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

The plan for boosting the breeding of pea

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Legume Generation Report 3

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Legume Generation

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List of Legume Generation consortium partner organisations (English names)

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Background

The purpose of Legume Generation is to boost the breeding of key legume species for European farmers. It is structured into six species-oriented innovation communities (ICs) and each link practical breeding with the supporting research-base in a transdisciplinary platform. This operational framework enables each of the six ICs to harness the relevant science base while focusing on individual species/species groups with coherence and synergies across the project. All six ICs innovate up to the point where newly-bred germplasm and tools are demonstrated at technology readiness level 7. This report presents the plan for boosting the breeding of pea within the Pea Innovation Community. How the pea IC is supported within Legume Generation is illustrated in Figure 2.

Peas belong to the species *Pisum sativum* and are a widely cultivated crop with diverse types adapted for different uses, for instance, peas grown for fresh consumption include garden peas, snap peas and snow peas while peas grown for their dry seeds include field peas, marrowfat peas, and forage peas. In the pea IC, we will mainly focus on genetic improvement of dry peas as they hold greater commercial importance because of their diverse applications in processing industries, ease of scalabilit and consistent market demand.

Establishing the Pea Innovation Community

The Pea Innovation Community (PIC) is developed within the Legume Generation with a goal to harness research-based knowledge to boost the breeding of peas. The PIC has six partners directly involved in the genetic improvement and breeding of pea:

1. John Innes Centre (JIC), UK
2. KWS, Lochow GmbH, Germany
3. RAGT, France
4. DANKO, Poland
5. SERIDA, Spain
6. Aberystwyth University (ABER), Wales

The community brings together experts with a focus on pea improvement through innovation in genomic tools, integration of high-throughput phenotyping and data analytics by tapping into diverse genetic resources to introduce novel alleles into the breeding pipeline. Direct participation of private and public breeders will ensure that novel tools and novel genetics will be used and introgressed in active breeding programmes, thereby tackling long-standing challenges to pea cultivation such as the phenomenon of soil fatigue that prevents pea being grown on the same land more often than once in 7-8 years. The community will also engage with the UK legume research network, Defra Pulse Crop Genetic Improvement Network (PCGIN), to widen its network-base and access wider resources. The community is further supported by the scientists from 12 partner organisations within Legume Generation (Table 1) with four full breeding programmes supported by KWS, RAGT, SERIDA and DANKO (Table 2).

Table 1 Members of the Pea Innovation Community

First name	Second name	Role	Organisation
Klaus	Oldach	Private-sector plant breeder; researcher	KWS
Donal	Murphy-Bokern	Policy specialist; research director	DMB
Laurent	Gervais	Private-sector plant breeder	RAGT
Ivo	Rieu	Researcher	SRU
Eric	Visser	Researcher	SRU
Ana	Campa	Researcher	SERIDA
Juan Jose	Ferreira	Public-sector plant breeder; researcher	SERIDA
Małgorzata	Niewińska	Private breeding company	DANKO
Agnieszka	Katańska-Kaczmarek	Private breeding company	DANKO
Amelie	Detterbeck	Private seed sector association	EURS
Lars	Østergaard	Researcher	UO
Lars-Gernot	Otto	Researcher	IPK
Jasmin	Karer	Network	DS
Catherine	Howarth	Researcher	ABER
Sanu	Arora	Researcher	JIC

Table 2. Description of breeding programmes operated by breeders in the Pea IC

Partner	Pre-breeding	Breeding	Description
KWS	1	1	Both pre-breeding and breeding programmes for dry pea with focus on yield, lodging and disease resistance, protein quality, and environmental adaptation.
SERIDA	1		Pre-breeding focusing on adaptation to local environment, organic farming system and resistance to diseases, mainly for green (vegetable) pea.
DANKO		1	Breeding programme for dry pea focusing on yield traits, uniform maturity, resistance to pod cracking and seed shedding, disease (*fusarium*, mildew, ascochyta blight) and lodging resistance, high protein content and environmental stress tolerance.
RAGT Seeds	1	1	Both pre-breeding and breeding programme for dry pea focusing on high yield and protein content, cold resistance, resilience to pest, diseases and climatic stress.

Resources supporting our Pea Innovation Community

The PIC brings together unique germplasm, resources and capabilities that are instrumental in the development of robust pea cultivars by identifying key traits and their associated markers. Our germplasm encompasses a diverse range including wild accessions, old landraces, both local old and modern cultivars and advanced breeding lines collected from different parts of the world.[11] This collection is curated using single seed descend and maintained at the Germplasm Resource Unit in John Innes Centre. Further, our partners from SERIDA have compiled a collection of old local cultivars collected from southern Spain, a region with markedly different climate compared to other European and UK pea-growing regions. Our breeding companies will utilise the genetic resources in their pre-breeding programmes and use their elite germplasm pools for introgression of novel traits. The structure and activities within PIC will also provide a route to impact (Fehler! Verweisquelle konnte nicht gefunden werden.).

Strategic objectives for pea improvement

Pea is a cool-season legume crop mainly cultivated in temperate region for human consumption and feed livestock. It is grown either for its mature, dry seeds (combining peas) for use in food, feed, and processing industries or harvested as immature seeds for fresh vegetable consumption or freezing (vining peas). Consequently, pea breeding efforts must address diverse challenges, which include improving agronomic traits and seed quality to enhance resistance against biotic and abiotic stresses. It is important that efforts to boost the breeding of pea draw on integrating advanced genomic, phenomic and breeding tools to support a range of breeding strategies tailored to specific pea types. This balance between underpinning support and specific targeting ensure sustainable innovations that meet market demands and future agricultural challenges.

Our strategic breeding objectives include:

1. to develop high-yielding cultivars with better adaptability to diverse environments as the crop is highly sensitive to fluctuations in climatic conditions during its growth cycle and various environmental stressors can affect its yield and quality;
2. to develop tolerance against drought and heat stress, particularly during the reproductive phase;
3. to improve resistance against key pathogens adapting the crop due to shifting climate conditions and scarcity of effective chemicals and the lack of well-characterized genetic resources to control these pathogens; and
4. to identify frost tolerant peas that can be sown in autumn and to extend the vegetation period to better cope with dry conditions in spring.

[1] C. Feng, C. Baizhi, et al., 2024, Genomic and genetic insights into Mendel's pea genes. *Biorxiv* (doi.org/10.1101/2024.05.31.596837)

Our plan for the genetic improvement of pea

Despite it being an important legume crop, pea cultivation has declined in Europe. However, there is a remarkable increase in pea production in Canada facilitated by recent investment in its breeding. In PIC, our strategy is to support on public-private pea breeding efforts to address the challenges faced by the crop to meet the needs of growers and producers.

Breeding for disease resistance

A major threat for pea cultivation is its susceptibility to numerous pests and pathogens whose prevalence is increasing with the changing climatic conditions and lack of plant protection products to treat peas. Vining peas that are harvested as fresh product are most affected by diseases of pods and leaves (mildews and viruses), dry peas are particularly by the root rot phenomenon, several viruses and blight. The challenge for breeding is:

- cultivated pea varieties often have a narrow genetic base and with this only a limited number of resistance genes that can be used for resistance breeding;
- many observed pea diseases are complex and their cause is not well understood or not clearly identifiable, which makes targeted selection of resistant material very difficult in breeding;
- a bridge between plant patholoy and pea breeding is required; and
- there is limited availability of robust molecular markers that can be used to select for existing resistance traits.

Experimental strategy and plan

We will screen the diverse pea germplasm collection (along with some local advanced breeding lines) in UK, Spain, Germany, Poland and France over two seasons for important diseases, including powdery and downy mildew resistance, root rot (damping off, *Fusarium* wilt and Ascochyta blight) and viruses. The different agroclimatic zones come with variations in their disease profile enabling a focus on different diseases in the different regions.

Although the field reflects the natural environment of a crop, it comes with the challenge that the plants are exposed to several pathogens simultaneously. For example, susceptibility to one disease can mask existing good resistance to another pathogen if their symptoms are similar. Artificial inoculations with well-defined pathogens in controlled environment will circumvent the problem of masking due to simultaneous infections and show the genuine plant response to a specific pathogen.

As an innovation community, we will benefit from analysing the phenotypic data across geographical locations which will help to identify traits important for better adaptability.

The data storage and analysis plan will be discussed in IC meetings.

Breeding for yield and resilience

Pea cultivation (both vining and dry peas) is sensitive to fluctuations during its growth cycle, and changing weather patterns can lead to various environmental stressors that ultimately affect yield and quality. Challenges include the increasing occurrence of spring drought and heat stress, particularly during the reproductive phase and pod filling stage. We identified key traits essential for prioritising the breeding of climate-adapted and resilient pea cultivars. Special attention was given to traits related to heat and drought stress, along with yield.

Experimental strategy and plan

1. We have discussed the important agronomic and seed traits that one needs to consider for achieving yield stability. We will screen the pea germplasm collection along with locally adapted cultivars either in small plots or wires (depending upon the available resources) and score for traits, including variation in seedling emergence, plant height, flowering time, number of pods, pod shape, seed number and weight. The JIC germplasm will be screened at different locations in Europe and UK (four locations over two years) for scoring these traits. The variation in genotypes will be statistically analysed and lines with high performance across locations and within the same location will be selected for making crosses by the breeders to start introgressing new genetics into elite germplasm. Each breeder will select their own elite germplasm leading to breeding material targeting all of Europe´s pea growing regions. The germplasm collection lines that are identified carrying traits of interest will form a mini-collection called core lines.

2. We will also screen for drought resilience at seedling stage under controlled conditions at the phenomics platform at Aberystwyth University. Due to the limited capacity of the phenomics facility, only selected lines from this screen will be taken forward for drought and heat stress screening at maturity in JIC glasshouses/growth rooms. Eventually, yield and drought/heat data will be compared to identify lines with better performance across traits for use in breeding by making crosses.

3. Another strategy to avoid heat and drought, and maintain the yield, is to sow peas in autumn. However, this will require identifying lines that are winter hardy. Within our IC, we will conduct winter trials of the pea germplasm collection at least at two locations for two years to identify winter hardy lines. While these trials are conducted, we will also search literature for any available for vernalisation genes in pea and identify if there are any varieties that have winter hardy traits. If the breeders have, these can this be used for making early crosses to understand the genetics and its transfer to breeding material.

Seed distribution and field trials

A significant aspect of the establishment of the IC involved strategic planning to facilitate the exchange of germplasm and breeding lines among collaborative partners. We have agreed a central procedure between partners for sharing the specific genotypes needed to conduct the experiments proposed. This mainly includes sharing 250 pea lines from JIC germplasm collection, seeds were bulked up at JIC fields in year 2023 and 2024 and sent by mail to individual partners in pea IC after signing a Standard Material Transfer Agreement (SMTA) generated by Germplasm Resource Unit (GRU) at JIC. All partners except RAGT have received the seeds. The location of all field trials in Europe and UK is given in Figure 1.

Figure 1. Map of pea field experiments (SERIDA, JIC, RAGT, KWS, DANKO). ABER will conduct high throughput phenotyping in phenomics facility.

Developing genomics tools to aid breeding

The development of genomic resources and tools for pea has lagged behind other crops due to its bigger genome size (4.2 Gb) and mainly lack of investment. Due to falling cost of sequencing and availability of high-performance computing infrastructure, we will develop genomic tools that can be utilized for GWAS studies and for the development of a marker-assisted breeding platform which would be of great value to the IC members.

Experimental strategy and plan

1. We will use the genotyping data of the JIC's germplasm panel sequenced to a depth of 20x coverage and develop GWAS pipelines to identify the QTLs associated with various traits phenotyped for disease and climate resilience.

2. These genomic tools will be used by IC members to design molecular markers associated with heritable trait loci. The molecular markers will be used by the breeders (RAGT, KWS, DANKO) to facilitate tracking of desirable alleles in crosses.

3. Our goal is to create and maintain a lasting collaborative Europe-wide network beyond existing national networks such as PCGIN in the UK, to ensure pre-competitive engagement in pre-breeding. The genotypes and markers identified within the pea IC will enhance the breeding efforts while ensuring development of adapted cultivars tolerant to various climatic conditions and are better adapted to specific regions through

targeted breeding. Through the pea IC network, we will serve the translation of research findings into improved cultivars coping with current and future challenges to pea crop.

Supporting innovation and exploitation

Training

Our IC proposes training activities on pea genomic resources and data analysis by organising a workshop at the UKLRC meeting in 2026.

Governance and policy

Our IC has identified that the acceptance of gene-edited varieties and other advanced breeding techniques (NBTs) present significant opportunities. Currently, in the EU, gene-edited plants must undergo extensive risk assessments similar to GMOs, making the approval process lengthy and complex. However, the regulatory framework for gene-edited varieties is under revision. In contrast, the UK government distinguishes gene-edited crops from traditional GMOs if the genetic changes could have occurred naturally, simplifying the approval process and encouraging agricultural innovation. The deregulation or revision of the regulatory framework in the EU could facilitate crop adaptation to climate change and drive further innovation.

In the EU, the European Commission's proposal for a new regulation on plants produced by certain new genomic techniques (NGTs) offers a promising environment for research and innovation. This proposal, part of the EU's Farm to Fork and Biodiversity strategies, aims to support SMEs and maintain high protection standards for health and the environment. The proposal distinguishes between two categories of NGT plants:

- Category 1 NGT plants: These plants could occur naturally or through conventional breeding and would be subject to a verification procedure. If they meet the criteria, they would be treated like conventional plants and exempted from GMO legislation requirements.

- Category 2 NGT plants: These plants would be subject to the current GMO legislation, including risk assessment and authorisation before being placed on the market.

In the UK, the Genetic Technology (Precision Breeding) Act streamlines the process for authorising innovative foods, including NGT plants. The UK has established the Regulatory Innovation Office (RIO) and the Food Standards Agency's (FSA) regulatory sandbox to provide pre-application support and reduce the time and cost associated with regulatory approval. The UK government is also investing significantly in alternative protein research, with initiatives like the National Alternative Protein Innovation Centre (NAPIC) and other private-sector research hubs.

To harness these opportunities, our IC will engage in fostering collaboration between governments, research institutions, and private breeders to share knowledge, pool resources, and advance testing methods. We also identified that it is very important to strengthen coordination between EU and UK regulatory bodies post-Brexit to ensure seamless variety approvals and access to wider markets.

Finance and business planning

Pea breeding enterprises are financed through a combination of royalties from Plant Breeders' Rights (PBRs), seed sales, and royalty fees from contract growing. However, the financial sustainability of pea breeding programmes is challenging due to high rates of farm-saved seed use, the relatively low value of certified seeds, and a significant decline in pea acreage in the EU over the past two decades. This has led to limited research and development (R&D) investments in peas compared to higher-value crops like maize and wheat, resulting in a widening competitiveness gap over time.

In Legume Generation IC, we aim to address these challenges by introducing new genetic diversity into breeding programmes as a combined effort by breeders and researchers. The project's identification of traits for disease resistance and abiotic stress tolerance, along with the development of genetic markers to track valuable loci will accelerate the breeding process. These innovations will support our commercial breeding partners in development of improved elite varieties that can be offered to farmers after registration and will create awareness of the value of original and certified seed.

Usually, new varieties are not sold to farmers directly by breeding companies but through private companies who multiply and distribute seeds, ensuring new varieties reach farmers. Alternative closed-loop models, where processors contract farmers specific varieties for cultivation, could offer additional opportunities for the pea industry. Such models benefit all stakeholders: processors secure preferred raw materials, farmers gain guaranteed markets, and breeders see clear demand for their varieties, making the effort to develop new genetics commercially viable. We will support our IC members in business planning to establish such tripartite systems by coordinating efforts with processors. By leveraging both traditional and innovative business models, the pea breeding industry can improve its financial viability and foster greater genetic advancements.

Dissemination, exploitation and communication

Dissemination

The primary dissemination route lies within the Innovation Community (IC) itself. A key purpose of the IC is fostering intensive knowledge and resource sharing among its members. All members are expected to actively participate in generating and sharing results, including trait phenotyping, genomic tools, technologies, and marker data. These results will be made accessible through a common platform, ensuring broad access within the community. This approach creates a precompetitive space for our breeders, enabling them to accelerate the incorporation of novel alleles into breeding programmes to develop pea varieties with enhanced environmental resilience. We will also consider intellectual property protection for any innovation that will lead to commercial gains and contributors to the results within the IC will be recognised as innovators.

Beyond our IC, the dissemination of results will be achieved through multiple avenues (i) publication in high-quality, peer-reviewed academic journals (with a minimum of two publications anticipated) (ii) publication of IC reports on the Legume Generation website and the Legume Hub (Europe's knowledge platform for legumes) (iii) presentations at national and international meetings. Planned events include UKLRC meetings in February 2026 and 2027, the International Legume Society conference in June 2026 and PAG in January 2026. Furthermore, we will actively engage in knowledge exchange with other public projects, particularly the Pulse Crop Genetic Improvement Network (PCGIN), by participating in their stakeholder meetings in 2025 and 2026.

Exploitation

Exploitation is a crucial part of the innovation cycle, where the findings and tools developed in the project are leveraged to create economic value and improve breeding outcomes. Our breeding partners will use phenotype data to select parental lines with enhanced disease resistance, better yield, and drought/heat tolerance for making pre-breeding crosses. These materials will be incorporated into their commercial breeding programmes to develop new pea varieties, aided by genetic markers and genomic tools developed within the IC. In the long term, seed companies can produce and distribute these new, more resilient varieties to farmers (Figure 3). If the project generates novel intellectual property (e.g., patents for unique genetic traits or breeding methods), this could be licensed to other companies or entities. Breeders and companies may pay royalties to use these innovations, generating revenue and providing a return to the PIC on its investment in research.

Furthermore, if these results are used to advocate for better agricultural practices or to inform crop breeding standards, this indirect exploitation could drive widespread improvement in the sector. All members of the IC will also contribute to knowledge transfer activities, such as field days (Breeders' Day at JIC in 2025 and 2026), open days at DANKO, KWS, and RAGT, as well as webinars and training workshops (as mentioned above).

Communication

Effective communication within and between the ICs is essential for the success of the Legume Generation programme. We aim to foster strong, collaborative relationships across ICs by facilitating the exchange of ideas on experimental design, phenotyping methodologies, and data analysis pipelines. We will use the Legume Hub as our primary communication outlet for timely spread of information and results. The Legume Hub is Europe’s open-access knowledge platform on legumes that guarantees a permanent availability of the project outputs. This will serve as a central hub for updates, resources, and project outcomes, accessible to all stakeholders. Additionally, we will leverage social media channels (e.g. LinkedIn and Bluesky) to communicate key outcomes and activities, reaching a broader audience. We have also appointed outreach ambassadors for our ICs to identify communication opportunities and contribute to the dissemination of the material. Our ambassadors are:

1. Delpierot Augustin (RAGT Seeds, France).
2. Juan Jose Ferreira (SERIDA, Spain).
3. Kumar Gaurav (JIC, UK).

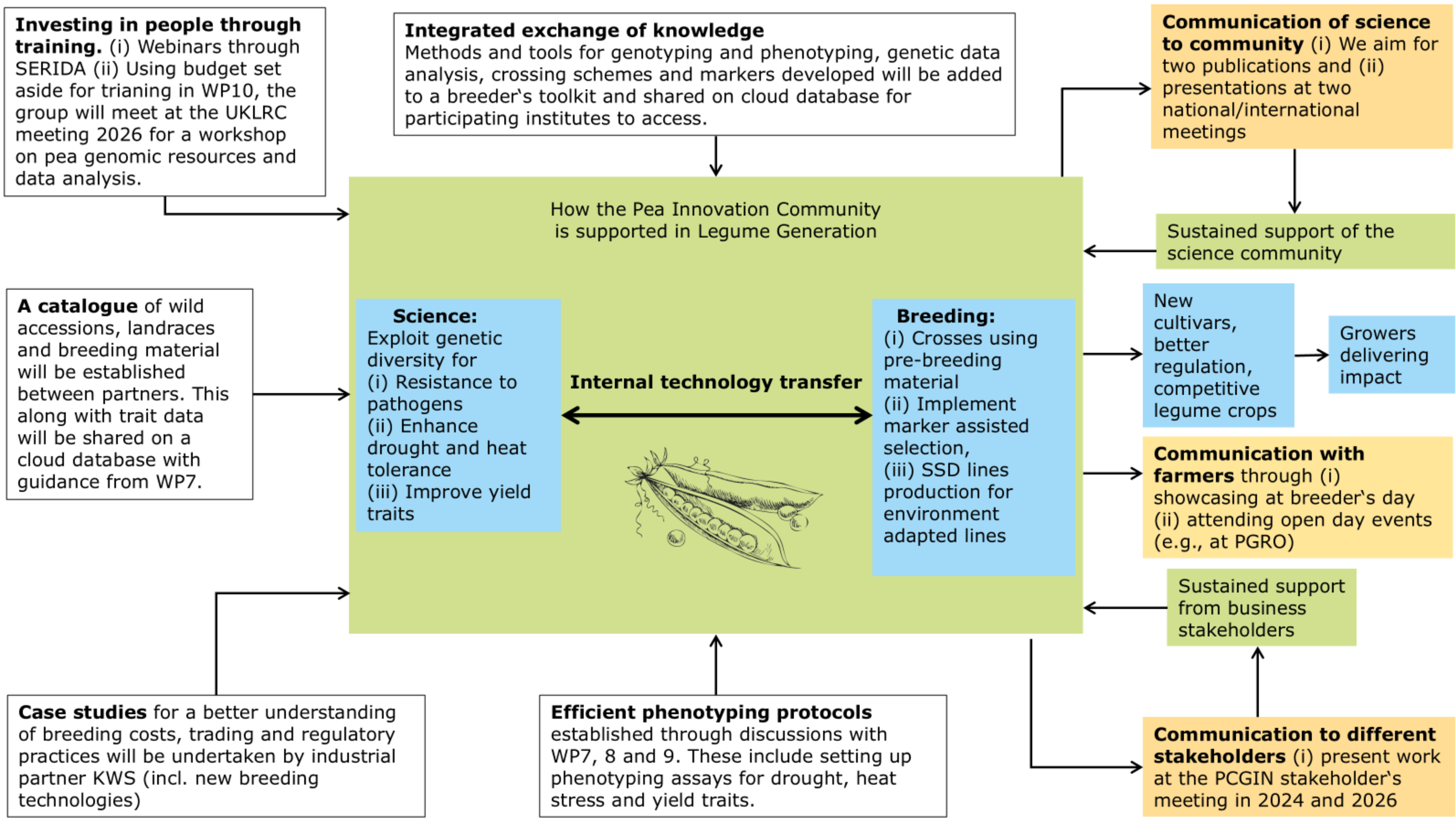

Figure 2. How the Pea Innovation Community is supported in Legume Generation

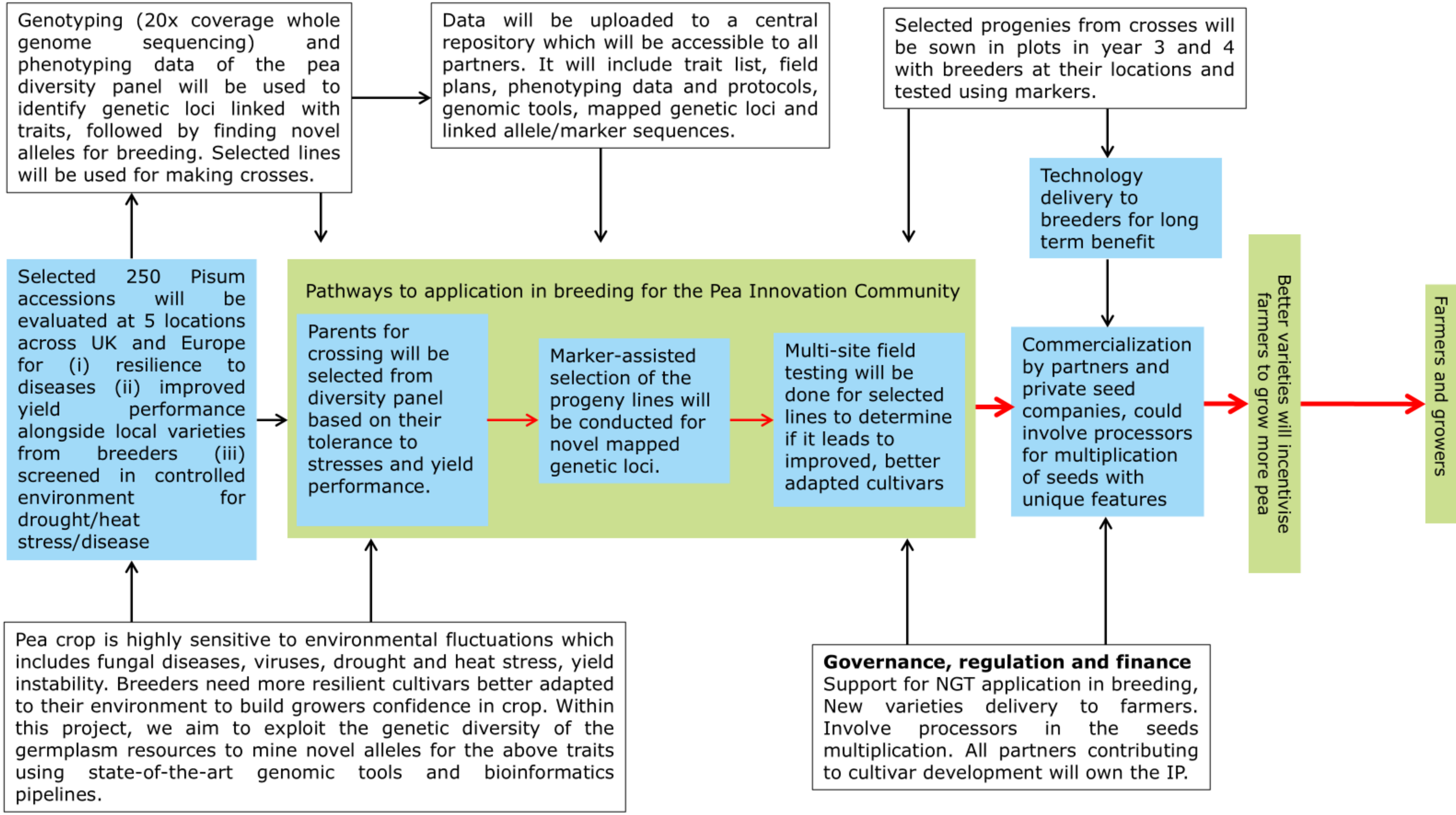

Figure 3. Pathways to application in breeding for the Pea Innovation Community