Boosting innovation in breeding for the next generation of legume crops for Europe

Plan for boosting the breeding of lentil

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Legume Generation Report 4

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Legume Generation

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Contents

Our goal and who we are

Our goal is the improvement of lentil (*Lens culinaris* Medik.), which was considered a neglected crop in Europe. However, lentil is increasingly promoted as healthy and affordable protein sources, rich in vitamins, minerals and fiber, free of fat or cholesterol, and especially suitable for low input and organic agriculture systems. Consumption in Europe is expected to increase with the demand currently met mostly by imports. Lentil is one of the most important pulse crops worldwide due to its nutritional characteristics but there is little investment in breeding in Europe.

Our project is structured and focused to directly support our breeding partners and associates as risk-taking innovators. A core principle is plant breeding as a species-specific entrepreneurial activity. Boosting it should be a species-specific effort. Consequently, our innovation community (IC) links practical breeding with the supporting research-base in a transdisciplinary platform. This operational framework enables us to harness the relevant science base provided by six cross-cutting science-support activities. We innovate up to the point where newly-bred germplasm and tools are demonstrated on farm at technology readiness level 7. How the innovation community is supported in Legume Generation is illustrated in Figure *2*.

In Europe, lentil has not been subject to broadly adapted breeding. As a result, the increase in lentil production and its related expansion in different European crop lands to meet growing demand is hindered by the limited number of available cultivars that are well-adapted to different agro-environments and farmers' needs. Recently, several pre-breeding efforts have been conducted for phenotypic and genotypic characterisation of lentil genetic resources in European environments. As far as we know, there is not a close connection between lentil research and breeders in Europe. The purpose of the Lentil Innovation Community is to make the missing connections.

The Lentil Innovation Community

It is important to expand the knowledge of consumers about lentil health benefits, since consumers shape demand. Also, there is interest to launch new products such as crisps and chips, or breakfast products containing lentil flour. Lentils are used to enhance the protein and fibre content in meat-free, ready-made products. So, it would be interesting to investigate the factors that constrain the expansion of lentil cultivation in Europe. The global market and world are changing, and it seems that there is a good potential for lentil in Europe.

The members of the Lentil Innovation Community are listed in Table *1*. The IC is led by the IHU in Greece which has long term experience in agronomic evaluation and works with lentil from previous breeding programmes. We have two partners in Italy (UNIVPM in molecular genetics) and (UNIBAS in field phenotyping) with previous work in lentil who bring in knowledge from the INCREASE project and one partner in Germany (KEY) which works already with several lentil accessions in related breeding schemes, focusing on organic agriculture and cold tolerance. One partner (LIDEA) in France is working with lentil breeding for conventional production. LIDEA will phenotype available lentil accessions in France. ESKUSA in Germany is a breeding company working extensively with legumes

(lupin) and provide an environment for lentil field evaluation on the central/north Europe. IPK will provide field evaluation of the available accessions and RU will investigate in detail the heat/drought resistance using innovative techniques. Three partners will do field phenotyping (IHU in Greece, UNIBAS in Italy and LIDEA in France) representing the southern area and three partners will do field phenotyping in Grmany (KEY, IPK and ESKUSA) representing the central/northern area. Since drought is an important limiting factor affecting yield, we will study drought responses under controlled conditions in detail under the guidance of RU in the Netherlands. KEY and IPK in other programmes are investigating cold tolerance so there is a possibility for further interactions regarding this characteristic and IHU will test disease tolerance under controlled conditions based on the evaluations from LIDEA, IPK, KEY and ESKUSA (areas with high humidity).

Table 1. Members of the Lentil Innovation Community

First name	Second name	Role	Organisation
Ulrike	Lohwasser	Researcher; genebank manager	IPK
Elizabeth	Ninou	Researcher	IHU
Donal	Murphy-Bokern	Policy specialist; research director	DMB
Patrice	Jeanson	Private-sector plant breeder	LIDEA
Elodie	Petit	Private-sector plant breeder	LIDEA
Ivo	Rieu	Researcher	RU
Eric	Visser	Researcher	RU
Amelie	Detterbeck	Private seed sector association	EURS
Lars-Gernot	Otto	Researcher	IPK
Jasmin	Karer	Network	DS
Anastasia	Giannakoula	Researcher	IHU
Stefanos	Stefanou	Researcher	IHU
Fred	Eickmeyer	Private-sector plant breeder	ESKUSA
Ioannis (John)	Mylonas	Researcher	IHU
Stamatis	Aggelopoulos	Researcher	IHU
Tania	Gioia	Researcher	UNIBAS
Roberto	Papa	Researcher	UNIVPM
Udo	Hennenkämper	Plant breeder, non-profit association	KEY
Philipp	Schober	Plant breeder, non-profit association	KEY

Our breeding and pre-breeding programmes are summarised in Table *2*. Work to support these is reported in Table *3*.

Table 2. Number and description of pre-breeding and breeding programmes operated by the lentil IC members

Partner	Pre-breeding	Breeding	Description
IHU	1	1	Use of SSD method to produce germplasm and new varieties from land races
KEY	1	1	Breeding for cold resistance and high yield, organic cultivation Production of SSD lines
UNIBAS	1		Production of SSD lines with high homozygosity levels
UNIVPM	1		The development of composite cross populations

Table 3. Summary of partners' activities that support pre-breeding and breeding

Partner	Description
IHU	The evaluation of plant genetic resources in local landraces. Focus on yield, environmental adaptation and seeds quality (NIR use under development). Development of pure lines with high homozygosity for high-yield or high protein
IPK	WiLGer - Winter Lentil Genetic Resources to breed winter lentils for mixed cropping. Testing different sowing time of lentils in Germany. Sowing time is autumn (October/November) which is not common in Germany. Normally it is March.
KEY	WiLGeR (winter lentil genetic resources) funded by the protein initiative of the German Ministry of Agriculture for the improvement to cold tolerance and yield
UNIBAS	Activities to support the effective use of plant genetic resources in lentil. We run several pre-breeding activities with the focus on genomic and phenotypic characterization of germplasm in Mediterranean environments, including especially locally adapted genotypes
UNIVPM	Within INCREASE, the identification and application of effective strategies for conservation and characterization of germplasm resources. These include the molecular characterisation and high-quality sequencing of genomes. The generation of molecular data for hundreds of lentil accessions, in particular for more than 400 SSD lines, that are part of the T-core collection. Characterization of those lines, from the metabolic profile to the phenotypic characterization in multi-location field trials. Combination of phenotypes and genotypic data enabled GWAS and identify molecular markers, that are effective tools to be used in marker assisted selection and genomic prediction/selection, to be further validated. In INCREASE, the establishment of a novel CRISPR-Cas9-based repeat depletion technique for high-throughput genotyping of complex plant genomes that can be employed for sequencing of large genomes, such as that of lentil, with positive implication in the breeding of the species (DOI: 10.1101/gr.277628.122). We are also developing a lentil pangenome. Investigation of the phenotypic and molecular diversity of a landrace population of lentil (Lenticchia di Castelluccio), that is highly adapted to higher altitude and specifically to the area of Castelluccio (Umbria region, Italy). Tested of local landraces and genotypes of interest in different environments, collecting relevant agronomical and nutritional information over the years. Experiments on intercropping between lentil genotypes and cereals (wheat) to investigate the effect of intercropping and to identify interesting genotypes that are suitable for this agronomical practice. We have assembled mixtures of different pure lines of lentil that can be used as a tool in pre-breeding and breeding (e.g., identification of interesting genotypes and markers, and marker validation).

Breeding targets

Lentil is an internationally traded commodity. It is also a traditional crop supporting the productivity in local communities. Europe is a net importer, mostly from Canada where it grows relatively well in the short summers. If lentil production is to expand in Europe, the crop must become more competitive on-farm with the other crops that farmers grow, especially cereals. It is important to address farmers' needs for high productivity and quality.

Lentil is cultivated as a spring-sown crop in northern Europe, and as a winter crop in the south. This means that we have to investigate the capacity of our available germplasm to capture resources and the connection with seed yield in very different cultivation period conditions.

Across Europe, there is interest in new cultivars that could better perform in the field and in improvements that brings new products, new process or food with improved quality. Also, since lentils are suitable for low-input agricultural systems another target is better competition against weeds and improved phosphorus uptake. The delivery of breeding lines that are suitable for conditions in organic farming is also important. The recorded characteristics will be based on a common descriptors list. Time from sowing to anthesis and from anthesis to maturity are important. Plant biomass at the beginning of anthesis will be used as an indicator of total photosynthesis, since possibly higher plant biomass in the vegetative stage often is connected to higher seed yield. Another important parameter for lentil consumption is seed quality, since lentils are used for human consumption in its cooked form.

Northern/central Europe: Crops in northern Europe are challenged by wet weather in summer that cause pods rotting, lodging and diseases. Farmers and seed markets need high stable yield performance from new disease tolerant varieties that grow in wet and 'cool' conditions during flowering time. KEY underlines the need for lentil production under organic farming management systems with high weed pressure and low phosphorous conditions.–In agricultural practice, companion crops like oat, barley or camelina are used at a low density (30-50% plants/m^2) and similar maturity type. In France other agricultural practices use wheat as intercrop at a density[1] 50 plants/m^2.

Drought and heat stress may increasingly affect lentil crop even in northern Europe. Also, probably it would be of great value to investigate the winter hardiness of lentil to extend the cultivation period (KEY, IPK working with this issue in other projects). Also, there is an interest in organic cultivation of lentil. From this, priorities for breeding for northern Europe include: seed yield, stability against lodging, homogenous ripening, seed health, cold tolerance and disease resistance. Increasing the winter-hardiness of lentil so that it can be sown in the autumn in northern Europe is also a target.

Southern Europe: The lentil crop is a winter crop and cultivated as monoculture, drought and heat stress may severely affect yield, early flowering and maturity could provide better adaptability. Pod shattering and lack of uniform maturity are some other problems that the crop may face. Recently, in south Europe there were conditions of high temperature and drought during anthesis that cause severe flower and new pod development abscission and

[1] https://www.remix-intercrops.eu/content/download/4091/38985?version=1

eventually yield losses. Arising from these, priorities for breeding include seed yield, stability, homogenous ripening, drought and/or heat tolerance, disease resistance, earliness, seed health.

Our approaches to the genetic improvement

The steps in our plan to boost the breeding of lentil are as follows:

1. Initial screening of germplasm.
2. The development of lines using single seed descent.
3. Genomic prediction.
4. The production of composite crosses.
5. Lentil field testing and demonstration.

Initial screening of germplasm

The cornerstone of our strategy is the exploition of the available genetic variability to support breeding. This is based on the evaluation of individual plants selected from within accessions. This identifies germplasm that has good characteristics to be developed into new cultivars.

Building on results from INCREASE, AGILE, LinSel, LentilBreed and on new genetic resources, we will evaluate a selected panel of the most promising populations (including landraces and accessions, advanced lines) at seven sites in Italy, Greece, France, Germany. The most prominent cultivars currently on the market will be also tested for comparison.

We start with gene bank accessions to include as much diversity as possible to exploit for the evaluation and for the introgression of our target traits. We use genetic resources (landraces and accessions, advanced lines), which have been conserved under ideal conditions *ex situ* (IPK, ICARDA). We will evaluate them in field for 2 years in different environments (Greece (IHU), Italy (UNIBAS), France (LIDEA), Germany (KEY, IPK), where feasible. KEY is active in breeding for organic farming, so germplasm from previous work locally evaluated is included. Our target is to identify germplasm with adaptability to the environments and evaluate its potential value to farmers and markets. We will record important characteristics that are relevant to the productivity, yield, quality and adaptability such as time of anthesis, height, lodging resistance, disease resistance, seed and cotyledon colour, using a common descriptor list. At this stage we included some cultivars only as common reference, the only purpose is to provide information to support stastical analysis of the data from across the envionments.

This will give us information about which landraces and other accessions have potential value for the different environments across Europe as a source for valuable genetic variability in the next steps.

IHU, LIDEA and KEY will carry out tests in rows to check for relevant characters. The promising genetic materials will be screened in plots for adaptation, productivity and seed quality in different environments in southern Europe (IHU, UP, UNIBAS, LIDEA) and in

northern Europe (ESKUSA, Keyserlingk). Our breeders will use this pre-breeding material and breeding lines in their selection and crossing schemes.

It is very likely that germplasm that yields well in the central/north areas (LIDEA, KEY, ESKUSA, IPK) will include useful diversity for possible disease resistance, while germplasm with good productivity in the south (IHU, UNIBAS) will have useful diversity for drought tolerance. As a result, it is possible that the SSD lines derived from the above mentioned sources will include genetic background to cope succsefully the above mentioned problems. This will be investigated in detail with experiments under controlled conditions.

The development of lines using single seed desent (SSD)

Based on information from previous projects (Linsel, where some of the IPK accessions evaluated under other conditions in previous work) and the results of the screening work described above, we will select around 100 seeds within the best performing accessions and sow them in field trials for 3 years as individial plants (IHU), based on the experience gained in LentiBreed project. IHU will start with selection using spaced plant trials and continue with selection within the best identified accessions resulting from the pan European tested resources. The selected high productive plants will produce progeny families with SSD lines after 3 years of selection and reproduction (selfing). At the end of the project, this will provide SSD lines with a high homozygosity level/pure lines with high productivity and good characteristics.

It is expected that we will provide landrace-derived breeding lines (SSD lines with high homozygosity) with upgraded productivity or good quality characters that are competitive to the commercial tester. These will be used as parents in targeted crosses (IHU) and good lines for further multiplication.

Genomic prediction

UNIVPM provides a genomic prediction tool to predict the combination ability between lines having genetic distance. This will identify among the high-productive lines those with high genetic distance to combine them in targeted crosses.

UNIBAS and UNIVPM have information and SSD lines from INCREASE, AGILE and LinSel projects with known genotypic and phenotypic profiles. UNIVPM is leading this part of work in connection to the composite crosses and the pre-breeding and breeding activities carried out by UNIVPM are currently involved in the development of composite cross population.

The production of composite crosses

A composite cross population (CCP) is developed by crossing plants from different lines with each other and then pooling the seeds from their offspring. This results in a genetically diverse plant population. This segregating population is sown and resown in different environments leading to the evolution of what might be called 'modern landraces'. This approach to plant breeding is particularly relevant to organic farming and the evolutionary phase requires the partipation of growers.

UNIVPM will develop a composite cross population from high yielding lines to combine genes that contribute to productivity. The resulting population will reach the F2:3

generation by the end of the project, and depending on the availablity seeds this will be delivered for trials where participatory breeding will be applied where feasible (Italy, Germany or Greece).

Lentil field testing and demonstration

Depending on the available seeds, the performance and the seed multiplication rate, the promising genetic materials (20-40) will be screened in plots for adaptation, productivity and seed quality in different environments in southern Europe (IHU, UNIBAS) and in northern Europe (ESKUSA, KEY, LIDEA), in 2026 and 2027. We will evaluate the target-traits in a panel of the most promising lines (including landraces and accessions, advanced lines) in Italy (UNIBAS), Greece (IHU), France (LIDEA), Germany (KEY, ESKUSA) in comparison with commercial cultivars as common testers, over two years.

Finally, a seed quantity from at least ~5-8 elite SSD lines will be available for further multiplication and evaluation. In the 5-7 elite 2 SSD lines will be included also 2-3 lines for biological cultivation covering the gap that exist in cultivars for biological cultivation. KEY also develops SSD lines in the greenhouse from single plant selection on the field.

We will also use a participatory approach where feasible (KEY, UNIVPM, IHU), including SSD lines and F2:3 composite crossings for further evaluation in their selection and crossing programmes.

We will also evaluate most of the promising materials (2-3 selected genotypes) in intercropping with a companion crop in Germany (KEY), Italy (UNIVPM) and in rotation systems comparing a 3-year wheat monoculture with wheat-lentil-wheat in Greece (IHU) to test the effect of intercropping on productivity of land (monocrops vs intercrops).

The work schedule is summarised as follows:

2025:
- Increase our understanding of the germplasm, identifying useful variability in both productive and quality traits.
- Produce and share an initial set of single seed descent (SSD) lines for further screening the following year, depending on the seed availability.
- Continue efforts to develop composite crosses.

2026:
- Enhance our knowledge regarding drought and heat resistance, if possible some important diseases
- Continue the second cycle of selection, focusing on high-yielding genotypes on an individual plant basis and increasing seed production of SSD lines
- Results of the screening activities
- Make further progress with the crossing population.

2027:
- Proceed with the third cycle of individual plant-based selection to identify high-yielding genotypes and further increase seed quantities.

- Maintain screening activities and, if necessary, incorporate additional lines.
- Make further progress with the crossing population,

Field trials

Locations

Experimental locations for the 2024 season are representing areas in the south and central/north Europe covering important growing regions of Europe including France, Germany, Greece and Italy, (see Figure 1).

Figure 1. Locations for field-testing lentil.

Seed distribution, logistics and documentation

The seed distribution was initially arranged with a simple exchange of emails and written communication with the available lists of germplasm resources and the specific codes needed. The main germplasm resource is IPK, also IHU contacted ICARDA to include several accessions from different areas. For the documentation of seed sources and seed exchange, a standard Material Transfer Agreement (SMTA) was signed by partners between IPK and the respective partners and ICARDA and IHU. Seed is then sent by mail to the experimenters' mail address. For documentation of seed sources and seed exchange, a standard Material Transfer Agreement (SMTA) will be issued and signed by partners at a later stage, for few seed exchanges within the other partners of lentil IC.

The procedure for lentil seed exchange has been set up and mainly regulated from IPK as the central seed sample provider, all participants of lentil experiments have received experimental seed on time for Year 1 (2023-2024). For Year 2 (2024-2025), IPK provided also a common set of studied accessions to UB and all the partners exchanged seeds of commercial cultivars. For the year 2025 and further experiments, seed harvested in 2024 can be used in each location.

Supporting experimentation

Data management

Under the guidance of the Earlham Institute (EI), we will provide a common list of characteristics for all the sites, and we will record the data which will be available in the knowledge management centre. We exchange data within the lentil IC for processing to be able to take decisions on the trials for the following years, the data will be processed to be able to design the next steps within the project, but we will publish publicly processed data after our common agreement within the lentil IC (=if it is necessary to present some results we will decide altogether if, when and which results we will present)

Drought and heat resistance

Radboud University (RU, Netherlands), will evaluate the drought and heat resistance of the best genotypes to ensure/confirm these attributes based on important physiological parameters. In parallel, we will use NDVI parameters and spectral reflectance for biomass evaluation (IHU), and apply of the breeding scheme based on individual plant.[2] UNIVPM may use these results, if possible, for further validaton of the molecular tool have already developed UNIVPM is currently processing the results from the INCREASE project.)

Disease resistance

Evaluation of lentil accessions in high-humidity environments can reveal valuable genetic variability related to disease resistance. IHU will attempt to conduct targeted, small-scale screening under controlled conditions where artificial inoculation will take place to identify promising genotypes. We will focus on important diseae according to the inoculum availability (e.g. Ascochyta).

Supporting innovation and exploitation

Training

We propose training activities on:

1. The value of lentil biodiversity for plant breeding in cases where commercial agricultural is practised (registered cultivars used) or local agricultural communities are supported (e.g. local landraces, PDO, PGI products).
2. Practical phenotyping for lentils (CPVO protocols, protein measurements).

[2] Ninou E, Papathanasiou F, Vlachostergios DN, Mylonas I, Kargiotidou A, Pankou C, Papadopoulos I, Sinapidou E, Tokatlidis I. Intense Breeding within Lentil Landraces for High-Yielding Pure Lines Sustained the Seed Quality Characteristics. Agriculture. 2019; 9(8):175. https://doi.org/10.3390/agriculture9080175

3. The use of digital farming tool or indices to evaluate plant biomass (e.g. NDVI)

Governance and policy

The Lentil IC will serve as a platform and bring together key stakeholders (breeders, farmers, scientists, policymakers, and industry representatives) to facilitate the easy exchange of information related to the needs from better varieties, the new challenges, and more effective solutions.

We propose the following case studies:

1. Case study about the different lentil types cultivated in Europe, connected with consumers preferences, the current status of the lenit registered cultivars and their future potential. .
2. Case study about what are the most suitable areas for lentil crop cultivation in Europe and the connected cultivars, where relevant: a) local communities with traditionally cultivated lentils (possible connection with PDO, PGI products), b) areas in the plain where drought maybe is a limiting factor (e.g., in South Europe), c) areas in north/central Europe with possible disease resistance.

Finance and business planning

The development of a new variety demands a long-term cycle of trials and investment of innovation (8-10 years). The lentil IC serves as a platform to provide support to the breeders. The production and supply of uniform high-yielding lentil varieties from seed companies to farmers is the basis of good quality lentil crop production. In general, lentil is a low input crop even cultivated under conventional agricultural production systems or an organic one. An important expected outcome from our breeding programmes will be pure lines produced by selfing having a high level of homozygosity with well-known characteristics and very well description across different environments. These can be used as parents to an elite breeding program. Also, early F3 generations of crosses of target crosses can then be further evaluated by the breeders in the target areas.

To capitalise on the market opportunities in lentils and ensure sustainability of the lentil IC, we can take several strategic steps in connection to:

1. **High-yield cultivars:** The availability of high-yielding cultivars of lentils is beneficial for EU farmers and consumers due to the need to cover the demand for lentils. This is currently covered by imports due to the scarcity of available farmland and the lentil's low yield. Farmers can also gain benefit from the reduction in production cost per unit due to higher yield per unit land area.

2. **Organic market:** In Europe, a consumer trend is recorded with a higher rising awareness regarding health and wellbeing, high prices for organic lentils can often be offered. This is related to the availability of lentil cultivars adapted to organic cultivation systems. The European Commission (EC) has set an ambitious goal of converting a minimum of 25% of the European Union's agricultural land to organic farming by 2030.

3. **High-protein lentils:** The availability of high-protein cultivars is beneficial to EU farmers and consumers because there is increasing interest in the availability of plant-

based protein, which elevates lentils to the status of superfood in the market. Health-conscious consumers, vegetarians, and the food-processing industry are looking for protein-rich supplements and plant protein alternatives.

4. **Opportunities in the food sector:** Building relationships with food processors to create lentil protein flour, lentil snacks, or meat substitutes. This will open new market opportunities and increase the demand for lentils.

Dissemination, exploitation and communication

Dissemination

We have to share the data within the Lentil IC. This is necessary to organise the work within the lentil IC. In case there is a need to present publicly some of the processed data, we will decide together if, where, when and which results we can publish.

Our dissemination activities will include presentations of project results to scientists at national and international conferences and at the organisation of different other occasions at lentil IC partners' locations (open field days). KEY has carried out an open field day for farmes.

The expected results can be classified as a) plant material, and b) data and tools to accelerate the breeding programmes. The main dissemination route is within the innovation community itself – between our members.

Table 4. The specific results (outputs) and their dissemination

Expected results (tangible outputs)	Users	Dissemination plan
Information on the agronomic characterisation and peerformance of existing lines in different environments	For breeding: LIDEA, KEY. For prebreeding and academic use: IHU and UNIBAS	All results and germplasm will be freely shared between the partrners.
Single seed descent lines	For breeding: LIDEA, KEY.	The SSD-generated germplasm will be freely available within the IC
Seed from composite crosses	For breeding: LIDEA, KEY. For prebreeding and academic use: IHU and UNIBAS	All results and germplasm will be freely shared between the partrners. KEY will take the compositee cross populations and multiply them in different environments.
Information from genomics		

Exploitation

LIDEA and Keyserlingk (KEY) will utilise project results (phenotyping, genotyping results) for selection of crossing parents and advanced breeding lines. They can use the information related to the recorded data of many accessions. The final outcome will be lentil lines grown on farmer fields with improved agronomic and product quality features and are well studied and have the potential to compete with other crops in yield and harvest product value.

KEY already has partners in the organic sector with special interest in new breeding lines. Rebio (producer organisation from around 60 farmers) seeks lentils with good dehulling

properties. Rapunzel (organic food retailer) already works with a Beluga-type lentil from KEY. Lauteracher Albfeldfrüchte (biggest producer of lentils in Germany) were the first partner in 14 years of breeding efforts at the Keyserlingk-Institut. AGRI-CPS is a dehulling specialist in northern France with a selection programme for lentils. In the last four years, there was an intense exchange of accessions, data and experiences. KEY has personal contact to the seed companies Südwestsaat and Biosaat. Further multiplication and seed trade could be done by them.

Sustainability plan for the Lentil Innovation Community

The Lentil Innovation Community operates in lentil supply through innovation in breeding, in other words, it aspires to contribute to the secure production and sustain of health and to good characteristics propagation material of lentil. Seed is the basis for a good crop, but in Europe there is little investment in lentil breeding for the development of new varieties.

Lentil IC could be transformed into an ecosystem to contribute to lentil crop production resilience around the related market lentil crop (release of new varieties-seed companies-lentil producers (lentil)-consumers or industry.

1. **Lentil IC diversification**: Some members of lentil IC are already members of the EVA network (ECPGR) to continue to evaluate lentil biodiversity for its value across Europe. Other possible benefits for the universities (e.g. IHU, UNIBAS, UNIVPM) direct information for the market needs in lentil varieties characteristics, targeted employability (better educated students to meet the market need, using also the Erasmus+ network for practices). Possible benefits for the private sector (e.g. LIDEA, KEY): application in market needs to re-feed experimental activities, knowledge transfer from the universities, access to a pool of well-educated students. Following market needs, KEY is member of The European Consortium for Organic Plant Breeding (ECO-PB) and willing to share results and accessions with other breeders in the organic sector.

2. **Seed multiplication**: Generate revenues from sale of improved seeds in case a registered cultivar will derive (if we will produce a product).

3. **Infrastructure**: Maintain a network of field trials in representative agricultural systems and conditions in Europe for lentil crops, for future breeding programes and evaluations, using the facilities of public and private sector for seed testing.

4. **Knowledge sharing:** Sustain the lentil IC platform of shared knowledge, including research findings, cultivation practices, and market trends. Develop digital platforms for remote collaboration and data sharing through the Legume Generation project (or/and Legume Hub).

The global situation is changing due to climate change but also international relationships, so the good collaboration between private – public sector will enhance the ability of the 'system' to identify 'early-warnings'/'signals' from the situation in the market transfer to the public sector the new challenges and new needs receive solutions or integrated new knowledge and to be able to adapt quickly to new conditions (climatic or socio-economic conditions).

Governance: Setting up a committee that will bring together key stakeholders (breeders, farmers, scientists, policymakers, and industry representatives) and easy exchange of information (new challenges, more effective solutions, better adaptability)

Networking: Encourage interaction among researchers, farmers, and market players for the required continuous feedback and innovation, participation in meetings, workshops, and webinars to share knowledge.

Collaborative breeding: Develop a platform for partners to collaboratively select and enhance lentil cultivars for region-specific adaptability.

Extension services: Offer technical advice, provide support to seed companies for decision making, provide training and resources for farmers for the adoption of improved cultivars and practices. Collaboration with institutions/organisations for local anchoring of the IC in the long term.

The sustainability of the lentil IC will depend on a collaborative ecosystem where all the stakeholders will share resources, expertise, and responsibilities. The financial models need to be aligned with community benefits, and the partnerships must be strong, so that the IC can remain impactful long after the project has ended**.**

Communication

Our outreach ambassadors will monitor developments in the regions, identify communication opportunities and supply content material for the project website and the Legume Hub. Through these and social media (LinkedIn and X), we ensure timely spread communication and information to the different audience groups.

Our ambassadors representing following areas:

Udo Hennenkaemper	(KEY, Germany)
Elizabeth Ninou	(IHU, Greece)
Ioannis Mylonas	(IHU, Greece)
Tania Gioia	(UB, Italy)

Our sites will be used to demonstrate the work of the lentil IC to local regional stakeholders.

Legume Hub

The Legume Hub is Europe's open-access knowledge platform on legumes that guarantees a permanent availability of the project outputs. The Hub serves as the main communication channel for reporting scientific results (academic or other publications) for the lentil IC and all project outputs.

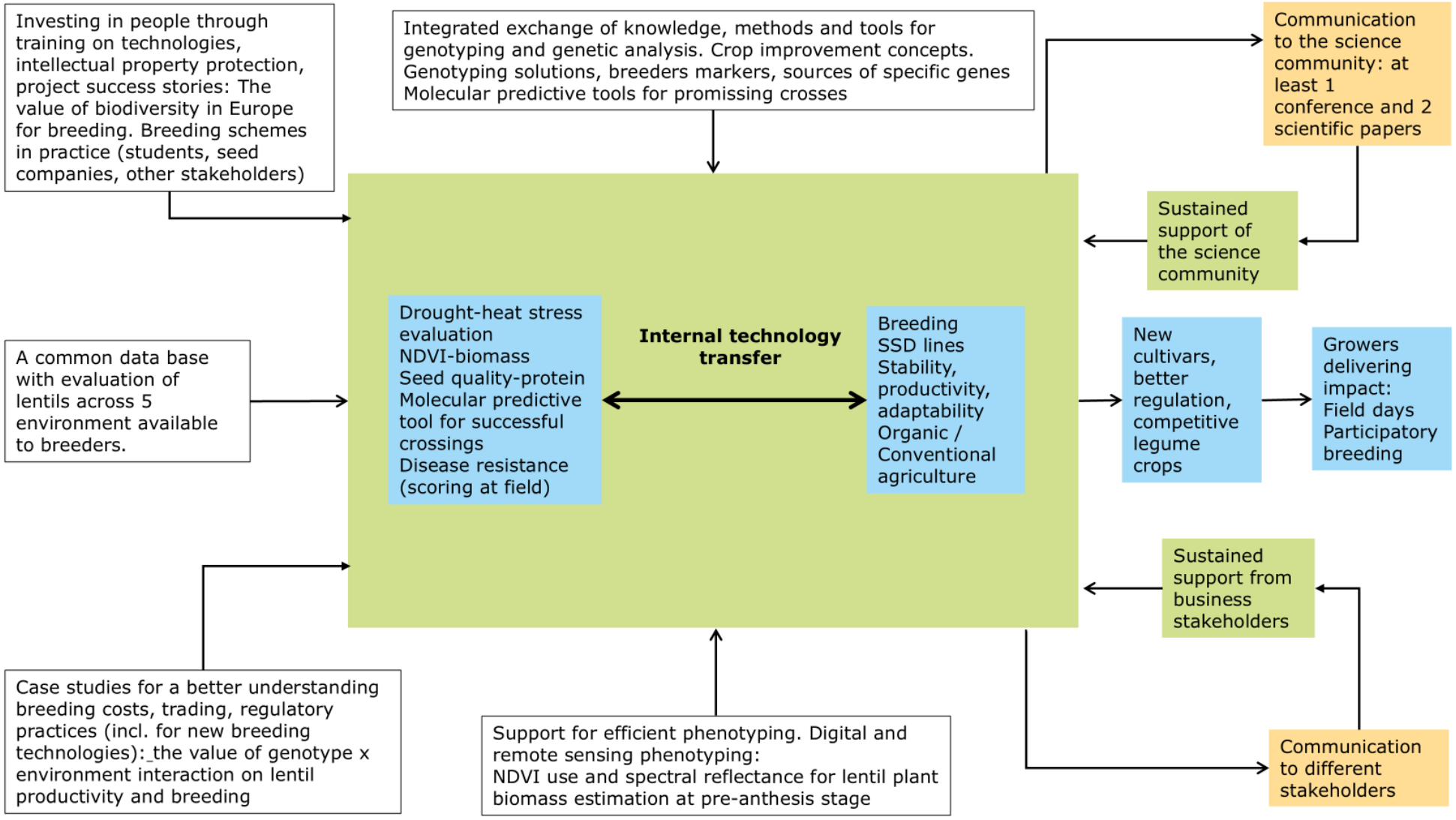

Figure 2. How the Lentil Innovation Community is supported in Legume Generation

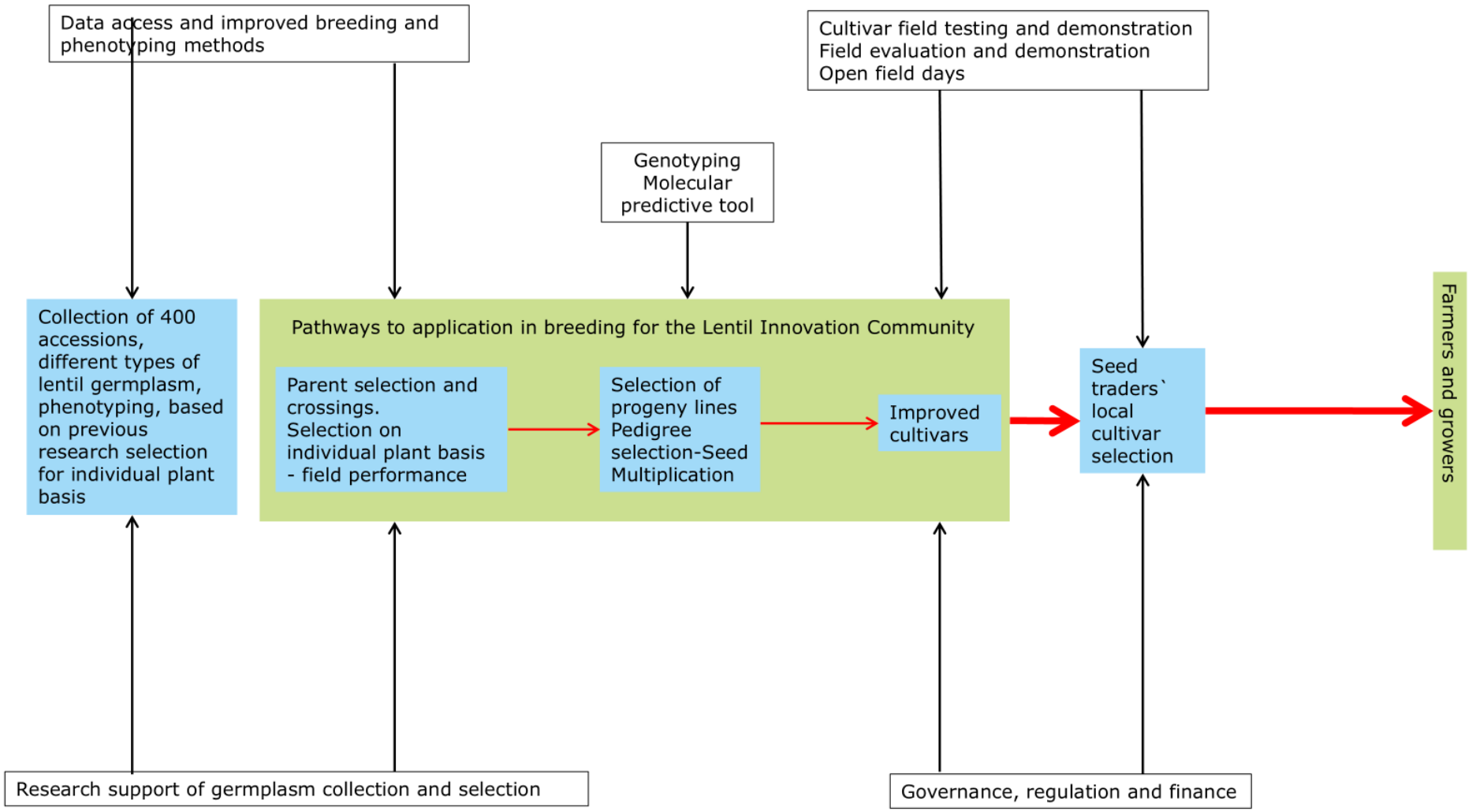

Figure 3. Pathways to application in breeding for the Lentil Innovation Community