emergence due to abiotic and biotic stress in the field can reduce crop stand, yield and farmers' income. Seed health and vigour, the ability of the seed and seedling to cope with such stresses, is of increasing importance for resilient crop production, in particular in the face of climate change.

At present seed health is almost exclusively oriented at controlling seed-borne pathogens by testing and eradication through sanitation treatments. But in recent years it has become clear that seeds can also contain beneficial microorganisms that aid the seedling against pathogens or abiotic stresses. Sanitation destroys also most of these beneficials. Although current knowledge is limited, this seed microbiome should also be taken into account when considering the resilience of seeds and seedlings. Thus, in an up-to-date seed health strategy developed in the scope of LIVESEED, the importance of seed vigour and the seed microbiome should be considered as part of seed health. Some information is available on how seed production and seed treatments influence seed vigour, but far less is known on how to establish an optimal seed microbiome. Because knowledge on the role of the seed microbiome and the effect of seed production conditions and treatments is limited, more attention and research are needed to produce and maintain seeds with an optimal seed microbiome. In this respect, soil biodiversity seems to be an important driver, as part of the seed microbiome originates from the soils. Knowing that organic soils have a higher biodiversity, the advantage for organic seeds should be explored. Organic seeds are often treated to control seed-borne pathogens. Although it is likely that this also reduces a significant part of the seed microbiome, knowledge is lacking on how this influences seed vigour and seedling establishment. When such treatments cannot be avoided, it might be useful to restore the microbiome by either bio-priming or coating the seeds with beneficial microorganisms originating from seed microbiomes. A workshop with stakeholders was organized on 24 June 2021 to discuss the draft of this new organic seed health strategy. In Annex 3, a more extended text with the draft strategy of the seed health strategy is presented. This text was sent to the participants as preparation for the workshop and will be revised based on their input. This strategy does not only provide perspectives for organic farming, but also conventional farming should make appropriate use of seed vigour and seed health to start their crop production with more resilient seeds and seedlings.

4.2. Current realities

Seed health and quality affect how well a crop will establish and perform, influencing crop yield, farmers' incomes and, ultimately, food security. For that reason, official seed quality certification is obliged in the trade of seeds. At present, routine seed testing by seed producers and seed certification bodies evaluates seed germination rates under optimal conditions and detects potential seed-borne pathogens, according to crop species. If a problematic level of seed-borne pathogen is detected, seed treatments can be used for disease control. In organic farming, these range from natural compounds (e.g., vinegar, mustrard oil) and physical treatments (e.g., steam or hot water treatments or brush cleaning) to the application of biologicals (e.g., antagonistic microorganisms). However, both practical experience and recent scientific findings tend to indicate that taking into account additional aspects to seed quality would benefit organic agriculture and other forms of sustainable agriculture (refraining from the use of synthetic chemical inputs). The increasing restriction on the use of synthetic chemical seed treatments, e.g., the European ban on seed treatments with the fungicide Thiram, urge for a paradigm shift in seed health approaches. For instance, in the Netherlands a research project is running at Wageningen University & Research, studying the potential of the seed microbiome and critical control points in the application of micro-organisms (biologicals) as alternative to chemical seed treatments. That project is in collaboration with several international seed companies and partly funded by the government.

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4.3. Scientific approaches and key results

In the framework of the LIVESEED project, Groot et al. (2021) have reported on 2 case studies of important organic seed health issues – *Alternaria* ssp. with carrot and common bunt (*Tilletia* spp.) with soft wheat – and established an inventory of current problematic issues for the quality of organic seed. These findings and a review of scientific literature, urge for a new strategy for organic seed health and quality.
A draft of this strategy (Fig. 14) has been presented at the online conference of the EUCARPIA Organic and low input section, jointly organized with LIVESEED, BRESOV, ECOBREED and FLPP projects on 8-10 March 2021. To discuss the draft of this new organic seed health strategy, also a workshop with stakeholders was organized on 24 June 2021. In Annex 3, a more extended text with the draft strategy is presented. This text was sent to the participants as preparation for the June workshop. Based on the input of the participants the LIVESEED seed health strategy will be updated and published in a peer-reviewed journal.

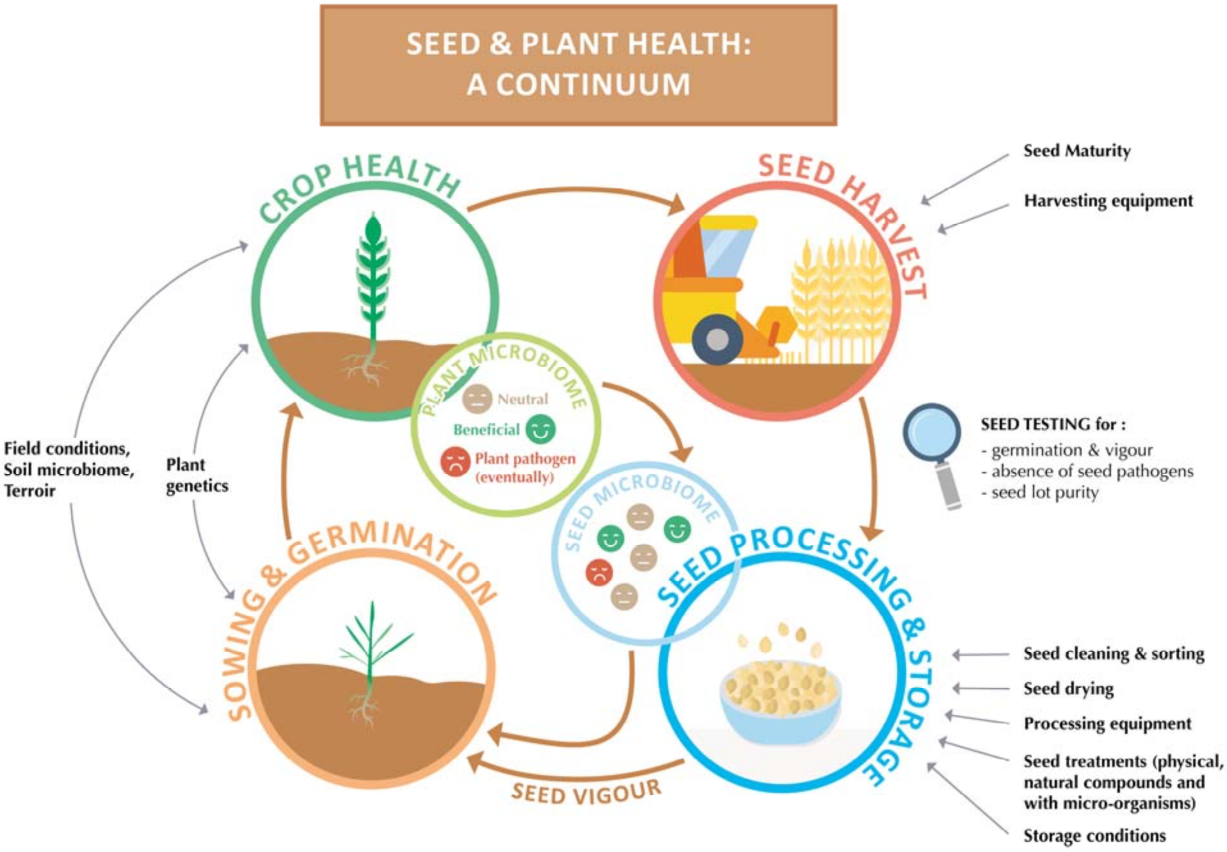

Figure 14: Representation of the continuum from plant to seed health, including the importance of the microbiome.

4.4. Evidence-based recommendations and actionable next steps

An up-to-date seed health strategy needs to take the importance of seed vigour more into account as means to obtain more resilient seeds and seedlings, whereas also the seed microbiome offers large perspectives to enhance resilience of seeds and seedlings against biotic and abiotic stresses. Optimizing seed vigour and the seed microbiome, might not be enough when seeds are severely contaminated with pathogens or with a quarantine organism. In such cases sanitation treatments may still be needed. When these cannot be avoided, it might be useful to restore the microbiome by either bio-priming or coating the seeds with beneficial microorganisms originating from seed microbiomes.

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More attention and research are needed to produce and maintain seeds with an optimal seed microbiome. A highly biodiverse microbiome seems to be advantageous for the seedling. The seed microbiome is partly originating from the soil. It is known that organic soils have a more biodiverse microbiome, which may give an advantage for organic produced seeds. If that can be confirmed it can support the use of 100% organic seeds for organic agriculture. Besides, also conventional agriculture will benefit from using seed with high vigour and an optimal microbiome for the highly needed more resilient cropping systems. The same will hold for nature restoration campaigns using multiplied seeds from wild plants. For many seed companies and farmers, the standard is 'seeds free of pathogens' and consequently the use of sanitation treatments that will destroy also large part of the beneficial seed microbiome and reduce seed vigour.
Research into the factors shaping diverse seed or even optimised microbiomes, over the entire process from seed production to storage, would provide a basis for the elaboration of practical recommendations for seed producers and enterprises in order to benefit from microbial life for resilient crops. Integrating these factors into the production of healthy, vigorous seeds, seedlings and crops, will also require another paradigm shift from a point of view that mainly aims at avoiding plant diseases to a perspective of sustaining plant health processes. The dynamic process allowing living organisms to evolve towards health was initially described as "salutogenesis" in the context of human health and taken up by in the context of plant health. With this in mind and in the long run, the science concerned with the health of plants may evolve from a stance of plant pathology – focussing on plant diseases – to a stance of plant salutology – focussing on health-sustaining processes.

The new seed health strategy results in the following recommendations:

- Stimulate research on the potential roles of seed vigour and the seed microbiome in establishing resilient cropping systems.
- Integrate the role of the seed microbiome in seed quality aspects, taking into account local variation and adaptation.
- Harness the potential of optimised seed microbiomes to aid in the protection of the seedling towards biotic (pathogens) and abiotic (e.g., climate) stresses, going towards more resilient cropping systems.
- Perform research on the risks of pathogens present on seeds in relation to the positive elements in the seed microbiome to support decisions on sanitation treatments.
- Study positive microorganisms and natural products as potential biocontrol agents to be used for seed or seedling treatments.
- Investigate the effect of seed production conditions (e.g., soil type, crop rotation, fertilization, crop management, weather conditions), harvesting time and method, postharvest treatments and seed storage on the seed microbiome, seed health and seed vigor.
- Combine research and breeding for root microbiome interaction with the seed microbiome.
- Place more emphasis on producing and maintaining high seed vigour to further improve stress resilience of seedlings.
- Raise awareness on the importance of seed health and using organic produced seeds instead of non-chemical treated conventional produced seeds.
- Indicate also for conventional agriculture and nature restoration projects the importance of seed vigour and an optimised microbiome for resilient crop and plant establishment (Seed companies and breeders targeting both organic and conventional markets).
- Highlight importance of seed health also for farm-saved seed and its acceptance by organic certifiers.
- Attract experienced organic farmers to engage in seed production and provide them training in seed production and simple seed quality testing, e.g., germination test under stress conditions in field soil.
- Invest in capacity building and local infrastructure (drying, cleaning, storage) for organic seed production.
- Provide incentives or subsidies for organic seed producers to meet the fast growing demand.
  More cooperation is needed between seed companies and seed producers to find new areas for local organic seed production in different geographic regions to minimize of crop failure.

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5. Recommendations on boosting organic plant breeding innovations (WP3)

5.1. Summary[1]

The current food system is based on an industrialized agricultural model characterized by low crop diversity and a variety of negative side effects. In order to achieve sustainable food security for a growing population, intensification of agricultural production needs to be implemented using fewer external inputs and without expanding existing agricultural lands. Biodiversity conservation and plant breeding linked with organic farming and multi-stakeholder participation at a local level are key for sustainable and resilient food systems to address the United Nations Sustainable Development Goals (UN SDG). Organic plant breeding is a holistic, value-based concept focused on breeding for diversity in the living organic soil and taking into account the nutrition and cultural aspects of food. Participatory plant breeding (PPB) contributes to genetic diversity, local adaptation, seed and food sovereignty, empowerment of farmers, and rural development. As such, organic and participatory breeding approaches have significant potential in supporting a transition toward healthy, locally adapted, and affordable diets. To effectively make such a transition, the participation of local stakeholders in decision making processes is of special importance. The effectiveness of multi-stakeholder approaches that link breeding to value chain actors has been demonstrated. However, up- and outscaling are needed to achieve a paradigm shift toward breeding for diversity. A systems-based breeding approach to support diversity, which considers the long-term societal and ecological benefits of breeding that extend beyond direct value chain interests, is required to address critical societal challenges for food security in the 21st century. These challenges impact food quality, societal justice, agrobiodiversity, and ecosystem services. Significant efforts are needed on global, regional, and national levels to create awareness and ultimately shift the attitudes of consumers, value chain actors, farmers, researchers, and policy makers.

5.2. Current realities

Although over 6'000 different crop species have been cultivated in humankind's history, current food production relies on fewer than 200 crops, and over 40% of daily calories are derived from only three crops (i.e., rice, wheat, maize). Farmer-selected and farm-saved seeds have been largely replaced by uniform varieties that are responsive to chemical inputs and broad geographic adaptation, resulting in significant reductions in the genetic diversity of cultivated crops in the 20th century. Plant breeding became increasingly specialized, privatized, and focused almost entirely on those major crops and hybrid development that could provide rapid return on investment. Food and seed markets are dominated by large multinational players with high market and political power, resulting in a homogenized food and agricultural system. Although it is theoretically possible to feed 8 billion people based on current agricultural production, due to the unequal distribution of and access to affordable food, 10% of the global population suffers from hunger, 2 billion people suffer from micronutrient deficiency, and 2 billion people suffer from obesity. Holistic approaches fostering a paradigm shift toward increased biodiversity, plant-based diets, and fair power distribution are needed to achieve resilient, sustainable food systems with the capacity to feed a population of 9.7 billion people in 2050 and avert rural depopulation (Frison et al. 2016).

5.3. Scientific approaches and key results

Biodiversity and plant breeding linked with organic farming and multi-actor participation at a local level are critical to building sustainable and resilient food systems that effectively address several UN SDGs (e.g., No Poverty [1], Zero Hunger [2], Good Health [3], Gender Equality [5], Clean Water [6], Decent Work [8], Reduced Inequalities [10], Responsible Consumption and Production [12], Climate Action [13]).

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[1] First presented and published under: Messmer M (2020) Systems-based Concepts for Innovative Organic Plant Breeding. In Sustainable Agriculture: The Role of Plant Breeding Innovation. A program and conference organized, facilitated, moderated, and convened by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds (Internet format) November 17—18, 2020 Policy Position paper

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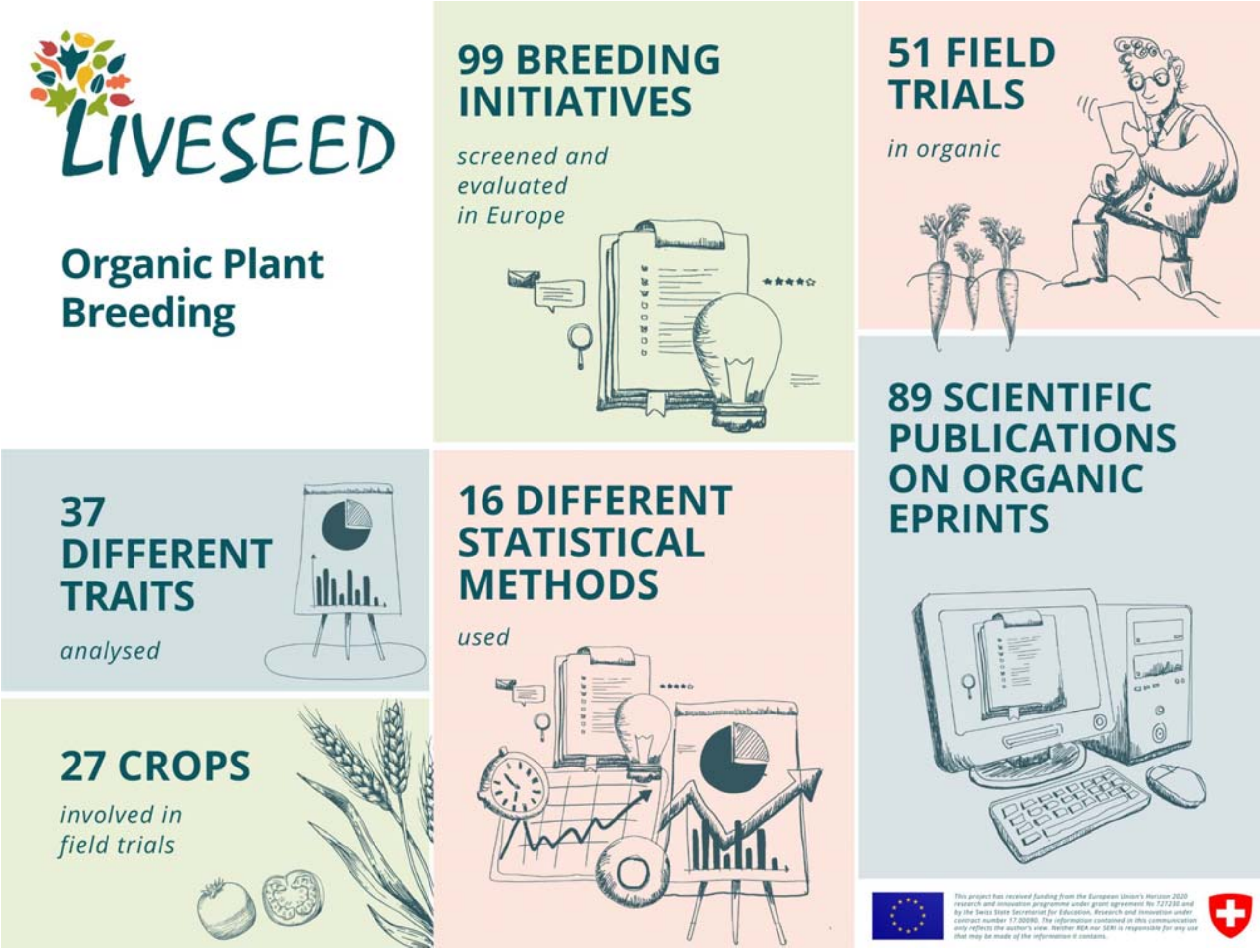

Figure 15: LIVESEED activities to boost organic plant breeding

Organic plant breeding is a holistic, value-based concept acknowledging the coevolution of humankind and crop plants. Organic breeders select for diversity in the living organic soil to foster resilient self-regulating (i.e., thriving with minimal external inputs) farming systems that provide nutritious, delicious food. This includes breeding a wide range of crop species for local adaptation to various growing systems and markets, and developing genetically diverse populations (e.g., composite cross populations (CCP) derived from complex crossings, evolutionary, or dynamic populations) (Chable et al., 2020, Nuijten et al. 2020). Organic plant breeding also encompasses breeding for mixed cropping, agroforestry, or variety mixtures to increase crop performance and resilience. The importance of selecting under organic farming conditions has been demonstrated, and the close interaction between plant and soil microorganisms is scientifically supported by the plant holobiont theory (i.e., viewing a plant and its associated microbiome as a single ecological unit) which corresponds to the influence of the gut microbiome on human wellbeing.

An effective transition of the food system requires (i) the participation of local stakeholders in decision making processes and (ii) the formation of effective linkages between breeding, farming, and the entire value chain, including consumers. PPB contributes to genetic diversity, local adaptation, seed and food sovereignty, empowerment of farmers, and rural development.

The multi-actor approach allows to incorporate ecological, technological, socioeconomic, and political aspects throughout the value chain. Evidence supporting the deployment of genetic resources of underutilized crops in farmers' fields, adoption of PPB and multi-actor approaches, usefulness of breeding

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for cultivar diversity, for mixed cropping systems and importance of plant-microbiome interactions has been collected during LIVESEED (Rodriguez et al. 2020).

LIVESEED project, building on the results of DIVERSIFOOD has connected farmers, citizen and value-chain networks with researchers through a collective learning and innovation process to foster organic plant breeding. However, upscaling such pilot programs remains challenging. Lammerts van Bueren et al. (2018) developed a systems-based breeding concept (Fig. 16) that considers the long-term societal and ecological benefits of breeding that extend beyond direct value-chain interests to address the societal challenges of food security, safety and quality, food and seed sovereignty, social justice, agrobiodiversity, ecosystem services, and climate robustness (Nuijten et al. 2019a).

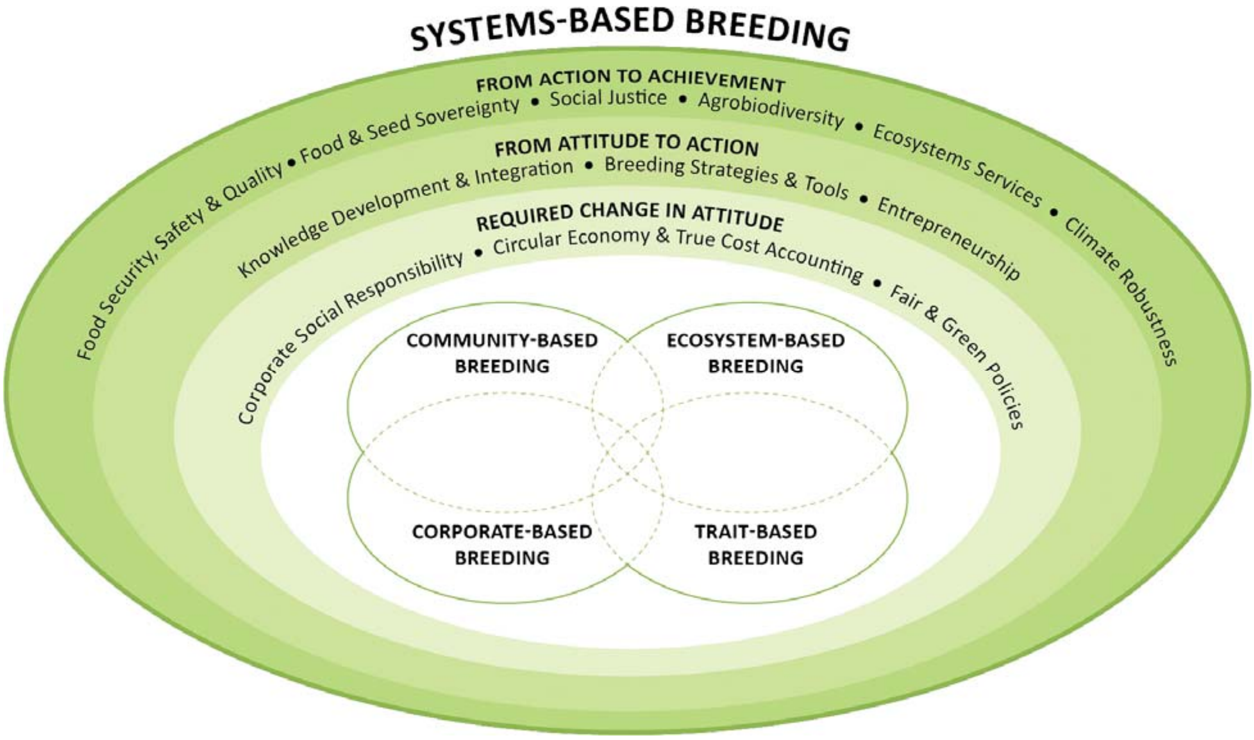

Figure 16. derived from Lammerts van Bueren, E.T., Struik, P.C., van Eekeren, N., and Nuijten, E. (2018). Towards resilience through systems-based plant breeding. A review. Agron. Sustain. Dev. 38(42). https://doi.org/10.1007/s13593-018-0522-6

5.4. Evidence-based recommendations and actionable next steps

In order to achieve 100% organic seed of adapted cultivars, the following recommendations, regarding breeding can be suggested based on LIVESEED results:

- Breeding activities should be conducted within the target farming system in order to be able to combine breeding and agronomic innovations.
- Organic plant breeding efforts should concentrate on the objective to deliver increased agrobiodiversity.
- In Organic plant breeding, breeding for mixed cropping systems should play an important role, in order to support crop diversification.
- Organic plant breeding should aim to put in practice the results from the cutting-edge research on breeding for improved symbiosis with soil and seed microbiome.
- Public institutes also need to conduct research on underutilized crops, breeding for diversity, and organic pest and disease management (including post-harvest losses).

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- Universities and research institutes need to promote multi-stakeholder approaches and give higher priority to providing continual funding for initiatives with demonstrated impact. These institutions need to reward researchers for their involvement in transdisciplinary projects.
- Researchers need to engage with farmers to explore and incorporate the significant experiential knowledge of farmers into their research.
- Organic breeders should join forces and increase collaboration among each and with public and private organisations breeding for the organic sector in order to improve efficiency of selection with limited resources.
- Decentralized participatory breeding involving all stakeholders in the breeding process (farmer, value chain, consumers, society) should be encouraged as this improves local adaptation, market oriented cultivars and long term commitment. It is essential that PPB are supported by a motivated and independent facilitator with high level of social skills.
- Regional and local governments need to invest in training and capacity building for farmers interested in in-situ conservation, cultivation, and processing of underutilized edible crop plants.
- A systems-based breeding approach to support diversity, which considers the long-term societal and ecological benefits of breeding that extend beyond direct value chain interests, is required.
- Research is required to quantify impact of new organic cultivars including all ecosystem services and true cost accounting.
- Scientifically sound indicators needed to be developed to assess sustainability of individual cultivars considering all social, environmental, economic, governance aspects according to the FAO SAFA guidelines which can be used as criteria or threshold for official cultivar release.
- Public funding is essential for further research on organic breeding and prebreeding. Support for practically organic breeding need to be largely increased in order to achieve the Farm to Fork goals.
- All publically funded breeding and pre-breeding should be conducted under organic conditions or at least without pesticides and low fertilizer input to develop cultivars fit for purpose for sustainable agricultural systems.

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6. List of recommendations to achieve a viable organic seed supply chain (D4.5, WP4)

6.1. Summary

The organic seed market is currently characterised by a situation of market failure. This is caused by a lack of market transparency with little information about demand and availability, the current extensively applied derogation regime for non-organic seed, and additional costs in the production of organic seed for certain crops. This can be due to small scale production due to lacking demand, increased risk of fluctuation of seed yield, detrimental seed quality, or declassification as certified seed.

Based on the work carried out in WP1 and economic analysis and actor based modelling in WP4 of LIVESEED, it is recommended that a stepwise approach to phase out derogations is adopted, together with the provision of subsidies and/or the introduction of price premiums for organic produced seed, in order to avoid seed shortages and gross margins reduction at farm level. The amount of these subsidies calculated to avoid financial deficit for farmers varies considerably between crops and country, ranging from 500 €/ha for carrots in Germany to 30 €/ha for durum wheat in Italy and perennial ryegrass in England. To reduce the difference in production cost between organic and non-organic seed, investment in research is needed to overcome the technical difficulties in organic seed production. From farmers' perspective, there is also a great lack of cultivars adjusted to organic production.

However, resources for organic breeding are scarce and limited to a few Central European countries. Based on the evidence gained in WP4, we recommend that funding for organic breeding should greatly increase through public research, public-private partnerships, and the involvement and contribution of supply chain actors. Private labelling represents an opportunity for product differentiation of food produced from organically bred varieties, and to set a premium price so that the additional costs are shared along the whole chain.

Finally, according to the results of the consumer survey in LIVESEED there appears to be a strong need to maintain clear standards and regulations that exclude the use of new genetic engineering techniques, also known as new plant breeding techniques (NPBTs) from the organic sector. As a consequence, the breeding and planting material available for the organic sector could be sharply reduces in a short timeframe. Thus organic breeding following the IFOAM position paper on breeding techniques becomes essential for the organic value chain. For a high market penetration it is important to focus selection on high product quality besides yield and resilience against biotic and abiotic stresses.

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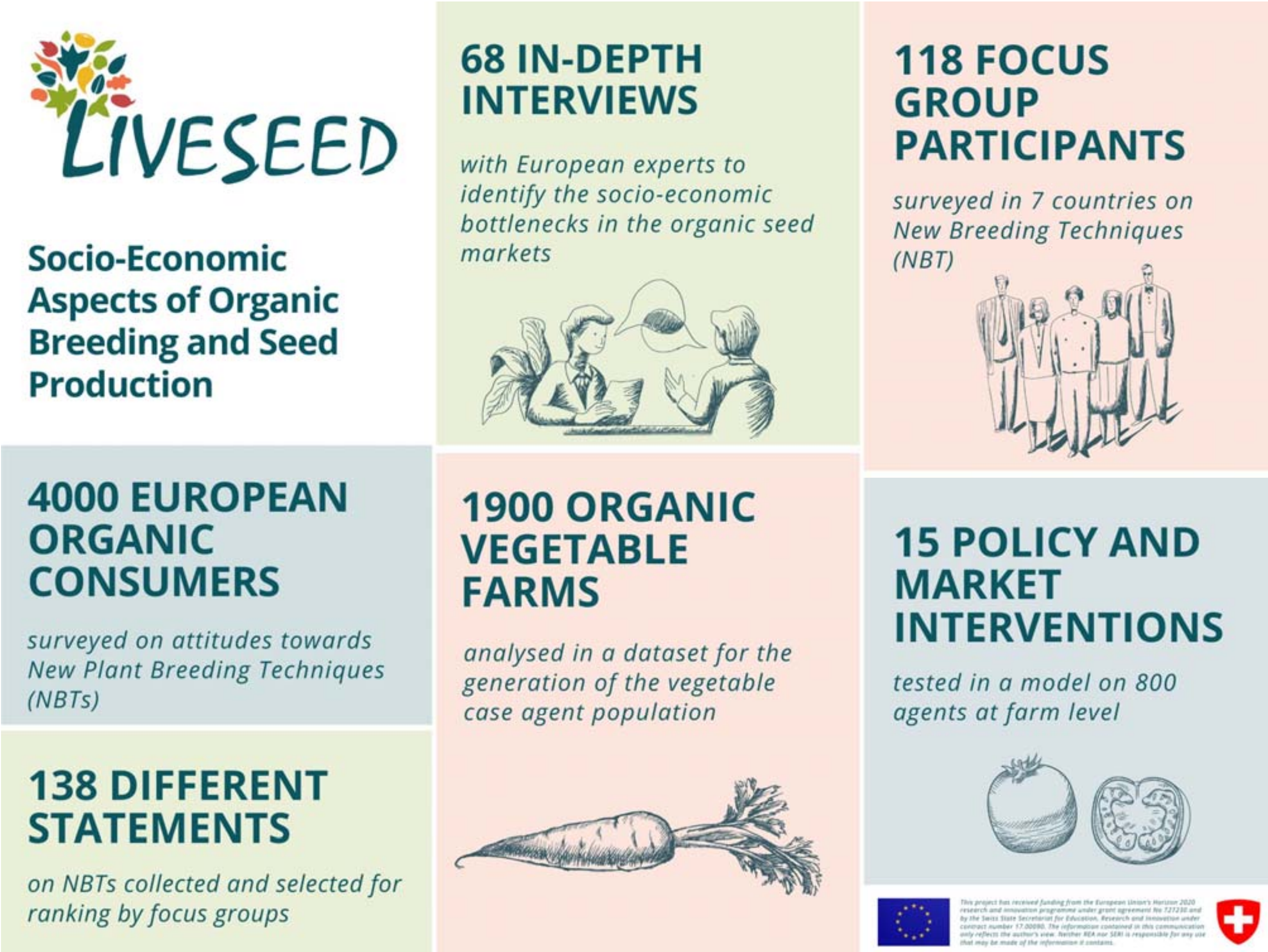

Figure 17: LIVESEED activities to overcome socio-economic bottlenecks and assess consumers attitudes towards new plant breeding techniques

6.2. Current realities

Organic seed

The market for organic seed in Europe is characterised by a potential demand that vastly outstrips supply for most crops in most countries. This results in a situation of market failure, caused by a lack of market transparency with little information about demand and availability, the current derogation regime, and additional costs and technical problems in organic seed production for some crops. At present the use of organic seed is particularly low in Eastern and Southern European countries, and in the larger and recently converted organic farms (Solfanelli et al. 2020, Orsini et al. 2020). Thus, on average the double amount of organic seed would need to be produced to reach 100% organic seed.

Improving the availability of organic seed for a wider range of species and varieties suitable to different European agro-ecological conditions appears to be critical for farmers. On the other hand, seed companies are discouraged from investing in organic seed multiplication by the common practice in some Member States of general derogation for non-organic seed for a large range of crops. Also, increasing organic seed supply is especially challenging for (1) crops that face substantially higher costs or yield losses in the multiplication under organic conditions such as biennial vegetable crops, and (2) for minor crops with a small market, such as some forage crops. As forage species often used as small fraction in a complex mixture, many countries have set up rules that seed mixture will be accepted as organic, if a defined share (e.g. 70%) of the total mixture is organically produced.

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As the organic farmland in Europe will increase in the next years, an increase in the use of non-organic seed via the derogation might occur if no interventions were taken to rapidly scale up organic seed production. Therefore, the foreseen phasing out of derogations by 2036, introduction of national non-derogation lists and monitoring of success as stated in the new Organic Regulation (EU 2018/848) are important pillars to develop the organic seed market.

Organic breeding

The promotion of organic breeding and easier commercialization of new cultivar types (organic heterogeneous population and organic varieties suited for organic production) are other important objectives set out by the new European Organic Regulation (EU 2018/848). However, at present funding for organic breeding is scarce and limited to few Central European countries, which explains difficulties for organic varieties to gain significance in the market.

Organic breeding activities are mainly funded through research projects, donations and, to a minor extent, royalties and seed sales. Whilst funding from research and donations are valuable, they do not guarantee long-term resources. Royalties and seed sales generate a certain amount of money backflow that can be invested in organic breeding, but this would not be sufficient if we strive for a wider range of varieties and crop species. In fact, the return on investments in dedicated organic breeding programmes is considered relatively low by most seed companies (Orsini *et al.*, 2019), mainly because of the smaller size of the organic sector compared to the conventional.

New Plant Breeding Techniques

Genetic engineering techniques and approaches are banned in European organic agriculture including genetic modification (GM) and new plant breeding techniques (NPBT). The European Court of Justice ruled in 2018 that NPBTs including gene editing should follow the same regulations of genetic modification, thus banning their use in organic farming. This judgment received broad support from the organic sector and civil society as it provides strict risk assessment, clear labelling and transparency. Besides the organic sector, also 17 EU Member States have used the opted out rule to ban GMO in their territory and Switzerland just prolonged the GMO moratorium. Also consumers are very critical with respect to GM-derived food. In 2020, only GM-maize has been commercially grown in Spain and Portugal. The International Federation of Organic Movement IFOAM published in 2017 a position paper on the compliances of breeding techniques with the principle of organic agriculture, which is stricter than the EU regulation and e.g., also rules out cell fusion. In fact, organic breeding respects these guidelines and provides already concrete innovation opportunities to meet demand of resilience, yield increase and stability, and food quality (Nuijten *et al.*, 2020). However, there is growing concern that the NPBT might contaminate genetic resources and organic breeding material in the near future due to the wide application of gene editing.

6.3. Scientific approaches and challenges

Organic seed

Within LIVESEED an ex-ante multi-agent value chain approach based on mathematical programming was developed to evaluate the impact of potential public and private interventions to boost the organic seed and breeding sector (Winter *et al.*, 2021). The evidence that emerged from the modelling is as follows:

- A phasing out of non-organic seed without further measures would lead to seed shortages and gross margin losses at farm level because of higher seed prices and the need to switch to alternative (and possibly less remunerative) crops, if not enough seed for a specific crop is available. The challenge is especially with seed for crops like wash/storage carrots in Germany that are more difficult to produce under organic conditions.

Meeting the demand is less problematic for other crops like durum wheat in Italy, especially in a situation where farm-saved seed is accepted as organic seed in all countries and can contribute to the supply. Yet, regardless of the crop, a sharp phasing out of derogation for non-organic seed use without gradual steps over time would make it difficult to provide farmers with organic seed for varieties suitable for different climatic

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conditions and soil types. Therefore, together with WP1 a roadmap was developed to achieve 100% organic seed till 2036, see recommendations in Chapter2.

The model looked at perennial ryegrass too, representing the prevalent forage crop in Europe, commonly grown in a mixture with clover crops. Meeting an increasing demand for grass is challenging too as grass needs nitrogen that under organic conditions cannot be provided through chemical fertilisation. However, there is an overall interest by seed companies to increase organic seed production for ryegrass given its widespread use.

To avoid income losses for farmers with a 100% organic seed use, Winter et al (2021) estimated that a subsidy of around 500 €/ha would be needed for wash/storage carrot producers in Germany, and approximately 30 €/ha for durum wheat in Italy and perennial ryegrass in England. Alternatively, premium price could be charged to compensate organic seed producers for the additional costs, corresponding to 10 €/tons of organic carrots and 10 €/tons of organic durum wheat (Winter et al 2021). Because social norm is a major motivational factor for farmers to use organic seed (Orsini et al. 2020), the size of these subsidies or the price premium could be reduced after the first few years, as supply increases and use of organic seed would be accelerated once the practice has diffused to the majority of farmers.

In this scenario where incentives are provided to farmers, seed companies would need to make major investments to increase their production capacity and meet demand. In order to make the organic seed production more competitive without impacting on farm income or relying heavily on specific subsidies, some technical improvements are needed. These should be achieved through research and breeding programmes such as improving germination rate of carrot seed or improving the nitrogen utilisation efficiency in grass seed production. Under such scenarios, organic seed production becomes more profitable than conventional, and overall organic seed production can be substantially increased.

Organic breeding

According to the farmers surveyed in LIVESEED, more investments in organic breeding would encourage the use of organic seed (Orsini et al. 2019).

In order to find solutions for the longer term to have more organically bred varieties on the market, a yield increase of around 10% on average as a breeding goal could be realistically pursued for a number of crops which would make the use of organic varieties by farmers more attractive (Winter et al. 2021). Under this scenario, use and production of organic seed from organic varieties would go up substantially without additional incentives (Winter et al. 2021). If less yield increase can be achieved in short or mid term, subsidies or premium price to promote the use of organic seed from organically bred varieties would need to be substantially higher than those used to incentivise organic seed from conventional varieties.

A cross-sector pool funding strategy is proposed by Winter et al. (2021) for joining forces among value chain partners to boost organic breeding. This approach entails a pool-funding concept involving the food industry in the provision of a contribution to organic breeding through a flat rate of 0.2% at the point of sale of the organic sales revenue. For example, around 51,023 tons of organic wash/storage carrots are produced in Germany. The average whole-sale price between 2015 and 2019 is per ton 1,583.54 and 0.20% of this would amount to 1.58 €, so around 161,595 € could go into organic breeding. This could be a good contribution to organic breeding. However, other funding sources would still be necessary to obtain a comparable breeding budget to successful breeding companies.

Hybrid financing models exist for some crops like durum wheat in Italy that were studied in-depth in LIVESEED. In this case market players downstream in the supply chain support the breeding process by indicating breeding goals so that the resulting cultivar is not only suitable to organic farming but to the processing needs and the market requirements too. This is the case of an organic variety of durum wheat developed in Italy. For this cultivar, a significant amount of the funding is provided by the retailer who decided to invest in this initiative. Furthermore, financing sources are provided through funding from the Rural Development Programmes, from a research institute and a foundation who conducting pre-breeding and practical breeding. The idea for the future of this initiative is to develop a private label for the organic variety so that consumers will also contribute by paying a premium price and the added value is distributed along the whole seed and food chain. Bioverita has already established a label to advertise the added value of organic plant breeding

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along the value chain for seed and produce derived from certified organic plant breeding. Until now 117 vegetable and 36 arable cultivars and fodder cultivars from Central Europe have been certified www.bioverita.ch.

New Plant Breeding Techniques

Within LIVESEED a consumer survey was conducted in eleven European countries to investigate organic consumers' attitudes towards the use of new plant breeding techniques (NPBTs) in organic farming (Dudinskaya et al. 2021). Overall consumers reject the use of NPBTs in organic farming, since they prefer "natural" and "not manipulated" food products, despite the claimed advantages of these genetic engineering techniques. They also favour the use of seed-saving practices allowing the re-sowing of non-hybrid, unpatented seed and, on average, prefer these to F1 hybrids. Importantly, all consumers demand transparency.

6.4. Evidence-based recommendations and actionable next steps

To achieve the transition towards 100% organic seed use in organic farming and promote organic breeding, the following actions should be implemented:

- **A stepwise approach to phase out derogations needs** to be adopted and needs to be accompanied by measures to avoid seed shortages and make the organic seed sector competitive. These measures are:
    - Providing farmers with subsidies or enable farmers to charge a premium price to avoid reduction of farm gross margins. The size of such interventions can be reduced over time until termination as organic seed supply increases and its use by farmers becomes common practice.
    - Investing in research to overcome technical difficulties related to seed production under organic conditions is needed. Improvements in organic seed yield, seed health and seed vigor will make organic seed production equally or more profitable than conventional, with no need to rely heavily on farm subsidies or to increase food prices.
    - Organic farm-saved seed should be promoted, which will ease a transition to 100% organic seed and to cope with the expected three fold increase in organic farm land by 2030 according to the EU farm to fork strategy. Therefore, is important that organic farmers should be trained and supported to produce high quality seed.
- Expert groups as suggested in WP1 should establish **a minimum threshold of seed in the forage mixture** that needs to be organic. Although this threshold should gradually increase over time, it is currently advisable that a certain amount of conventional seed is allowed. This way farmers can diversify and include minor crops in the mixture for which it is currently very difficult to find organic seed in the market. With such an approach, it would also be easier to harmonise the composition requirements across countries, ultimately resulting in a level playing field on trade in forage mixtures.
- **Funding for organic breeding** should increase through:
    - Public research and partnerships between public institutes and the private sector, including foundations and seed companies.
    - The direct involvement of supply chain actors from breeders to retailers. In this case the breeding goals should be targeted to the market needs and the additional costs associated with organic breeding can be distributed along the whole chain. Private labels represent an opportunity for product differentiation of food produced from organically bred varieties, and to set a premium price for consumers.
    - Resources from the Common Agricultural Policy (CAP) Rural Development Programmes (RDP) should promote supply chain initiatives that support organic seed production and use from organically bred varieties. RDP measures linked to organic seed, breeding and supply chain partnership should be grouped into a unique RDP measure clearly dedicated to organic breeding.
- Alternative more **holistic breeding strategies need to be implemented**.
    - Multi-actors of the organic sector, from breeders to farmers, processors, traders and policy makers, who strive to meet consumer demand should act in a precautionary and transparent way concerning the origin and quality of the seed used.

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- The evidence gained from the organic consumer survey in LIVESEED reinforces the necessity to maintain clear standards, regulations, and transparent labelling that exclude the use of new plant breeding techniques (NPBTs) from the organic sector and measures must be implemented to avoid any contamination. This is very important to maintain consumers' trust.
- Organic breeding programs need to refrain from breeding techniques which are not compatible with organic principles (e.g., genetic engineering, cell fusion, irradiation). The systems-based breeding concept and breeding approaches identified in LIVESEED (Nuijten et al 2020) should be further explored, validated and transferred to other crop species and countries to boost breeding innovations in Europe.
- Organic breeding aims to emphasise product quality as much as yield and resilience, in conformity with the current European political agenda on food production, as detailed in the European Commission Farm to Fork Strategy (European Commission 2020).

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7. Outreach activities (WP5)

Great efforts have been undertaken by LIVESEED consortia for knowledge exchange and the uptake and transfer of LIVESEED results and innovations into research, agricultural, marketing and policy practice. A LIVESEED Plan for Exploitation and Dissemination of Results (PEDR) was developed to address the different multi-actor groups within the consortium, the registered 145 stakeholders and a broad scientific and public audience. Given that the project is implemented in 18 EU countries providing a linguistic and cultural diversity, all project partners engaged in dissemination and exploitation through their established network of stakeholders in ways best suited to their contexts to reach different target audiences. The PEDR served as a living document to guide the project partners and is updated regularly.

Figure 18: LIVESEED activities to disseminate and exploit results for specific target groups

Most results of LIVESEED have been presented at the International Conference on BREEDING AND SEED SECTOR INNOVATIONS FOR ORGANIC FOOD SYSTEMS (Devite et al. 2021) and are already publically available as LIVESEED reports and booklets (see links of References) at the LIVESEED website (www.liveseed.eu) and the organic repository organic eprints. Eighteen peer reviewed scientific papers have been published so far and several are in the pipeline for the special issue in the Journal "Sustainability". 65 Practice abstracts have been published and uploaded together with 46 smart praxis tools on the Organic Farmknowledge Platform under the newly implemented "Seeds and Breeding" theme. This platform is focussing on knowledge transfer and exchange among organic practitioners and offers automatic translation.

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8. References of LIVESEED publications

Abco de Buck A, Frédéric Rey F, Pierre Rivière P, Matteo Petitti M, Lazzaro M, Fehér J (2021). Guidelines for organic on-farm cultivar trials – A practical guide for researchers and facilitators, LIVESEED booklet, Andreoni MP, Petitti M, Bruszik A, Rey F (editors) LIVESEED Booklet.

Alkemade J, Messmer MM, Arncken C, Leska A, Annicchiarico P, Nazzicari N, Książkiewicz M, Voegele RT, Finckh M, Hohmann P (2021) A high-throughput phenotyping tool to identify field-relevant anthracnose resistance in white lupin. Plant Disease. https://doi.org/10.1094/PDIS-07-20-1531-RE

Ares A, Costa J, Joaquim C, Pintado D, Santo, D, Messmer MM, Mendes-Moreira PM (2021) Effect of Low-Input Organic and Conventional Farming Systems on Maize Rhizosphere in Two Portuguese Open-Pollinated Varieties (OPV), "Pigarro" (Improved Landrace) and "SinPre" (a Composite Cross Population). Frontiers in Microbiology 12 https://doi.org/10.3389/fmicb.2021.636009

Bruszik A, Gutzen K, Rey (2020a). **D2.2** Reports on the outcomes of the cross-visits on organic seed production. LIVESEED Report.

Bruszik A, Nuijten E, Rey F, Chable V, Moreira P (2020b). Project outcomes and results: LIVESEED – Boosting organic seed and plant breeding across Europe,LIVESEED booklet, Bruszik A,Costanzo A, Schaefer F, Petitti M, Messmer M, Groot S, Orsini S, Klaedtke S, Mariegaard Pedersen T (editors) LIVESEED Booklet

Bruszik A, Barta L (2021). **D5.10** Report on the Final Stakeholder Event. LIVESEED Report.

Burruezo AR, Annicchiarico P, Uehlinger N, Koutis K, Bollinger N, Baćanović-Šišić J, Backes G, Borgen A, Pettiti M, Sestili S, Campanelli G, Nuijten E, Lazzaro M, Messmer M (2021). **D 3.8** Progress report on breeding activities of white lupin, cell fusion free brassica vegetables, apple, common bunt resistance in winter wheat and participatory tomato breeding. LIVESEED Report.

Chable V, Nuijten E, Costanzo A, Goldringer I. Bocci R, Oehen B, Rey F, Fasoula D, Feher J, Keskitalo M, Koller B, Omirou M, Mendes-Moreira P, van Frank G, Naino J, Abdel K, Thomas M, Rossi A (2020) Embedding cultivated diversity in society for agroecological transition. Sustainability. 12(3): 784; https://rb.gy/8ccd2g

Costanzo A, Bickler C, Messmer M, Rey F, Pettiti M, Vollenweider C, Ytting NK (2018). **M2.8** Main outcomes and SWOT of experiences from marketing populations under the Temporary Experiment into the commercialisation of heterogeneous populations in the European Union. LIVESEED report.

Costanzo A, Bickler C, Nuijten E, Rey F, Messmer M. (2019). **D2.8** Proposal for a toolbox for identification and description of organic heterogeneous material. LIVESEED report.

Devīte M, Rābante L, Dzedule L, Bleidere M, Skrabule I (editors) (2021) Abstract E-book and E-poster collection. . Proceedings zu: International Conference on BREEDING AND SEED SECTOR INNOVATIONS FOR ORGANIC FOOD SYSTEMS. By EUCARPIA Section Organic and Low Input Agriculture jointly with LIVESEED, BRESOV, ECOBREED, FLPP projects and ECO-PB, Institute of Agricultural Resources and Economics, Latvia, 8-10 March 2021. Conference Proceedings.

Dudinskaya EC, Mandolesi S, Naspetti S, Zanoli R (2021). **D4.4** Report on consumer attitudes to new breeding techniques and likely impact on the organic market. LIVESEED Report (unpublished).

European Commission (2020). A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system COM/2020/381.

Forst E, Enjalbert J, Allard V, Ambroise C, Krissaane I, Mary-Huard T, Goldringer I (2019). A generalized statistical framework to assess mixing ability from incomplete mixing designs using binary or higher order variety mixtures and application to wheat. Field Crops Research, 242, 107571.

Frison EA IPES-Food (2016) From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. Louvain-la-Neuve (Belgium). IPES: 1-96 https://rb.gy/xky4ek

Fuss A, Kovács T, Mariegaard Pedersen T, Raaijmakers M, Schäfer F, Gatzert X, Brühl K, Petitti M, Bocci R (2020). How to implement the Organic Regulation to increase production & use of organic seed- Policy Recommendations for national and authorities, LIVESEED booklet, Petitti M, Bocci R, Moeskops B, Fuss A, Messmer M (editors) LIVESEED booklet

Groot SPC, Klaedtke S, Messmer M, Rey F (2020). **D2.5** Organic seed health. An inventory of issues and a report on case studies. LIVESEED Report.

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Hohmann P, Schlaeppi K, Sessitsch A (2020) miCROPe 2019 – emerging research priorities towards microbe-assisted crop production. FEMS Microbiology Ecology, 96, pp. 1-7

Kovács T, Pedersen TM, (2019). **D2.1** Overview on the current organizational models for cultivar testing for Organic Agriculture over some EU countries. LIVESEED Report.

Lammerts van Bueren ET, Struik PC, van Eekeren N, Nuijten E (2018) Towards resilience through systems-based plant breeding. A review. Agronomy for Sustainable Development 38(5) https://orgprints.org/id/eprint/34336/

Mendez-Moreira P, et al. (2021) **D3.6** Enhancing resilience at systems level through breeding for diverse cropping systems, LIVESEED Report

Messmer M (2020) Systems-based Concepts for Innovative Organic Plant Breeding. In Sustainable Agriculture: The Role of Plant Breeding Innovation. A program and conference organized, facilitated, moderated, and convened by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds (Internet format) November 17—18, 2020 Policy position paper

Nuijten E (2019a). **D3.1** LIVESEED workshop on new concepts and strategies for organic plant breeding-Internal report on the results of Workshop 1 for input from formal and informal breeders involved in breeding for organic farming systems for priority setting of research needs for organic plant breeding and selection methods. LIVESEED Report.

Nuijten E, Vonzun S, Messmer M (2019b). **D3.9** State of the art of existing breeding initiatives & actions planned to strengthen collaborations. LIVESEED Report.

Nuijten E, Lazzaro M, Costanzo A, Chable V, Annicchiarico P, Burruezo AR, Klaedtke S, Ceccarelli S, Kölling A, Messmer M (2020). **D3.5** Innovative organic breeding concepts: challenges and examples. LIVESEED Report.

Orsini S, Padel S, Solfanelli F, Costanzo A, and Zanoli R (2019a). **D4.1** Report on relative importance of factors encouraging or discouraging farmers to use organic seed in organic supply chains. LIVESEED Report.

Orsini S, Solfanelli F, Winter E, Padel S, Ozturk E (2019b). **D4.2** Report describing three crop case studies investigating in detail the socio-economic factors influencing the behaviour of various stakeholders regarding the use of organic seed. LIVESEED Report.

Orsini S, Costanzo A, Solfanelli F, Zanoli R, Padel S, Messmer MM, Winter E, Schaefer F (2020). Factors Affecting the Use of Organic Seed by Organic Farmers in Europe. Sustainability, 12(20), 8540, https://www.mdpi.com/2071-1050/12/20/8540

Ortolani L, Petitti M, Andreoni, MP Rey F, Basler A, Moeskops B (2021). **D2.6** Promotion of Smart Practices. LIVESEED Report.

Pedersen TM, de Buck A, Flamm C, Rey F (2021). **D2.4** Guidelines for adapted DUS and VCU testing of organic varieties. LIVESEED Report.

Raaijmakers M, Bruszi A, Schäfer F (2019). **D1.7** Report on the National Visits. LIVESEED Report.

Raaijmakers M, Schäfer F, (2019). D1.9 Report on Political Obstacles and Bottlenecks on the Implementation of the Rules for Organic Seed in the Organic Regulation. LIVESEED Report.

Raaijmakers M, Heining N, Solfanelli F, Ozturk E, Zanoli R, Feher J, Schäfer F, Toncea I (2020). Creating incentives for farmers to use organic seed, LIVESEED booklet, Raaijmakers M, Schäfer F, Winter E, Orsini S, Ortolani L, Petitti M, Bruszik A (editors) LIVESEED Booklet

Rey F, Bruszik A, Moretti M, Petitti M, de Buck A, Meyer K (2020). Success stories on organic seed production & breeding – Experiences from LIVESEED cross-visits, LIVESEED booklet, Matteo Petitti M, Rey F, Messmer M, Bruszik A (editors) LIVESEED Booklet

Rey F, Rivière P, Flipon E, de Buck A, Feher F, Costanzo A, Lazzaro M (2021). **D2.3** Frugal, multi-actor and decentralised cultivar evaluation models for organic agriculture: methods, tools and guidelines. LIVESEED Report.

Rodriguez A, Koutis K, Annicchiarico P, Nuijten E, Messmer M (2020). **D3.4** Report on breeding gaps and key factors for strengthening small breeding initiatives: Experiences on five crops. LIVESEED Report.

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Rodriguez A, Annicchiarico P, Uehlinger N, Koutis K, Bollinger N, Baćanović-Šišić J, Backes G, Borgen A, Pettiti M, Sestili S, Campanelli G, Nuijten N, Lazzaro M, Monika Messmer (FiBL-CH) (2021) **D3.8** Progress report on breeding activities of white lupin, cell fusion, cell fusion free brassica vegetables, apple, common bunt resistance in winter wheat and participatory tomato breeding. LIVESEED Report.

Schäfer F, Gatzert X, (2020a). **D1.5** Report on the European Router Database. LIVESEED Report.

Schäfer F, Gatzert X, (2020b). European Router database Guide for Authorities. LIVESEED Report.

Schäfer F, Gatzert X, (2020c). European Router Database Guide for Suppliers. LIVESEED Report.

Solfanelli F, Ozturk E, Zanoli R, Schäfer F (2019). **D1.2** Report on current production and use of organic seeds and synopsis of databases. LIVESEED report (publication under preparation).

Solfanelli, F, Ozturk, E, Orsini, S, Schäfer, F, Messmer, M, Zanoli, R (2020). **D1.5** The EU organic seed sector – statistics on organic seed supply and demand. Working Paper.

Solfanelli F, Ozturk E, Zanoli R, Orsini S, Schäfer F (2021). The State of Organic Seed in Europe, LIVESEED booklet, Petitti M, Ortolani L, Schäfer F, Messmer M (editors) LIVESEED Booklet.

Sommer M, Barta L, Gatzert X, Meyer K, Raaijmakers M (2021). **D1.6** European Progress Report on Organic Seed: Conclusions & Recommendations. LIVESEED Report.

Vonzun S, Messmer M (2019). D6.5 List of projects with potential relevance for LIVESEED. LIVESEED Report.

Wille L, Messmer, MM, Studer B, Hohmann P (2018) Insights to plant-microbe interactions provide opportunities to improve resistance breeding against root diseases in grain legumes. Plant Cell Environ. 42(1):20-40

Wille L, Messmer MM, Bodenhausen N, Studer B, Hohmann P (2020) Heritable variation in pea for resistance against a root rot complex and its characterisation by amplicon sequencing. Frontiers in Plant Science 03 https://doi.org/10.3389/fpls.2020.542153

Winter E, Aurbacher J, Grovermann C, Orsini S, Solfanelli F, Zanoli R, Messmer M (2021). **D4.3** Report on analysing and optimising organic seed markets, supply chains and business models of breeders and seed producers based on interactive modelling. LIVESEED Report (publication under preparation).

Further LIVESEED readings: https://orgprints.org/view/projects/eu-liveseed.html

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Annex 1 Guidelines on how to improve seed derogation data collection and publication

The annual reports of national authorities on the use of non-organic seed and vegetative planting materials provide important information on crop species, sub-species and varieties used in organic farming as non-organic plant propagating material. However, the quality of these reports is often inconsistent among EU countries. A standardized format for data collection and publication procedures are needed to ensure the harmonization of data and output, allowing coherence and comparability among EU countries. This is of crucial importance, as without good quality information it is difficult for policymakers and competent authorities to determine if the amount of non-organic PRM used is actually changing. In addition, if the derogation reports are more comparable and reliable the reports can provide relevant data to researchers and seed producers. The process of data collection should be done according to the following standards of good practices:

Harmonize the statistical process for data collection on the derogations granted by:

- Harmonizing the definitions, nomenclature and classifications, as well as the way how crops statistical information is aggregated. EUROSTAT – CPA (Commission Regulation (EU) No 1209/2014)[2] international classifications should be adopted by all member states competent authorities as a basis for classification systems. If EUROSTAT - CPA classifications are not detailed enough, it is always possible to include additional sub-categories to extend the classifications (i.e. addition sub-category for crop and variety name). To ensure that variety names are written correctly, it is possible to refer to the EU plant variety database.[3]

- Harmonizing the units of measurement of the volume of derogations. The amount of seeds granted through derogation should be expressed in weight (kg of seeds), units of 100.000 seeds etc. or number of plants concerned. Different unit of measures (i.e. amount of seed derogation for maize is sometimes expressed in kg, unit or packages) should be avoided, at least for the same crop species. If a unit of measurement is not applicable for the specific needs, specific conversion rate should be adopted for all member states (e.g. for maize or sunflower a specific coefficient could be used to convert number of seeds into kg of seeds).

Data processing, storage and analysis

- Data reliability and validity. Data reliability and validity is a prerequisite for seed data comparison and calculation. As a number of inconsistencies can be identified in the national report, it is strongly recommended to conduct simple quality checks (e.g. comparison between two years; comparison with countries with similar farming conditions). Another easiest data analysis and also quality check is to refer all derogations granted to a specific crop area and compare the potential seeding rate. This would require that farmers indicate in the derogation request on what area they are planning to sow the requested amount of seed.
- Incomplete data. In the past, there is was no record about which species and sub-species are listed under Category 3 (general derogation) nor which cultivars and respective volume of non-organic seed have been used by organic farmers in the European Union. Currently, only in Germany, Luxembourg and Italy,

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R1209&from=EN

[3] https://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search/public/index.cfm

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farmers need to notify the authorities and control bodies about the cultivars and the volume of non-organic seed used for crop species or sub-species included in this general derogation category. However, this information is not included in the yearly reports to the European Commission. From 2022 onwards it will become obligatory to collect data on the amount of non-organic PRM used for crops on the list for general derogations (Art 1.8.5.7 EC 2020/1794). To ensure complete data sets of each country, it is of high importance to add collected data on cultivars and volume of non-organic seed to the national derogation reports and make them publicly available.

Publication and dissemination

- Accessibility. Not all derogation reports are easily accessible online in the national organic databases of each country. Currently, only few countries implement an online website in which it is possible to search for available derogation reports. To increase the transparency and the availability on the use of non-organic seed in the EU it would be recommended that, in future, all derogations reports could be accessible online at EU level, either directly at the European Commission organic website or at the newly established EU Router Database (seeds4organic.eu). Within the LIVESEED project, each national competent authority have received an account to the EU Router database, thus authorities could upload the national derogation reports. The EU Router Database can make all reports publicly available at one place.
- Format of publication. It is important that the data on derogations are presented in a way that they can be analysed, compared and compiled. So the data should indeed be available (at least to the Commission) in an standardized format (see Table 1). The possibility of automatic data entry into the MS Access database should be programmed, based on the MS Excel format in Table1. The use of look-up tables is recommended, as these enable standardized data entry and reduce the possibility of errors when inserting data.

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Annex 1, Table 1 : Suggested format for publication of data on derogations

Crop group /sub- group (Code)	Crop group /sub- group (Heading)	Scientific name of the species	Variety/denomination	Number of derogations	Derogation category	Number of operators for which derogation is granted	Crop area (ha) for which derogation is granted	Total weight of seeds or number of plants derogated		Conversion rate to kg (*It should be used for the unit measures other than kg or number. e.g., packages, sacks, units*)
								Quantity	Unit measure (e.g., kg for seeds, number for plants)	
01.1	Non-perennial crops									
01.11	Cereals (except rice)									
01.11.3	Barley, rye and oats									
01.11.31	Barley									
01..11.31.1	**Spring barley**	***Hordeum vulgare***	**Odyssey**	**1**	**single/general**	**1**	**5**	**1.000**	**Kg**	
01.2	Perennial crops									
01.24	Pome fruits and stone fruits									
01.24.1	**Apples**	***Malus domestica***	***Camelot***	**1**	**single/general**	**1**	**1**	**5.000**	**nr. plants**	

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Annex 2: Template suggested for adjusted DUS for organic varieties suited for organic production for the temporary experiment

Proposal for an adapted DUS protocol for Organic Varieties

Example species: Carrot

Addendum to the document TITLE: Support for participation in temporary experiment to foster development and release of organic varieties suitable for organic production.

In 2020, the Raad voor plantenrassen (Dutch plant variety board) funded a one year investigation to obtain some first experience on the registration procedures for Organic Varieties. Field registration trials for organic carrot and kohlrabi varieties were executed in a collaboration between Naktuinbouw, ECO-PB (the European platform for organic plant breeding), Bingenheimer Saatgut (DE) and Louis Bolk Instituut (NL). Knowledge on organic breeding and variety concepts developed in the EU H2020 LIVESEED project was used. The uniformity of two organic carrot varieties were examined according to the official DUS (Distinctness Uniformity Stability) protocol in two field trials, one at Naktuinbouw (NL) and at a parallel trial at Bingenheimer Saatgut (DE). The outcomes of these carrot trials served as a model case in the discussion on the UPOV criteria, how to assess the uniformity of an Organic Variety, and an alternative protocol for examining organic carrot varieties was proposed.

Currently, DUS for carrot takes 31 CPVO / UPOV characteristics into account, for which every candidate variety is assessed (presented on page 2). Seventeen characteristics are so-called asterisk criteria and denote those characteristics which should always be observed when a UPOV guideline is utilised for the purpose of international harmonization of variety descriptions and included in the variety description (except when the state of expression is inappropriate for the regional environmental conditions). All characteristics are selected to enable distinction between the varieties within the species in the most efficient way; e.g. easy observable and stable expression under different environmental conditions. These characteristics include traits that have no value for the grower, packer, trader or consumer. In order to get a variety registered in EU the candidate variety needs to pass the DUS test of all 31 criteria. Therefore, the breeder might have to bring down the level of genetic diversity risking inbreeding depression in order to fit within the requirements of uniformity. However, this is entirely opposed to the enhanced genetic diversity that is required in organic agriculture for its specific needs, e.g. for tolerance and adaptation to diverse local soil and climate conditions and a broad disease resistance as defined in the new Organic Regulation for
Organic varieties suited for organic production (2018/848).

Following the current CPVO DUS guidelines is a pre-condition for registration and commercialization of a vegetable variety in the EU, and precondition for obtaining Plant Variety Protection enabling the unhampered trade of seeds. The purpose of an alternative or more flexible registration process would be to facilitate the registration of Organic Varieties. In a proposed alternative test protocol all current CPVO / UPOV characteristic are included and still need to be described for a candidate variety. The only difference to the current CPVO protocol is that there is a new classification into optional and mandatory characteristics according to their market relevance. The characteristics where uniformity is relevant for the users are mandatory and need to be sufficiently uniform (estimation: 20 traits for

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carrot). The non-market-relevant traits are called optional characteristics and do not need to be uniform at the same level, meaning that requirements for uniformity are less strict. However, all characteristics are assessed for description. For a successful registration, the variety needs to differ in at least one of the market-relevant (mandatory) traits to any other variety.

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Example for the alternative carrot protocol (washing + storage)

UPOV Nr.	asterix characteristics	characteristics of the UPOV protocol for carrots usable for fresh market (marketing without leafs)	relevance of utility for: farmers / producers	relevance of utility for: trade / processors	relevance of utility for: consumers	important characteristics for selection of organic breeders: estimation of 8 carrot breeders	ECO-PB proposal for adapted protocol: Characteristics to be considered mandatory	ECO-PB proposal for adapted protocol: characteristics to be considered optionally on request (or recommendation) of the applicant
			(0=none, 1=medium, 2=great)			(0=not important, 1=medium important, 2= very important)		
1		**Foliage: width of crown**	2	0	0	1	**1**	***0***
2		**Leaf: attitude**	2	0	0	1	**1**	***0***
3	(*)	**Leaf: length (inkluding petiole)**	1	0	0	1	**0**	***1***
4	(*)	**Leaf: division**	0	0	0	1	**0**	***1***
5	(*)	**Leaf: intensity of green colour**	0	0	0	1	**0**	***1***
6	(*)	**Leaf: anthocyanin coloration of petiole**	0	0	0	1	**0**	***1***
7	(*)	**Root: length**	1	2	1	2	**1**	***0***
8	(*)	**Root: width**	1	2	1	2	**1**	***0***
9	(*)	**Root: ratio length / width**	1	2	1	2	**1**	***0***
10	(*)	**Root: shape in longitudinal section**	1	2	1	2	**1**	***0***
11		**Varieties scoring between 4 and 6 for characteristic 10 only: Root: tendency to conical shape**	1	2	1	2	**1**	***0***
12	(*)	**Root: shape of shoulder**	1	2	1	2	**1**	***0***
13	(*)	**Root: tip (when fully developed)**	2	2	1	2	**1**	***0***
14	(*)	**Root: external colour**	2	2	2	2	**1**	***0***
15		**Excluding varieties with white external root colour: Root: intensity of external colour**	2	2	2	2	**1**	***0***
16		**Root: anthocyanin coloration of skin of shoulder**	2	2	1	2	**1**	***0***
17		**Root: extent of green colour of skin of shoulder**	2	2	2	2	**1**	***0***
18		**Root: ridgning of surface**	2	2	1	2	**1**	***0***
19	(*)	**Root: diameter of core relative to total diameter**	1	1	1	2	**0**	***1***
20	(*)	**Root: colour of core**	1	1	1	2	**0**	***1***
21		**Excluding varieties with white core: Root: intensity of colour of core**	0	1	1	1	**0**	***1***
22	(*)	**Root: colour of cortex**	1	2	2	2	**1**	***0***
23		**Excluding varieties with white cortex: Root: intensity of colour of cortex**	0	2	2	2	**1**	***0***
24		**Root: colour of core compared to colour of cortex**	1	2	1	2	**1**	***0***
25	(*)	**Root: extent of green coloration of interior (in longitudial section)**	2	2	2	2	**1**	***0***
26		**Root: protrusion above soil**	2	0	0	2	**1**	***0***
27		**Varieties with blunt tip only: Root: time of development of rounded tip**	2	0	0	2	**1**	***0***
28		**Root: time of coloration of tip**	1	0	0	1	**0**	***1***
29		**Plant: heigh of primary umbel at time of its flowering**	0	0	0	1	**0**	***1***
30	(*)	**Plants: proportion of male sterile plants**	1	0	0	1	**0**	***1***
31	(*)	**Plant: type of male sterility**	0	0	0	0	**0**	***1***
						characteristics in total:	***20***	***11***

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If that is not the case, one of the non-market-relevant (optional) characteristics can be taken into account when assessing distinctness; provided that this characteristic has to be sufficiently uniform, like the mandatory traits. For the purpose of description, all characteristics have to be taken into account. Hence, the so called optional ones (which are not needed for distinction) might be describable by using frequencies. The use of the whole range of characteristics for description is necessary to get a complete description of the new variety in application. Such an approach will be in line with the existing systems for both registration and plant variety protection (IPR).

The proposal is based on an evaluation that Bingenheimer Saatgut AG undertook among the stakeholders of the organic sector about the relevance of uniformity for the user: farmers and producers, traders and processors as well as consumers have been interviewed about their needs. The organic breeders have also given their input. This is a novel approach as so far only breeders and seed companies had a say in defining the registration process.

For all partners in the carrot project, it was a useful exercise to re-consider the way of looking at accepted heterogeneity of an Organic Variety, the needs of uniformity for users and market, and the requested uniformity for variety registration. The results of the examination of the carrot varieties according to the current protocol for DUS testing provided discussion topics with respect to the proposal for the adapted protocol:

- Carrot is a rather heterogeneous crop in itself; even the F1-hybrid varieties. The uniformity of OP varieties is assessed in comparison within the group of the same type of OP varieties (references). The examiner is used to work with so-called ‘relative uniformity’: uniformity assessed at plot level in comparison to other comparable open-pollinated varieties, not at the level of individual plants.
- It is useful to develop a common set of organic reference varieties.
- Uniformity might not only be a genetic factor, but in part environmental. For one carrot variety, the trial showed a low level of uniformity and a deviation on the shape of the root tip, which are asterisk criteria and important for the market. This needs further examination in a next year.
- The genetic background has an influence on the uniformity of certain traits; it is a valid interpretation of the CPVO guidelines and current practice to adapt the way of assessing uniformity of these characteristics. A solution for Organic Varieties might be to define different levels of uniformity.
- Concerning stability: is some adaptation or some level of variance acceptable some time after the registration and official variety description? Is adjusting a variety description possible?
- Focus on the distinction of a variety as a main goal over uniformity and stability in reproduction.
- For variety protection and IPR, DUS must be very clear and stable. The possibility of variety protection for Organic Varieties registered via adapted protocols has to be discussed
- Would it be possible to have an adjusted implementation of the DUS system, just for the registration of an organic variety, with more flexible requirements on a reduced number of DUS criteria?

March 7, 2021. Abco de Buck (Louis Bolk Instituut, NL), Gebhard Rosmanith (Bingenheimer Saatgut AG, DE) and Barbara Maria Rudolf (Saat:gut e.V. , DE); on behalf of ECO-PB.

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Proposal for an adapted DUS protocol for Organic Varieties

Example species: Kohlrabi

Addendum to the document TITLE: Support for participation in temporary experiment to foster development and release of organic varieties suitable for organic production.

Technical outcomes of the kohlrabi trials

Kohlrabi is a uniform crop type. Uniformity of kohlrabi OP varieties is relative, is compared within the same group (based on earliness and leaf characteristics) and can express differently. Almost all present day PVP applications for kohlrabi are F1 hybrid varieties with a high level of uniformity. As there is not much reference, a point of attention is the experience of the examiners to assess "relative uniformity" for OP kohlrabi varieties. A solution would be to agree on a larger list of reference OP varieties in the test.

The trial showed that one of the candidates is sufficiently uniform; for the other candidate the level of relative uniformity for registration is not sufficient. Moreover, uniformity of one reference variety was doubtful, but the distinctness was sufficient within the group. The candidate variety showed uniformity issues on different kinds of traits: morphologic, market relevant, UPOV and non-UPOV characteristics (any characteristic is used to assess uniformity). The low level of uniformity on market relevant characteristics might be a reason to reject this candidate, also for registration as an organic variety. However, the results have to be confirmed in another test, as the expression of characteristics is dependent on the growing conditions. Kohlrabi proved to be a suitable model crop to look at the differences in heterogeneity / relative uniformity within organic OP varieties, compared to conventional F1 hybrids.

Proposal for an adapted protocol

Currently, uniformity in candidate kohlrabi varieties is assessed using 24 UPOV characteristics; 14 out of 24 characteristics are so-called asterisk criteria (mandatory in the variety description for the purpose of international harmonization, except when the state of expression is inappropriate for the regional environmental conditions). The characteristics are selected to enable distinction between the varieties within the species in the most efficient way; e.g. easy observable and stable expression under different environmental conditions. These characteristics include traits that have no value for the market. In order to get a variety registered in EU the candidate variety needs to pass the DUS test of all 24 criteria. Therefore, the breeder might have to bring down the level of genetic diversity risking inbreeding depression in order to fit within the requirements of uniformity. However, this would be opposed to the enhanced genetic diversity that is required in organic agriculture for its specific needs, e.g. for tolerance and adaptation to diverse local soil and climate conditions and a broad disease resistance as defined in the new Organic Regulation for Organic varieties suited for organic production (2018/848).

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Example for the alternative kohlrabi protocol:

UPOV Nr.	asterix characteristics	grouping characteristics	type	stage	method	characteristics of the UPOV protocol for kohlrabi	farmers / producers	trade / processors	consumers	farmers / producers	trade / processors	consumers	estimation of 2 kohlrabi breeders	Characteristics to be considered mandatory	characteristics to be considered optionally on request (or recommendation) of the applicant
							(0=none, 1=medium, 2=great)			(0=none, 1=medium, 2=great)			(0=not important, 1=medium important, 2=very important)		
1	(*)	x		(a)		Seedling: anthocyanin coloration of cotyledons	1	0	0	0	0		0	0	*1*
2				(a)		Seedling: intensity of green coloration of cotyledons	1	0	0	0	0		0	0	*1*
3				(a)		Petioles: crossing	2	2	1	0	0		2	1	*0*
4	(*)			(a)		Petiole: length	2	2	1	0	0		2	1	*0*
5				(a)		Petiole: thickness (in the middle)	1	1	1	0	0		0	0	*1*
6	(*)			(a)		Petiole: attitute	2	2	1	2	0		2	1	*0*
7	(*)			(a)		Leaf blade: attitute	2	2	0	2	0		2	1	*0*
8	(*)			(a)		Leaf blade: length	1	1	0	0	0		0	0	*1*
9	(*)			(a)		Leaf blade: width	1	1	0	0	0		0	0	*1*
10				(a)		Leaf blade: shape of apex	0	0	0	0	0		0	0	*1*
11	(*)			(a)		Leaf blade: divisions to midrib (on lower part of leaf)	0	0	0	0	0		0	0	*1*
12				(a)		Leaf blade: number of margin incisions (on upper part of leaf)	0	0	0	0	0		0	0	*1*
13				(a)		Leaf blade: depth of margin incisions (on upper part of leaf)	0	0	0	0	0		0	0	*1*
14				(a)		Leaf blade: shape in cross section	0	0	0	0	0		0	0	*1*
15	(*)			(a)		Leaf blade: blistering	1	1	0	0	0		0	1	*0*
16				(a)		Leaf blade: waxiness	2	2	2	0	0		2	1	*0*
17	(*)			(a)		Leaf blade: hue of green color	2	2	2	0	0		2	1	*0*
18	(*)			(a)		Leaf blade: intensity of green color	2	2	2	0	0		2	1	*0*
19				(b)		Kohlrabi: number of inner leaves	0	0	0	0	0		0	0	*1*
20	(*)			(b)		Kohlrabi: color of skin	2	2	2	0	2		2	1	*0*
21	(*)			(b)		Kohlrabi: shape (in longitudinal section)	2	2	2	0	2		2	1	*0*
22				(b)		Kohlrabi: shape of apex	2	2	2	0	2		2	1	*0*
23	(*)	x		(b)		Harvest maturity	2	0	0	2	0		2	1	*0*
24	(*)	(x nur bei CPVO)	QL	(a)	VG/MS	Male sterility									
													characteristics in total:	*12*	*11*

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Following the current CPVO DUS guidelines is a pre-condition for registration and commercialization of a vegetable variety in the EU, and precondition for obtaining Plant Variety Protection enabling the unhampered trade of seeds. The purpose of an alternative or more flexible registration process would be to facilitate the registration of Organic Varieties. In a proposed alternative test protocol all current CPVO / UPOV characteristic are included and still need to be described for a candidate variety. The only difference to the current CPVO protocol is that there is a new classification into optional and mandatory characteristics according to their market relevance. The characteristics where uniformity is relevant for the users are mandatory and need to be sufficiently uniform (estimation: 15 characteristics for kohlrabi). The non-market-relevant traits are called optional characteristics and do not need to be uniform at the same level, meaning that requirements for uniformity are less strict. However, all characteristics are assessed for description. For a successful registration, the variety needs to differ in at least one of the market-relevant (mandatory) traits to any other variety. If that is not the case, one of the non-market-relevant (optional) characteistics can be taken into account when assessing distinctness; provided that this characteristic has to be sufficiently uniform, like the mandatory traits. For the purpose of description all characteristics have to be taken into account. Hence the so called optional ones (which are not needed for distinction) might be describable by using frequencies. The use of the whole range of characteristics for description is necessary to get a complete description of the new variety in application. Such an approach will be in line with the existing systems for both registration and plant variety protection (IPR).

A lot of UPOV characteristics are about the leaves of Kohlrabi because it meets the goals to efficiently assess Distinctness and Uniformity. Market characteristics are not always suitable for the goal of Distinctness and Uniformity: not easy to observe, no clear variety differences and not stable (due to growing conditions or heritability). It is up to discussion if we can allow heterogeneity on certain leaf characteristics for organic varieties that have a good production and value for the market.

March 7, 2021.

Abco de Buck (Louis Bolk Instituut, NL) and Gebhard Rosmanith (Bingenheimer Saatgut AG, DE); on behalf of ECO-PB.

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Annex 3: Seed health strategy – draft for discussion with stakeholders

Need for a new seed health strategy

This text is a draft for a new seed health strategy to be discussed with stakeholders

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Summary

Seed quality is important for seedling establishment - an essential step for crop production. Poor seedling emergence due to abiotic and biotic stress in the field can reduce crop stand, yield and farmers' income. Seed health and vigour, the ability of the seed and seedling to cope with such stresses, is of increasing importance for sustainable farming, in particular in the face of climate change. Although current knowledge is limited, it has become clear that the seed microbiome should also be taken into account when considering seed health. Until recently, seed health was almost exclusively oriented at controlling seed-borne pathogens, but seeds can also contain beneficial micro-organisms that aid the seedling against pathogens or abiotic stresses. In an up-to-date seed health strategy, the seed microbiome should be considered as part of seed health. More attention and research are needed to produce and maintain seeds with an optimal seed microbiome. In this respect, soil biodiversity seems to be an important driver, as part of the seed microbiome originates from the soils. Knowing that organic soils have a higher biodiversity, the advantage for organic seeds should be explored. Organic seeds are often treated to control seed-borne pathogens. Although it is likely that this also reduces a significant part of the seed microbiome, knowledge is lacking on how this influences seed vigour and seedling establishment. When such treatments can't be avoided, it might be useful to restore the microbiome by either biopriming or coating the seeds with beneficial microorganisms originating from seed microbiomes. In the references list, background scientific literature is provided, including the abstract to aid the reader.

Introduction

Seed health and quality affect how well a crop will establish and perform, influencing crop yield, farmers' incomes and, ultimately, food security. In the framework of the LIVESEED project, Deliverable 2.5 has reported on 2 case studies into organic seed health issues – *Alternaria ssp*. with carrot and common bunt (*Tilletia* spp.) with soft wheat – and established an inventory of current problematic issues for the quality of organic seed. Based on these findings and on a review of scientific literature, we here aim at designing a strategy for organic seed health and quality.

To assess seed quality, routine seed testing evaluates seed germination rates and detects potential seedborne pathogens, according to crop species. If a problematic level of seedborne pathogen is detected, seed treatments can be used for disease control. In organic farming, these range from natural compounds (e.g., vinegar) and physical treatments (e.g., hot water treatments or brush cleaning) to the application of biologicals (e.g., antagonistic microorganisms). However, both practical experience and recent scientific findings tend to indicate that taking into account additional aspects to seed quality would benefit organic agriculture and other forms of sustainable agriculture (refraining from the use of chemical inputs).

Seed vigour is understood as the tolerance of seeds and seedlings to environmental constraints. Despite all the care taken by farmers before and during sowing, due to weather, field conditions can vary, which can put a strong restraint on the establishment of seedlings. Such uncertainties and

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unpredictable stress factors are expected to increase with global climate change. Research in the frame of the European project LIVESEED showed that high seed vigour not only provides more tolerance to abiotic stresses as drought and cold but can also make seedlings more tolerant to pathogens.

Unfortunately, farmers are not always aware of its importance or do not have access to high vigour seed. For instance, even when total seed emergence is good, slower emergence due to lower seed vigour will result in stronger competition by weeds, requiring more labour for weed removal. Awareness on the importance of seed vigour needs to increase with both seed producers and farmers, even more in the case of farm-saved seeds. Training to recognise seed vigour aspects and relatively simple test methods can aid in this.

Taking seed vigour more into account as a leverage for resilient organic agriculture has implications for seed production, processing, testing, treatments and storage. Seed vigour can also have a genetic basis, which can be incorporated into plant breeding programs for resilient varieties. Concerning seed production, the (most) healthy mother plants should be selected, and nutrient limitations avoided. Seeds need to be harvested at full maturity whenever possible. During storage, ageing of the seeds should be avoided by proper dry conditions and protection from pests.

The **plant microbiome** is understood as the microbial ecosystem, composed of bacteria and fungi, associated to plants. These micro-organisms can have a positive, neutral or negative effect on plant health. In the latter case they are referred to as pathogens. Plants transfer part of their microbiome to the next generation as the seed microbiome. Until present, attention was almost exclusively paid to pathogens in this seed microbiome, called seed-borne pathogens. But the pathogenicity seems to depend on the concentration and the on the presence of other microorganisms in the seed microbiome. Seed can also contain micro-organisms that aid the seedling against pathogens or abiotic stresses. Although scientific research on the seed microbiome has started only recently, several important influences on seedling establishment have already been discovered.

Approaches and challenges

Based on the considerations above, seed vigour and seed microbiota are expected to have an important role to play in leveraging the potential and resilience of organic cropping systems. They are relevant elements to take into account for redesigning seed and cropping systems for agroecological transitions. At this stage, knowledge on seed vigour and microbiota has broadened our view on the complexity of seed and plant health. In the aim of leveraging this potential for the benefit of organic seed production, multiple new fields and topics arise for future research and development. These also have to be addressed at the different geographic scales, from local seed production on farm to entire seed systems.

Interactions of seed vigour and seed microbiota: It has become clear that both seed vigour and seed microbiota contribute to the health of seeds, seedlings and, ultimately, crops (Das Gupta and Austenson, 1973; Nelson et al., 2018). It remains unclear how the two mutually affect each other. Nevertheless, in the LIVESEED case study on carrot cited above, high vigour un-aged seeds were more tolerant to damping-off caused by *Alternaria radicina* than artificially degraded, low-vigour seeds. This illustrates that seed vigour and microbial activity on seeds and seedlings are inter-related, although it does not allow to determine which of the two is the driver (if any of the two should be considered the driver). These findings broaden the picture on seed and plant health beyond the mere detection of pathogens. They indicate that seed health and seed quality are intimately intertwined. The following infographic illustrates an understanding of seed and plant health as a continuum that is based on interaction with microbial life.

Factors shaping microbiota: More attention and research are needed to produce and maintain seeds with an optimal seed microbiome. A highly biodiverse microbiome seems to be advantageous for the seedling (Wassermann et al., 2019). Since the seed microbiome is partly originating from the soil and organic soils have a more biodiverse microbiome (Hartmann et al., 2015; Lupatini et al., 2017), this

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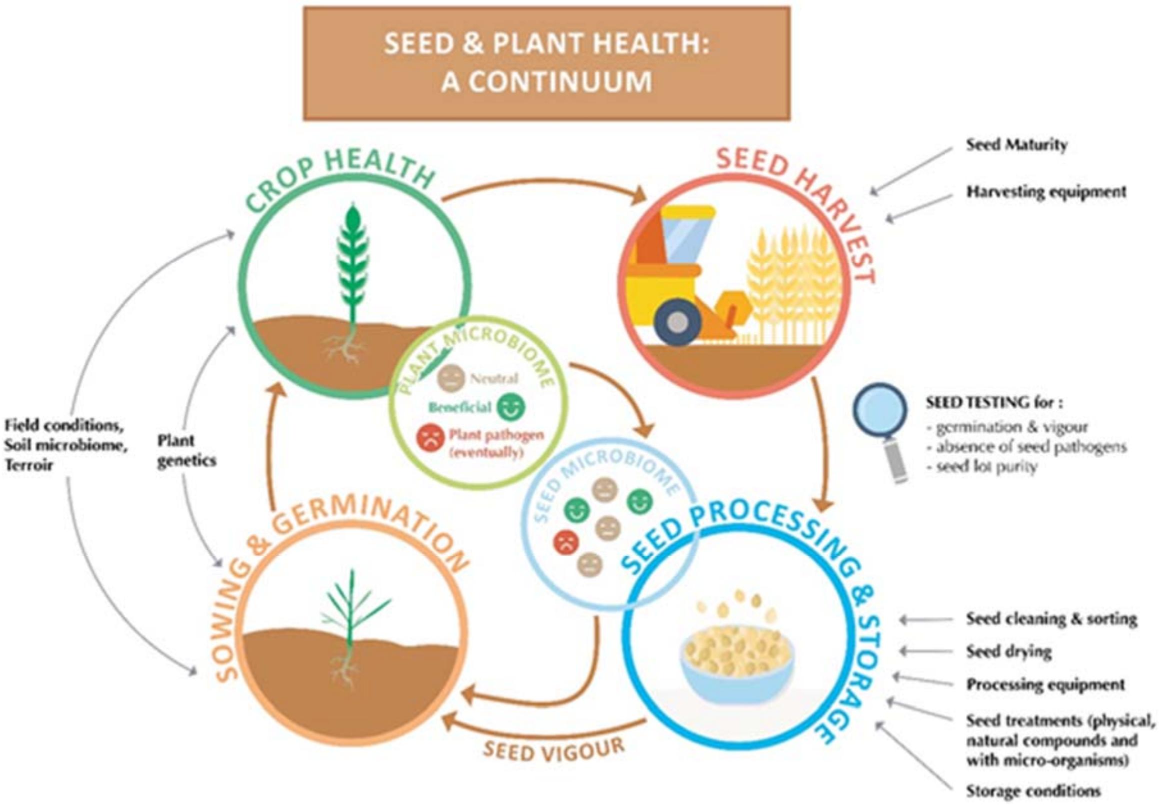
may give an advantage for organic produced seeds. Research into the factors shaping diverse seed or even optimised microbiomes, over the entire process from seed production to storage, would provide a basis for the elaboration of practical recommendations for seed producers and enterprises in order to benefit from microbial life for resilient crops. Integrating these factors into the production of healthy, vigorous seeds, seedlings and crops, will also require a paradigm shift from a point of view that mainly aims at avoiding plant diseases to a perspective of sustaining plant health processes. The dynamic process allowing living organisms to evolve towards health was initially described as *salutogenesis* in the context of human health (Antonovsky, 1996) and taken up by (Döring et al., 2012) in the context of plant health. With this in mind and in the long run, the science concerned with the health of plants may evolve from a stance of plant pathology – focussing on plant diseases – to a stance of *plant salutology* – focussing on health-sustaining processes.



<u>Implications for seed sanitation</u>

When seeds are infected, sanitation treatments may be necessary to control seed-borne pathogens. Organic seeds may be treated with physical methods (e.g. heat, brush cleaning), natural compounds (e.g., vinegar, etheric oils) or biologicals (e.g., *Pseudomonas chlororaphis* strains). It is likely that treatments with some physical methods and natural compounds also reduce a significant part of the seed microbiome. Moreover, physical seed treatments often have negative influences on seed vigour. In the longer run, in terms of seed and plant health strategies, this poses the question of how to articulate the substitution of chemical seed treatments in conventional agriculture, on one hand, and the agroecological transformation of cropping systems towards systems based on microbial life, on the other. Fully basing cropping systems on resilient ecosystem interactions, and a thriving microbial environment in particular, may be in contradiction with seed sanitation treatments aiming at disinfecting seed surfaces. We argue that both strategies may be complementary. Bio-diverse, resilient cropping systems (in combination with sound organic cropping and seed production practices) may strongly reduce the need for "corrective" seed sanitation treatments. The

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latter are expected to remain sometimes necessary, at least as occasional support or safety net, e.g. for the management of common bunt in soft wheat. When such treatments can't be avoided, it might be useful to restore the microbiome by either biopriming or coating the seeds with beneficial microorganisms originating from seed microbiomes.

Implications for plant breeding

To date, considerations for plant and seed health in plant breeding have mainly led to breeding programs for genetic resistance to diseases, providing genetically resistant cultivars to facilitate the control of plant diseases in crops. Recent research with rice has shown that certain microbiomes transmitted by seeds may confer disease tolerance, or even resistance (Matsumoto et al., 2021). Integrating the role of seed-transmitted microbiota and genetic effects on seed vigour into breeding programs may be a way to ensure seed and plant health in the future, as a complement to resistance breeding.

Geographical scale of seed production

In the long run, fully integrating the seed and plant microbiomes in how we produce seeds may also affect recommendations on the geographical scale of seed production. Research with common bean has shown that local environmental factors described as “"terroir” shape the composition of seed microbiomes (Klaedtke et al., 2016). It remains widely unknown how the structure of plant microbial communities varies at different geographical scales and whether or not locally produced seeds provide some advantage in the form of microbial adaptation to local conditions. However, achieving such a level of comprehension of the seed microbiota still requires considerable research both into the factors shaping seed and plant microbiomes and their functional attributes.

Conclusion

We recommend the following strategy for an organic seed health and quality system:

- Integrate the role of the seed microbiome in seed quality aspects.
- Harness the potential of optimised seed microbiomes to aid in the protection of the seedling towards biotic (pathogens) and abiotic (e.g., climate) stresses, going towards more resilient cropping systems.
- Investigate into optimised seed microbiomes and their implications, taking into account local variation and adaptation.
- Investigate the effect of seed production conditions, harvesting, treatments and seed storage.
- Place more emphasis on producing and maintaining high seed vigour to further improve stress resilience of seedlings.
- Study the interactions between crop genetics, the seed microbiome and seed vigour, in particular the role of crop diversity and overall diversity in production systems and incorporate this in breeding programs.
- Train seed producers, seed companies and farmers on the role of the seed microbiome and seed vigour.

References with abstracts for background information

Antonovsky, A. (1996) The salutogenic model as a theory to guide health promotion. Health promotion international. 11, 11-18. https://doi.org/10.1093/heapro/11.1.11

This paper provides a critical look at the challenges facing the field of health promotion. Pointing to the persistence of the disease orientation and the limits of risk factor approaches for conceptualizing and conducting research on health, the salutogenic orientation is presented as a more viable paradigm for health promotion research and practice. The Sense of Coherence framework is offered as a useful theory for taking a salutogenic approach to health research.

Das Gupta, P.R. and Austenson, H.M. (1973) Analysis of Interrelationships among Seedling Vigor, Field Emergence, and Yield in Wheat1. Agron. J. 65, 417-422.

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To evaluate various seed quality criteria, 86 samples of spring wheat (*Triticum aestivum* L. 'Manitou'), obtained from farmers in 1969, were grown in the same year with and without Panogen 15 seed treatment in replicated field trials at three locations in Saskatchewan. Untreated seed samples were grown again in 1970 at one of the locations. Determinations were made in the laboratory of various seed and seedling characteristics supposedly related to seedling vigor. Grain yield was increased significantly due to Panogen 15 treatment by 2.5 and 4.9% at two of the three locations. Seed samples high in 'unaided' vigor as reflected particularly by a modified germination test of untreated seeds, showed little response to the fungicidal treatment. Yield variations between samples were most consistently dependent on standard germination, 02 uptake, and field emergence. It was concluded that the standard germination test could be supplemented with other tests to more reliably assess expected crop performance. The rate of 02 uptake by seed during the 8th and 9th hours of imbibition was found satisfactory. Further research to develop a rapid and efficient method of determining early seedling growth in darkness is recommended.

Döring, T.F., Pautasso, M., Finckh, M.R. and Wolfe, M.S. (2012) Concepts of plant health – reviewing and challenging the foundations of plant protection. Plant Pathology. 61, 1-15. https://doi.org/10.1111/j.1365-3059.2011.02501.x
Plant health is a frequently used but ill-defined term. However, there is an extensive literature on general health definitions and health criteria in human medicine. Taking up ideas from these philosophical debates, concepts of plant health are reviewed and a framework developed to locate these concepts according to their position in several philosophical controversies. In particular, (i) the role of values in defining plant health in a naturalist versus a normativist approach; (ii) negative and positive definitions of plant health; (iii) reductionist versus holistic perspectives; (iv) the focus on functionality versus resilience, i.e. the ability of the plant to perform under stress with or without human interference; (v) materialist versus vitalist approaches; and (vi) biocentric versus anthropocentric views, are surveyed. The ways in which these perspectives relate to mainstream and alternative approaches to plant protection are explored and we suggest how the contradicting views might be reconciled. It is argued that none of these perspectives is without inherent contradictions, but that by combining contrasting approaches it is possible to provide a comprehensive though fuzzy concept. Rather than giving a new definition of plant health, a conceptual framework is developed that suggests what questions may be answered in debates on plant health issues and how such debates could be organized.

Hartmann, M., Frey, B., Mayer, J., Mäder, P. and Widmer, F. (2015) Distinct soil microbial diversity under long-term organic and conventional farming. The ISME journal. 9, 1177-1194. https://doi.org/10.1038/ismej.2014.210
Low-input agricultural systems aim at reducing the use of synthetic fertilizers and pesticides in order to improve sustainable production and ecosystem health. Despite the integral role of the soil microbiome in agricultural production, we still have a limited understanding of the complex response of microbial diversity to organic and conventional farming. Here we report on the structural response of the soil microbiome to more than two decades of different agricultural management in a long-term field experiment using a high-throughput pyrosequencing approach of bacterial and fungal ribosomal markers. Organic farming increased richness, decreased evenness, reduced dispersion and shifted the structure of the soil microbiota when compared with conventionally managed soils under exclusively mineral fertilization. This effect was largely attributed to the use and quality of organic fertilizers, as differences became smaller when conventionally managed soils under an integrated fertilization scheme were examined. The impact of the plant protection regime, characterized by moderate and targeted application of pesticides, was of subordinate importance. Systems not receiving manure harboured a dispersed and functionally versatile community characterized by presumably oligotrophic organisms adapted to nutrient-limited environments. Systems receiving organic fertilizer were characterized by specific microbial guilds known to be involved in degradation of complex organic

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compounds such as manure and compost. The throughput and resolution of the sequencing approach permitted to detect specific structural shifts at the level of individual microbial taxa that harbours a novel potential for managing the soil environment by means of promoting beneficial and suppressing detrimental organisms.

Klaedtke, S., Jacques, M.-A., Raggi, L., Préveaux, A., Bonneau, S., Negri, V., Chable, V. and Barret, M. (2016) Terroir is a key driver of seed-associated microbial assemblages. Environmental Microbiology. 18, 1792-1804. 10.1111/1462-2920.12977
Seeds have evolved in association with diverse microbial assemblages that may influence plant growth and health. However, little is known about the composition of seed-associated microbial assemblages and the ecological processes shaping their structures. In this work, we monitored the relative influence of the host genotypes and terroir on the structure of the seed microbiota through metabarcoding analysis of different microbial assemblages associated to five different bean cultivars harvested in two distinct farms. Overall, few bacterial and fungal operational taxonomic units (OTUs) were conserved across all seed samples. The lack of shared OTUs between samples is explained by a significant effect of the farm site on the structure of microbial assemblage, which explained 12.2% and 39.7% of variance in bacterial and fungal diversity across samples. This site-specific effect is reflected by the significant enrichment of 70 OTUs in Brittany and 88 OTUs in Luxembourg that lead to differences in co-occurrence patterns. In contrast, variance in microbial assemblage structure was not explained by host genotype. Altogether, these results suggest that seed-associated microbial assemblage is determined by niche-based processes and that the terroir is a key driver of these selective forces.

Lupatini, M., Korthals, G.W., de Hollander, M., Janssens, T.K.S. and Kuramae, E.E. (2017) Soil Microbiome Is More Heterogeneous in Organic Than in Conventional Farming System. Frontiers in Microbiology. 7. https://doi.org/10.3389/fmicb.2016.02064
Organic farming system and sustainable management of soil pathogens aim at reducing the use of agricultural chemicals in order to improve ecosystem health. Despite the essential role of microbial communities in agro-ecosystems, we still have limited understanding of the complex response of microbial diversity and composition to organic and conventional farming systems and to alternative methods for controlling plant pathogens. In this study we assessed the microbial community structure, diversity and richness using 16S rRNA gene next generation sequences and report that conventional and organic farming systems had major influence on soil microbial diversity and community composition while the effects of the soil health treatments (sustainable alternatives for chemical control) in both farming systems were of smaller magnitude. Organically managed system increased taxonomic and phylogenetic richness, diversity and heterogeneity of the soil microbiota when compared with conventional farming system. The composition of microbial communities, but not the diversity nor heterogeneity, were altered by soil health treatments. Soil health treatments exhibited an overrepresentation of specific microbial taxa which are known to be involved in soil suppressiveness to pathogens (plant-parasitic nematodes and soil-borne fungi). Our results provide a comprehensive survey on the response of microbial communities to different agricultural systems and to soil treatments for controlling plant pathogens and give novel insights to improve the sustainability of agro-ecosystems by means of beneficial microorganisms.

Matsumoto, H., Fan, X., Wang, Y., Kusstatscher, P., Duan, J., Wu, S., Chen, S., Qiao, K., Wang, Y., Ma, B., Zhu, G., Hashidoko, Y., Berg, G., Cernava, T. and Wang, M. (2021) Bacterial seed endophyte shapes disease resistance in rice. Nature Plants. 7, 60-72. https://doi.org/10.1038/s41477-020-00826-5
Cereal crop production is severely affected by seed-borne bacterial diseases across the world. Locally occurring disease resistance in various crops remains elusive. Here, we have observed that rice plants of the same cultivar can be differentiated into disease-resistant and susceptible phenotypes under the same pathogen pressure. Following the identification of a seed-endophytic bacterium as the

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resistance-conferring agent, integration of high-throughput data, gene mutagenesis and molecular interaction assays facilitated the discovery of the underlying mode of action. Sphingomonas melonis that is accumulated and transmitted across generations in disease-resistant rice seeds confers resistance to disease-susceptible phenotypes by producing anthranilic acid. Without affecting cell growth, anthranilic acid interferes with the sigma factor RpoS of the seed-borne pathogen Burkholderia plantarii, probably leading to impairment of upstream cascades that are required for virulence factor biosynthesis. The overall findings highlight the hidden role of seed endophytes in the phytopathology paradigm of 'disease triangles', which encompass the plant, pathogens and environmental conditions. These insights are potentially exploitable for modern crop cultivation threatened by globally widespread bacterial diseases.

Nelson, E.B., Simoneau, P., Barret, M., Mitter, B. and Compant, S. (2018) Editorial special issue: the soil, the seed, the microbes and the plant. Plant and Soil. 422, 1-5. https://doi.org/10.1007/s11104-018-3576-y

Despite many decades of little interest and research attention, the microbiota of seeds is now developing into a major focus area for the exploration and understanding of plant microbiomes and beneficial plant-microbial interactions. Seeds, like no other plant organ, provide insights into the origin of plant microbiota, but also how the interactions of seed-associated microbes may be utilized to improve plant growth. This Special Issue focusing on soil, seeds, plant and microorganisms has highlighted important advances in understanding the complex plant-seed-soil-microbe interface. While important foundational data on microbial taxa, their putative functions and interactions with other plant parts and the soil are discussed. This Special Issue also points the way for additional studies to gain a more comprehensive knowledge and understanding of the ecology of seed microbiota. Presently, our knowledge of the ecology of seed microbiota lacks far behind our understanding of the rhizosphere and phyllosphere microbiota. And while the work highlighted in this Special Issue represents only the beginning of what may be a fruitful path forward in understanding the origin of seed microbiota, the routes and modes of seed colonizing, the sites of establishment within seeds, and the function of these microbes in plant and soil habitats, we can expect great advances in coming years. Many questions remain. For example, what factors determine efficient seed colonization by microorganisms and the successful establishment of populations in and on seeds? As with the rhizosphere and phyllosphere, does the plant physiotype shape the composition of microbial seed assemblages? Are seed microbiota different between plant families? What are the factors that allow microbes to persist in dormant seeds? What are the functional traits necessary for microbes to be able to invade and establish in plant seeds? Very often dormancy in seeds is concomitant with extreme drying begging the question of whether microbes require some level of desiccation tolerance to survive during seed dormancy. Some pioneer studies are indeed pointing to the capacity of some microorganisms to cope with stress conditions likely accompanying the seed maturation process as an essential component of efficient seed colonization (Pochon et al. 2012, 2013). What role do seed microbiota play in the assembly of the plant microbiota? Because the seed microbiota represent the initial microbial colonizers of emerging seedlings before they recruit microbes from the surrounding environment (rhizosphere or phyllosphere), the seed microbiota might play important roles in the assembly and function of the plant microbiome. While these and many other questions remain to be answered, the research highlighted in this Special Issue suggests that the future is bright for this emerging and productive area of inquiry.

Wassermann, B., Cernava, T., Müller, H., Berg, C. and Berg, G. (2019) Seeds of native alpine plants host unique microbial communities embedded in cross-kingdom networks. Microbiome. 7. https://doi.org/10.1186/s40168-019-0723-5

Background: The plant microbiota is crucial for plant health and growth. Recently, vertical transmission of a beneficial core microbiota was identified for crop seeds, but for native plants,

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complementary mechanisms are almost completely unknown. Methods: We studied the seeds of eight native plant species growing together for centuries under the same environmental conditions in Alpine meadows (Austria) by qPCR, FISH-CLSM, and amplicon sequencing targeting bacteria, archaea, and fungi. Results: Bacteria and fungi were determined with approx. 1010 gene copy numbers g-1 seed as abundant inhabitants. Archaea, which were newly discovered as seed endophytes, are less and represent only 1.1% of the signatures. The seed microbiome was highly diversified, and all seeds showed a species-specific, highly unique microbial signature, sharing an exceptionally small core microbiome. The plant genotype (species) was clearly identified as the main driver, while different life cycles (annual/perennial) had less impact on the microbiota composition, and fruit morphology (capsule/achene) had no significant impact. A network analysis revealed significant co-occurrence patterns for bacteria and archaea, contrasting with an independent fungal network that was dominated by mutual exclusions. Conclusions: These novel insights into the native seed microbiome contribute to a deeper understanding of seed microbial diversity and phytopathological processes for plant health, and beyond that for ecosystem plasticity and diversification within plant-specific microbiota.

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