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

The plan for boosting the breeding of soybean

Johann Vollmann
University of Natural Resources and Life Sciences Vienna, Austria

Volker Hahn
University of Hohenheim, Germany

Donal Murphy-Bokern
Kroge-Ehrendorf, Germany

Mária Škrabišová
Palacký University in Olomouc, Czech Republic

Legume Generation Report 1

Legume Generation (Boosting innovation in breeding for the next generation of legume crops for Europe) has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No.101081329. It also receives support from the governments of the United Kingdom, Switzerland and New Zealand.

Legume Generation

Legume Generation (Boosting innovation in breeding for the next generation of legume crops for Europe) is an innovation action funded by the European Union through Horizon Europe under grant agreement 101081329. The Legume Generation consortium comprises 33 partners in 15 countries.

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Citation

Please cite this report as follows:
Vollmann, J., Hahn, V., Murphy-Bokern, D. and Škrabišová, M., 2024. The plan for boosting the breeding of soybean. Legume Generation Report 1.
Available from www.legumegeneration.eu and www.legumehub.eu

Legume Generation consortium partner organisations

Leibniz Institute of Plant Genetics and Crop Plant Research (IPK, Germany)
Donal Murphy-Bokern (DMB, Germany)
University of Natural Resources and Life Sciences (BOKU, Austria)
Julius Kuhn-Institute, Federal Research Centre for Cultivated Plants (JKI, Germany)
Universita Politecnica Delle Marche (UNIVPM, Italy)
Donau Soja (DS, Austria)
Radboud University (SRU, Netherlands)
KWS Lochow GmbH (KWS, Germany)
International Hellenic University (IHU, Greece)
Saatzucht Gleisdorf GmbH (SZG, Austria)
University of Hohenheim (UHOH, Germany)
Bavarian State Research Centre for Agriculture (LfL, Germany)
Danko Hodowla Roslin. (Danko, Poland)
Aarhus University (AU, Denmark)
RAGT Seeds (RAGT, France)
Lidea Seeds, (Lidea, France)
Keyserlingk Institut (Keyserlingk, Germany)
Palacký University Olomouc (UP, Czech Republic)
Serida - Regional Service for Agrofood Research and Development (SERIDA, Spain)
University of Basilicata (UNIBAS, Italy)
ESKUSA GmbH (ESKUSA, Germany)
Institute of Plant Genetics, Polish Academy of Sciences (IPG, Poland)
Euroseeds (EURS, Belgium)
Agrobioinstitute (ABI, Bulgaria)
John Innes Centre (JIC, United Kingdom)
Germinal Holdings Ltd (GER, United Kingdom)
Aberystwyth University (ABER, United Kingdom)
Earlham Institute (EI, United Kingdom)
United States Department of Agriculture (USDA, United States of America)
WBF Agroscope (AGS, Switzerland)
AgResearch (AGR, New Zealand)
Van Waveren Seeds GmbH (vanW, Germany)
Oxford University (OU, UK)

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Our goal and who we are

This plan to boost the breeding of soybean is about supporting our breeding partners and associates as risk-taking innovators. This links practical breeding across Europe with the supporting research-base in a transdisciplinary platform. Our collaboration combines innovation focus on soybean with synergies from across the project's five other innovation communities. Innovation is supported up to the point where newly-bred germplasm and tools are demonstrated on farm at technology readiness level 7. In this way, the innovation harnesses science to improve our individual soybean breeding programmes. How the Soybean Innovation Community is supported within Legume Generation is illustrated in

Figure *2*.

Developing the Soybean Innovation Community

The Soybean Innovation Community emerged from a European Soybean Improvement Network (ESIN) which was established in 2018. Since 2019, the ESIN has supported the 'Haberlandt' project between Chinese and European breeders/breeding research institutions, in which Chinese and European elite cultivars were reciprocally exchanged and investigated for increasing genetic diversity of early maturity germplasm[1] and improving the potential for regional adaptation[2] both in China and Europe. A main goal of our innovation community (IC) is to harness research-based knowledge to boost the breeding of soybean. In Legume Generation, this is realised through the collaboration between research institutes in Germany, Czech Republic, The Netherlands, Austria and Bulgaria with the most relevant private sector plant breeding companies from France, Germany, Poland, Switzerland and Austria representing major soybean production areas of the European Union.

Through Legume Generation, the ESIN network was extended to include more partners from the European soybean breeding and research community as well as along the soybean value chains. All major European private and public soybean breeders and research institutions dealing with the soybean crop (see Table 1) are in our breeder-led innovation community. Thus, unique research infrastructure present across Europe (i.e., phenotyping capacities and genotyping expertise) is utilised to jointly generate new knowledge and data about European soybean breeding materials which continuously flow back to the private sector breeding partners. This flow of information between research and private breeding partners is a key feature of the IC. It immediately supports breeders with additional information for selection. However, as the research within Legume Generation is also directed to cover some of the major future challenges of the agri-food system (i.e. adaptation to drought, heat and other climate extremes, nutritional transformation towards increased use of plant-based protein foods to reduce animal-based food consumption), a long-term perspective is supporting breeder decisions for new crosses and breeding strategies which will materialise in new soybean cultivars within a time-frame of 10 to 15 years.

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[1] Yao, X.,. Xu, J.-Y., Liu, Z.-X., Pachner, M., Molin, E.M., et al., 2023. Genetic diversity in early maturity Chinese and European elite soybeans: A comparative analysis, Euphytica 219:17. (doi: 10.1007/s10681-022-03147-0)

[2] Yao, X., Pachner, M., Rittler, L., Hahn, V., Leiser, W.et al., 2024. Genetic adaptation of phenological stages in Chinese and European elite soybeans (*Glycine max* [L.] Merr.) across latitudes in Central Europe. Plant Breeding 143: 695-705. (doi: 10.1111/pbr.13197)

The Innovation Community has 15 partners, of which 8 are directly involved in soybean breeding. IC members such as Donau Soja and BOKU University were lead organisers of the World Soybean Research Conference 11 taking place in Vienna/Austria in June 2023, where the Legume Generation Soybean IC had its first (informal) meeting. Additionally, Donau Soja is the leading European organisation for domestic soybean certification, soybean research coordination, and stakeholder action along the whole agri-food value chain. EUROSEEDS is a membership-based association representing the seed sector on the European level. IPK Gatersleben, Radboud University Nijmegen, AgroBioInstitute Sofia, Palacky University of Olomouc, and BOKU University of Vienna provide science and unique services to the breeding programmes. Donal Murphy-Bokern is an agronomist and a legume policy expert on the European level. Public and private plant breeders (Agroscope, RAGT Seeds, LIDEA Seeds, KWS, University of Hohenheim, Danko, Saatzucht Gleisdorf) are jointly bringing in germplasm and multi-location field experimenting capacity. They also guide the research according to the project and future strategic needs (for more details on breeding partners see section on pre-breeding and breeding programmes below).

Our pathways to Europe's farmers

Boosting the breeding of soybean to impact on farm businesses requires technical and commercial routes between research and practical plant breeding and the provision of improved cultivars to farmers. Our routes to application are illustrated in Figure 3.

The Soybean Innovation Community receives major input from previous projects of the network (Haberlandt project and other activities) and from Legume Generation through data access, improved phenotyping/genotyping methods, and general research support (supporting work packages, other crop ICs). The pathway to application follows the classical breeding schemes (selection of parental materials, hybridisation, selection in segregating generations, and later selection for environmental adaptation and stability in multi-environmental trials), finally delivering new cultivars to farmers. Here, a two-fold technology delivery is taking place through improved cultivars:

1. Farmers and growers receive high-yielding soybean cultivars with improved adaptation to their environments, stress conditions, and agronomic needs.

2. The food/feed industries receive high protein cultivars suitable for livestock feeding and for the development of new plant-protein based food applications requested by consumers and needed for a sustainable transformation of the agri-food system.

Thus, the pathway to farmers and applications is mainly enabled through improved cultivars. For economic reasons, European farmers can only grow more soybeans if new cultivars are competitive to other crops in yield, wider agronomic performance (for example rotation benefits), and/or in the economic value of the harvest product. Barriers to technology transfer exist and need to be addressed. Farmers tend to use farmer-saved seed which could be reduced by better delivering seed as a service (healthy seed with high germination rate, and pre-inoculated with rhizobia etc.). Food processors need time to develop new products and to find marketing pathways and consumer-acceptance. Here, Legume Generation IC members such as Donau Soja and EUROSEEDS are playing important roles in addressing these barriers to successful technology transfer and impact creation.

Our pre-breeding and breeding programmes

We represent both private (commercial) and public soybean breeders. Our breeding partners bring in a diverse range of breeding materials depending on the partner's size, business and marketing background, target environment(s), and individual breeding or research strategies. This is an ideal starting point for an innovation community to intensify breeding efforts for increasing overall breeding progress.

We have seven full breeding programmes and four pre-breeding programmes (see Table 2). LIDEA Seeds and RAGT Seeds operate large soybean breeding programmes across all maturity groups from MG 000 to II for soybean production in all possible growing regions of Europe. Their breeding work covers agronomic competitiveness (i.e., yield performance) and broad adaptation to various environments. Agroscope has a long-term programme established in the 1980s in Switzerland which focuses on central European soybean growing regions with a special emphasis on adaptation to chilling (low temperature at flowering), tolerance, yield and quality traits such as TOFU and lipox-free. Saatzucht Gleisdorf has a long-term programme focusing on central European regions, they introduced the first Kunitz trypsin inhibitor null cultivar in Europe for livestock feeding without the need of heat treatment. DANKO has a breeding programme focusing on very early maturity (MG 000-0000) soybeans adapted to high latitudes and cooler environments such as in Poland. KWS is presently evaluating soybean breeding / pre-breeding options through screening of germplasm suitable for high-latitude environments. University of Hohenheim is operating a successful breeding programme focusing on yield and processing quality (e.g., for tofu production) as well as on selection methodology research. BOKU University has a small pre-breeding programme with main emphasis on research in harvest-product quality for food-grade soybeans, genetic diversity, adaptation and digital phenotyping.

Table 1. Members of the soybean innovation community

First name	Second name	Role in the innovation community	Organisation
Johann	Vollmann	Researcher; public-sector plant breeder	BOKU
Donal	Murphy-Bokern	Policy specialist; research director	DMB
Volker	Hahn	Researcher; public-sector plant breeder	UHOH
Anelia	Iantcheva	Researcher	ABI
Mária	Škrabišová	Researcher	UP
Klaus	Oldach	Seed company; private-sector plant breeder	KWS
Ahmad Fardin	Malikzai	Seed company; private-sector plant breeder	KWS
Jasmin	Karer	Network; researcher	DS
Roman	Ferrant	Seed company; private-sector plant breeder	LIDEA
Patrice	Jeanson	Seed company; private-sector plant breeder	LIDEA
Ivo	Rieu	Researcher	RU
Eric	Visser	Researcher	RU
Małgorzata	Niewińska	State breeding company	DANKO
Agnieszka	Katańska-Kaczmarek	State breeding company	DANKO
Claude-Alain	Betrix	Public-sector plant breeder; Researcher	AGS
Chalhoub	Boulos	Public-sector plant breeder; Researcher	AGS
Amelie	Detterbeck	Private seed sector association	EURS
Lars-Gernot	Otto	Researcher	IPK
Eveline	Adam	Seed company; private-sector plant breeder	SZG
Maria	Bernhart	Seed company; private-sector plant breeder	SZG
Jennifer	Köppel	Seed company; private-sector plant breeder	SZG
Laurent	Gervais	Seed company; private-sector plant breeder	RAGT
Amandine	Gras	Seed company; private-sector plant breeder	RAGT
Philippe	Dufour	Seed company; private-sector plant breeder	RAGT

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

Partner	Pre-breeding	Breeding	Description
LIDEA Seeds		1	Large breeding programme across all maturity groups from MG 000 to II. Focus on yield, environmental adaptation and food traits.
RAGT Seeds		1	Large breeding programme across all maturity groups from MG 000 to II. Focus on yield and environmental adaptation.
Agroscope	1	1	Agroscope's soybean breeding program was launched in 1981 to breed varieties adapted to Swiss growing conditions. Emphasis was initially placed on cold tolerance (chilling) at the blooming stage and low cumulative temperature needs (earliness). Since the 2000s, the focus has been on food quality, with emphasis on taste and processing as well as other agronomic traits such as yield and canopy cover. New breeding technologies such as genome selection, speed breeding and genome wide association studies are now being implemented.
Saatzucht Gleisdorf		1	Long-term breeding programme focusing on central and eastern European regions, introduced the first Kunitz trypsin inhibitor null cultivar in Europe for livestock feeding without the need of heat treatment. Breeding focus on yield.
DANKO		1	Breeding programme focusing on very early maturity (MG 000-0000) soybeans adapted to high latitudes and cooler environments such as in Poland. Focus on combining high yield with earlier maturation.
University of Hohenheim	1	1	Breeding for grain yield, early maturity, adaptation research, tofu and food-grade soybean development. Various breeding research topics.
KWS	1	1	Screening and adaptation of soybean to high latitudes.
BOKU University	1		Small pre-breeding programme with main emphasis on research in harvest-product quality for food-grade soybeans, genetic diversity, environmental adaptation and digital phenotyping.

Strategies for crop improvement

Soybean is the most widely grown, most protein-productive and most needed grain legume crop in Europe. It is an essential crop species for European efforts to increase plant protein production. To be chosen by farmers, soybeans or other legume crops must have a combination of crop output, value per unit output, benefits for the cropping system, and acceptable input costs to make the crop economically competitive with the other cropping options farmers have. Raising the yield potential of soybean across a range of relevant environments provides the foundation. This is built on with work to improve soybean quality for premium markets for food.

Based on the framework outlined above, the key strategy for soybean improvement is adaptation to diverse environments and needs. Due to the need for photoperiodic adaptation to different latitudes (as mirrored by the existence of different maturity groups) and other environmental conditions (conventional vs. organic farming, different regional growing conditions etc.) there is no clear or universal soybean ideotype, and plant breeders widely utilise genomic selection approaches or direct selection for grain yield instead.

However, while facing the effects of global climate change in southeast and central Europe during previous seasons, searching for improved tolerance to drought and high temperature is a common strategy for preserving yield stability and overall competitiveness of soybean. This also includes adaptation of soybean to higher latitudes which is widely requested by the farming community. Another long-term strategy is seen in the increased need for food-grade soybeans which requires selection for various product-quality features depending on specific processing needs. This is in line with the overall European protein strategy as well as with growing consumer demands for sustainable and plant protein-based food products.

The innovation cycle in plant breeding has a rather long time-frame of 12-15 years, and further changes of global agricultural markets (world soybean trade), climate change effects, EU regulatory frameworks including the GAP (domestic legume production, organic farming etc.), and consumer demands (plant-based protein etc.) are not predictable precisely for such time-periods. Therefore, our commercial partners need to adopt precautionary strategies to cover a range of scenarios. Apart from yield competitiveness, this includes high-protein soybeans for feeding (e.g., low-trypsin inhibitor variants), food-grade soybeans with generic food traits (suitability of different food products to be developed), and environmental adaptation for serving different soybean growing regions, cropping systems or disease pressures.

Our approaches to the genetic improvement of soybean

Breeding for yield and adaptation

Soybean production is well-established in Italy and central European regions. However, long daylength suppresses flowering in soybean. Overcoming this to flower under long-day conditions found at high latitudes and then to progress to maturity under relatively cool conditions (compared with the southern environments) is key to adaptation. The expansion of European production further north requires specific adaptation to low temperatures and longer day-length for appropriate timing of flowering and maturity. In addition, temperature and water stress as well as various biotic sources of stress (such as the southern green stink bug, *Nezara viridula*) will increasingly challenge European soybean production in the near future. At the same time, progress in soybean yield performance is essential to maintain the competitiveness of soybean in crop rotations.

Cultivars are classified within maturity groups based on time to flowering and subsequent observations of progress to maturity in autumn in cultivar field testing.

Experimental strategy and plan
Within the different maturity groups, joint yield trials across countries and seasons will generate valuable series of data for all members of the IC with respect to stress tolerance and performance of their breeding materials/cultivars under different agro-ecological conditions. Extreme earliness (adaptation to high latitudes) can be exploited at low latitude through off-season cropping (very early or very late / second crop sowing) as a possible strategy to escape stress during critical stages of development. This will be implemented by early-sowing of early-maturity genotypes in a low-latitude and late-maturity site to test adaptation options and performance of breeding materials under such conditions.

As a community of breeders, we will benefit from joint genotyping and specialised phenotyping experiments which will generate valuable additional information about breeding materials (e.g., on high temperature, drought tolerance or extra seed quality features). Genotyping platforms will be tested for their suitability on European breeding materials. They can be utilised later for GWAS studies, QTL introgression, or for the development of tailored genomic selection models by individual IC members. In addition to yield trials, dedicated phenotyping approaches both under field and controlled environment (growth chamber) conditions using various phenomics tools such as imaging, hyperspectral or other spectral techniques will generate new and valuable information towards a deeper understanding of physiological mechanisms of stress tolerance. Such findings can be utilised for the development of high-throughput phenotyping procedures, in parent selection or for the development of selection markers for stress tolerance.

Having discussed the structuring of joint yield experiments in breeders' locations our plan is to conduct three yield experiments, each with newest cultivars and advanced breeding lines grown in two replications over two years in multiple locations:

1. MG 000 and 0000: For high-latitude long-day environments, northern Europe.
2. MG 00: Adapted to central European growing conditions.
3. MG 0-I: Late cultivars for low-latitudes, southern Europe.

No MG II experiment will be carried out because of a limited importance in the market recently. The ABI in Bulgaria will carry out a special yield experiment (approx. 20 cultivars) for testing early, mid and late maturity germplasm for early sowing in a hot/dry environment with the focus on drought/heat stress mitigation.

We have a procedure for entering cultivars into a list of entries for each experiment. Entry lists, locations for each of the 3 yield experiments and further experimental parameters/recording details to ensure the generation of most meaningful data are now established. Moreover, digital phenotyping approaches (which tools/instruments are available at which location), field scoring and data sharing issues are also decided.

For adaptation testing of genotypes, *E*-gene analysis provided through genotyping and options of 'enviro-typing' for controlling genotype by environment interaction were also discussed.

Breeding for specific food-grade quality traits

Due to its high seed protein content of over 40%, soybean plays a crucial role in the transformation of the agri-food system towards an increase of plant-based protein uses in human nutrition. However, dedicated efforts in breeding for food-grade traits such as high protein content or extra-large seed size are not attractive for commercial breeders at present due to negative correlations with grain yield and a lack of market mechanisms to reward specific harvest product qualities.

Experimental strategy and plan for food-grade quality

Breeding for harvest product quality traits requires analytical capacities and methods suitable for the analysis of large numbers of samples. Instead of time-consuming classical chemical analysis, universal screening methods such as near-infrared reflectance spectroscopy (NIRS) are widely utilised by plant breeders as they are sufficiently precise, can manage large numbers of samples and allow non-destructive measurements. However, separate or specific calibrations are required for different traits/constituents, NIRS instruments and genetic populations. In addition, for supporting the selection of specific characters, genetic markers associated with loci influencing quality and food safety traits can be utilised. Thus, as individual project partners are bringing in different analytical facilities, we can benefit from the joint analytical power, and cultivars and other genetic materials can be characterised in food quality and food safety traits.

Our existing food-grade cultivars identified in work on yield combined with further breeding materials and additional genotypes (large/small seed size, high protein content, high sucrose etc.) will form a set of food-grade genotypes to be tested in single-row plots in different environments / breeders' locations. Harvest samples will be collected for seed quality analysis utilising internal and external services. IC members will receive an overview about genetic/environmental variation in seed quality data (e.g., content of seed protein, oil, sucrose, isoflavones, saponins, food safety traits etc.), which will support development of new cultivars for specific end-use quality. IC members can also benefit from sharing collections of reference samples which they can use for developing individual NIRS calibrations. Genotyping approaches will also support the selection for quality traits. The presence of new end-use quality features for the food market and its accurate description will help IC members in marketing their cultivars in new value chains.

Experimentally, food-grade soybeans from consortium members and new germplasm with special features will be tested in single-row plots at multiple sites for two years. Harvest products will be analysed for seed composition traits. Emphasis will be on 'generic traits' of food quality, as detailed requirements (e.g., tofu quality) are greatly differing between soy-food manufacturers. Generic traits include seed protein and sucrose content, food safety traits such as reduced Cd accumulation and the presence/absence of allergens, taste components (jasmin flavor, isoflavones, saponins) and processing traits (seed size/cooking duration).

NIRS-ring tests were proposed to enable consortium members the establishment of NIRS calibrations for specific traits using reference samples. Apart from chemical analysis, marker systems for the identification of specific food quality traits (seed protein content QTL) will be implemented.

Field trials

All genotypes from our experiments on yield and food quality are grown at BOKU-Tulln, so consortium partners could see all materials at one single site.

We plan to conduct three different yield trials and one trial focusing on food-grade characters. We have identified the number of genotypes to be contributed by each IC partner and the individual experiments are in progress:

Yield 1: MG 000 and earlier: 60 genotypes (Table 3)
Yield 2: MG 00: 45 genotypes (Table 4)
Yield 3: MG 0 and I: 30 genotypes (Table 5)

In addition, the experiment for testing and characterising food-grade soybeans has 70 genotypes across all maturity groups (Table 6).

All genotypes involved are registered cultivars or advanced breeding lines (candidate cultivars under evaluation) from WBF Agroscope (Switzerland), Danko Hodowa Roslin (Poland), LIDEA Seeds (France), RAGT Seeds (France), Saatzucht Gleisdorf (Austria), University of Hohenheim (Germany) and BOKU University (Austria) representing a perfect cross-section of the most relevant European soybean breeding initiatives.

Yield trials use standard yield plots (ca. 10 m^2 plot area depending on local practice and machinery). Food-grade soybeans will be screened in single row plots (ca. 2 m length, approx. 1 m^2 area). All experiments will use two replications per location as randomised complete block (RCB) or generalised lattice designs.

Locations

Experimental locations for the 2024 season are covering the major soybean growing regions of Europe including Austria, Bulgaria, France, Germany, Poland, Romania, Switzerland, and Ukraine. Individual yield experiments will be carried out in over 10 different locations, food-grade experiments in 8 locations (Figure 1).

Figure 1. Map of soybean experimental sites

Seed distribution logistics and documentation

A de-centralised procedure of seed distribution between project partners is being used in which the field experimenter sends a simple request to the respective breeder (contact for seed request) for seed of specific genotypes needed. Seed is then sent by mail to the experimenters' mail address. Phytosanitary certificates are not required for seed transfer of soybean seed within the European Union countries and Switzerland. 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. Although the soybean crop is not listed among the species for the multilateral system of access and benefit-sharing in the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) of FAO, an sMTA signed by all partners of the IC will still regulate the status and protection of breeding lines which are not yet registered and where the breeders' privilege does not yet apply. As sMTAs commonly are bilateral contracts between a donor and a recipient of genetic materials, the Soybean IC will try to avoid signing a number of over 70 bilateral sMTAs. Thus, one specific MTA covering and documenting all exchange activities will be designed and sent around to all partners concerned for confirmation/signing in.

Supporting experimentation

Genotyping

All the soybeans in the project will be genotyped together. Originally, an existing commercial marker panel was proposed for genotyping (Agriplex 1K Soybean Community Panel). However, in new light of advances published since the beginning of the project, we have an urgent need to update the marker panel. Therefore, we performed a bioinformatics analysis of new re-sequenced data for soybean, confronted it with the available worldwide soybean diversity and genotyped it *in silico* with all currently available marker panels. As a result, we identified markers suitable for differentiating the specific European collection of MG 0000-I varieties, which will finally be used for genotyping. Additionally, we are presently innovating this marker set by including all the recently identified new genes that underly important agronomical and nutritional traits (flowering time genes, protein content, plant architecture, etc.). In more detail, we will include variant positions of the causative mutations controlling desired phenotypes (earlier flowering and maturity, cold and drought resistance, etc.). Further, being aware of the current technical limitations of available genotyping technologies in detecting larger Indels, we predicted perfect proxy markers (SNPs in direct correspondence with the Indels based on the highest accuracy values) for all the causative Indels (white flowers, stay-green phenotype, *e1-nl*, *e3*-variants, *e4*-variants, etc.). Since we envision additional flowering time and maturity genes discovery within the time frame of the project, we predicted candidate alleles of such genes and added their variant positions to the marker panel. In the end, we will utilise a total of ~5000 diagnostic, trait-specific, candidate and CM-markers ready to be manufactured by any genotyping platform.

Digital phenotyping

Digital phenotyping utilises novel sensing technologies to determine plant characteristics which can hardly be determined in conventional field experiments. Thus, differences in numerous physiological characteristics between genotypes can be described. These traits can be utilised for selection of breeding materials, for identification of promising parent genotypes, for characterising individual gene effects of phenotype as well as for overall classification of cultivars or genetic resources. Hyperspectral reflectance measurements are based on plant canopy reflection of light in the wavelength range between 325-1075 nm. Spectral data will be collected from each individual genotype, and vegetation indices can be calculated thereof. At the Tulln experimental site, spectral data are being collected from all genotypes to support the soybean breeding community with totally new insights into their breeding materials.

Supporting innovation and exploitation

Training

On the level of the IC, training activities are proposed on:

1. General phenotyping for plant breeding.
2. Practical phenotyping for soybean.

Governance and policy

Our IC also engages in various governance and policy-related questions. This requires constant interaction with public authorities for cultivar testing in the different countries. For instance, we need a most appropriate and fair classification of cultivar candidates in official yield trials; assignment of particular candidates to maturity groups might differ between countries or regions, which might be disadvantageous for certain candidate lines. In addition to the catalogue of traits considered by cultivar testing authorities at present, we are considering particular food-grade characters to better protect specific breeding efforts for various types of specialty soybeans. Depending on the progress of the public discussion and regulatory status of new genomic techniques (NGT, genome editing), the IC as a major stakeholder and concerned party will elaborate joint statements and future policies on that matter as related to soybean breeding.

Case studies contributing to Legume Generation are proposed:

1. Developing a business plan for a long-lasting innovation community.
2. A joint study on official testing for cultivar registration with special focus on new traits for soy-food production. This would be carried out in collaboration with EUROSEEDS, the commercial soybean breeders within the consortium, and government institutions such as AGES in Austria, etc.
3. Depending on the development in the field of EU legislation of new breeding technologies (NGT, genome editing), a case study on the impact of EU legislation in that field on European soybean breeding would be carried out as a seminar or workshop.

Finance and business planning

Due to the long duration of an innovation cycle in plant breeding, cutting costs of selection (field experimentation, genotyping) through the application of high-throughput phenotyping and genotyping/genomic selection in larger breeding programmes will support

our commercial breeding partners. Thus, the pre-competitive space within the Legume Generation IC will be used to strengthen the breeders' competitiveness through technology transfer.
Soybean is an in-bred crop which means the seed is an almost perfect copy of its parent. Farmers can grow seed for the next crop themselves. The use of farmer-saved seed has increased during the past decade which has a drastic effect on breeders' revenues. Moreover, regulations about royalty fee payments for farm-saved seeds differ between countries. Therefore, production models based on identity preservation production such as in Donau Soja certification or organic farming, where the use of certified seed is required, will support breeders' investments in their breeding programmes. Dissemination and communication activities (see below) with stakeholders along the soybean value chain are important opportunities for us to continuously create awareness of the value of original and certified seed, which can also deliver extra benefits to farmers (pre-inoculation with rhizobia, high germination and field emergence rate, vigour, seed treatments etc.). Apart from classical cultivar registration, we will consider alternative licensing models such as specialty use cultivars, which are not registered on a national list of cultivars but grown on a contract basis instead for a particular food processing company etc.

We are also supporting the soybean IC members in business planning with respect to the use of NGTs such as CRISPR/Cas9 for which licencing platforms have been developed for commercial breeders. Here, intellectual property protection is present on a different level which might affect the farmer-saved seed discussion as well.

Dissemination, exploitation and communication

Dissemination

Dissemination is the sharing and transfer of results between those who generate them and those who use them. Our main dissemination channel is within the IC itself. All research and breeding partners are involved jointly in generating results and all these results will be pooled and shared with all IC members. This includes the targeted transfer of germplasm and technologies as they emerge.

As part of an innovation action, we recognise that research is not our primary purpose, but we know that our work to support innovation will generate new knowledge. It is important that the scientific evidence used to support our innovation is quality-assured. This means we will publish most results in the peer-reviewed press, guided by the needs of our plant breeding partners. In addition, this report and our report of progress (up to mid-2025) and our report of achievements up to 2028 will be published as citable Legume Generation Reports via the project website www.legumegeneration.eu and the Legume Hub. The Legume Hub is Europe's open-access knowledge platform on legumes that guarantees a permanent availability of the project outputs.

In addition to our own internal data exchange, dissemination and joint consultations are intented to take place with other public projects, in particular BELIS. Further presentations of project results to scientists will be carried out at national and international conferences (e.g. annual plant breeders conferences in Germany, Austria and other countries, EUCARPIA section meetings of the Oil and Protein Crops section, International Legume Society conference 2026, ILS 5, June 8-12, 2026, Dubrovnik, Croatia) and at different other occasions at partner locations (field days). Together with the other ICs, the Soybean IC was presented at the 2nd Leguminosenkongress in Leipzig, Germany on 7 – 10 October 2024 (Second National Legumes Congress in Leipzig - legumehub.eu).

Exploitation

Our underlying strategic purpose is to foster joint pre-competitive investment to boost our soybean breeding programmes. Subsequent competitive nearer-market activities are the responsibility of each member. Our breeding partners will be able to fully utilise various project results (phenotyping, genotyping results) for selection of crossing parents and advanced breeding lines, or for assigning genotypes to particular regions depending on their adaptation genetics (maturity group). In the long-term perspective, breeders will additionally be able to adopt their technologies (phenotyping tools, analytical methods, genetic marker sets, QTL etc.) for improving the efficiency of procedures within their individual breeding programmes. This also includes genomic selection models which can be tailored to the specific genetics of a particular company. The final outputs are soybean cultivars grown on farmer fields with improved agronomic and product quality features which have the potential to compete with other crops in yield and harvest product value.

Communication

Our communication plan is in line with the overall project communication plan. Internal communication by email and newsletters and external communication through the Legume Generation website, social media (LinkedIn and X), and the Legume Hub ensure timely spread information to the different audience groups. We use the Legume Hub as our main platform for ensuring publications are available to the public into the future.

We have appointed outreach ambassadors who will monitor developments in the regions, identify communication opportunities and supply content material for the project website and the Legume Hub.

Our ambassadors are:

Laurent Gervais	(RAGT Seeds, France)
Volker Hahn	(University of Hohenheim, Germany)
Maria Bernhart	(Saatzucht Gleisdorf, Austria)
Jasmin Karer	(Donau Soja, Austria)

Our sites will be used to demonstrate our work to local regional stakeholders.

Overview of Legume Generation soybean genotypes used

Table 3. Genotypes of maturity group 000 and earlier (Yield experiment 1)

No	Breeder	Name/identifier
101	**AGS**	CH21414 Tiguan
102	**AGS**	CH21507 Gallec
103	**AGS**	CH22172 Obélix
104	**AGS**	CH22232 Toutatis
105	**AGS**	CH22526 Tarock
106	**AGS**	CH22624 Arnold
107	**AGS**	CH22645 Farmosa
108	**AGS**	CH22711 Noa
109	**DANKO**	Erica
110	**DANKO**	DS 21001
111	**DANKO**	DS 22004
112	**DANKO**	DS 22014
113	**DANKO**	DS 22020
114	**DANKO**	DS 22031
115	**DANKO**	DS 22013
116	**DANKO**	DS 22019
117	**DANKO**	DS 22030
118	**DANKO**	DS 22034
119	**DANKO**	DS 22035
120	**DANKO**	DS 22024
121	**LIDEA**	ES-COMANDOR
122	**LIDEA**	ES-SENATOR
123	**LIDEA**	ES-CHANCELLOR
124	**LIDEA**	ES-COLLECTOR
125	**LIDEA**	ES-FAVOR
126	**LIDEA**	LID-DIAMANTOR
127	**LIDEA**	ES-CONDUCTOR
128	**LIDEA**	ES-COMPOSITOR
129	**RAGT**	RGT SIGMA
130	**RAGT**	SANKARA
131	**RAGT**	RGT SALSA
132	**RAGT**	RGT SPHINXA
133	**RAGT**	STEPA
134	**RAGT**	SAHARA
135	**RAGT**	RGT SATELIA
136	**RAGT**	STAPELIA
137	**RAGT**	SIRELIA
138	**SZG**	GL crème
139	**SZG**	GL Britta
140	**SZG**	GL Melanie

141	**SZG**	GL Begonia
142	**SZG**	GL Theresa (GL 1917012)
143	**SZG**	GL Sanne (GL 201213)
144	**SZG**	GL Susanna
145	**SZG**	GL ###1
146	**UHOH**	UHOH-1
147	**UHOH**	UHOH-2
148	**UHOH**	UHOH-3
149	**UHOH**	UHOH-4
150	**UHOH**	UHOH-5
151	**UHOH**	UHOH-6
152	**UHOH**	UHOH-7
153	**UHOH**	UHOH-8
154	**UHOH**	UHOH-9
155	**UHOH**	UHOH-10
156	**UHOH**	UHOH-11
157	**UHOH**	UHOH-12
158	**UHOH**	UHOH-13
159	**AGS**	CH22172 Obélix
160	**RAGT**	RGT STUMPA

Table 4. Soybean genotypes of maturity group 00 (Yield experiment 2)

No	Breeder	Genotype name
201	**AGS**	CH22177 Galice
202	**AGS**	CH22508 Paprika
203	**AGS**	CH22554 Simpol
204	**AGS**	CH22681 Prolix
205	**AGS**	CH90075 Talisse
206	**AGS**	CH90093 Soramax
207	**AGS**	CH90132 Benno
208	**AGS**	CH90139
209	**AGS**	CH22910
210	**AGS**	CH90166
211	**LIDEA**	LID-CONSTRUCTOR
212	**LIDEA**	ES-DIRECTOR
213	**LIDEA**	ES-INSPECTOR
214	**LIDEA**	ES-LIBERATOR
215	**LIDEA**	ES-LOUXOR
216	**LIDEA**	ES-MENTOR
217	**LIDEA**	ES-PROFESSOR
218	**LIDEA**	ES-VISITOR
219	**RAGT**	RGT STUMPA
220	**RAGT**	RGT SEFORA
221	**RAGT**	RGT SAKUSA
222	**RAGT**	SUZA
223	**RAGT**	SQUADRA
224	**RAGT**	SHIVA
225	**RAGT**	SIBELLA
226	**SZG**	GL Pia (GL 1816014)
227	**SZG**	GL 201212
228	**SZG**	GL 201811
229	**SZG**	GL 201117
230	**SZG**	Xonia
231	**SZG**	GL 221712
232	**SZG**	GL 221623
233	**SZG**	GL 221715
234	**SZG**	GL Tilda
235	**UHOH**	UHOH-51
236	**UHOH**	UHOH-52
237	**UHOH**	UHOH-53
238	**UHOH**	UHOH-54
239	**UHOH**	UHOH-55
240	**UHOH**	UHOH-56
241	**UHOH**	UHOH-57
242	**UHOH**	UHOH-58
243	**UHOH**	UHOH-59

244	**UHOH**	UHOH-60
245	**AGS**	CH22172 Obélix

Table 5. Soybean genotypes of maturity group 0 and I (Yield experiment 3)

No	Breeder	Genotype name
301	**AGS**	CH50155 Panoramix
302	**AGS**	CH50263
303	**AGS**	CH50274 Magalix
304	**AGS**	CH50328
305	**AGS**	CH50333
306	**AGS**	CH50343
307	**LIDEA**	ES-ADVISOR
308	**LIDEA**	ES-ANIMATOR
309	**LIDEA**	ES-TRIBOR
310	**LIDEA**	ES-WARRIOR
311	**LIDEA**	ES-CONQUEROR
312	**LIDEA**	ES-CONNECTOR
313	**LIDEA**	ES-PALLADOR
314	**LIDEA**	ISIDOR
315	**RAGT**	RGT SPEEDA
316	**RAGT**	RGT SICILIA
317	**RAGT**	RGT SCALA
318	**RAGT**	RGT STRAVIATA
319	**RAGT**	RGT STOCATA
320	**RAGT**	RGT SINEMA
321	**RAGT**	SHAMA
322	**RAGT**	RAGT2401
323	**SZG**	GL Valerie
324	**SZG**	GL Leonie
325	**SZG**	GL Lilas
326	**SZG**	GL 201527
327	**SZG**	Svelte
328	**SZG**	GL 221627
329	**AGS**	CH22172 Obélix
330	**RAGT**	RGT STUMPA

Table 6. Soybean genotypes for soy-food use (Food experiment)

No	breeder	genotype name
401	**AGS**	CH21912 Protéix
402	**AGS**	CH22101 Protibus
403	**AGS**	CH22138 Amandine
404	**AGS**	CH22144 Falbala
405	**AGS**	CH22315 Marquise
406	**AGS**	CH22517 Miraculix
407	**AGS**	CH22645 Farmosa
408	**AGS**	CH22681 Prolix
409	**AGS**	CH50155 Panoramix
410	**AGS**	CH90166
411	**AGS**	CH21715 Aveline
412	**AGS**	CH22164 Gourmandine
413	**AGS**	CH22338 Helix
414	**DANKO**	Erica
415	**DANKO**	DS 22020
416	**DANKO**	DS 22031
417	**DANKO**	DS 22019
418	**DANKO**	DS 22030
419	**DANKO**	DS 22035
420	**DANKO**	DS 21002
421	**DANKO**	DS 22032
422	**DANKO**	DS 22008
423	**DANKO**	DS 22009
424	**LIDEA**	ES-INSTRUCTOR
425	**LIDEA**	COMBINATOR
426	**LIDEA**	ES-BACHELOR
427	**LIDEA**	ES-INSPECTOR
428	**LIDEA**	ES-MENTOR
429	**LIDEA**	ES-WARRIOR
430	**LIDEA**	ES-COMPETITOR
431	**LIDEA**	ISIDOR
432	**LIDEA**	LID-LINGODOR
433	**RAGT**	RGT SALSA
434	**RAGT**	RGT SPHINXA
435	**RAGT**	STEPA
436	**RAGT**	SUZA
437	**RAGT**	SHIVA
438	**RAGT**	RGT SPEEDA
439	**RAGT**	RGT STOCATA
440	**RAGT**	RAGT2401
441	**RAGT**	RGT SICILIA
442	**RAGT**	RGT SINFONIA
443	**RAGT**	RGT SINEMA

444	**RAGT**	RGT STARBELA
445	**SZG**	GL Valerie
446	**SZG**	GL Lilas
447	**SZG**	GL Britta
448	**SZG**	GL Creme
449	**SZG**	GL Begonia
450	**SZG**	GL 201117
451	**SZG**	Xonia
452	**SZG**	Svelte
453	**UHOH**	UHOH-Food-1
454	**UHOH**	UHOH-Food-2
455	**UHOH**	UHOH-Food-3
456	**UHOH**	UHOH-Food-4
457	**UHOH**	UHOH-Food-5
458	**UHOH**	UHOH-Food-6
459	**UHOH**	UHOH-Food-7
460	**UHOH**	UHOH-Food-8
461	**UHOH**	UHOH-Food-9
462	**UHOH**	UHOH-Food-10
463	**BOKU**	BOKU-01 GT10X-15-1-4
464	**BOKU**	BOKU-02 GT8X-24-1
465	**BOKU**	BOKU-03 G2B1X-185-10
466	**BOKU**	BOKU-04 G2B1X-88-2
467	**BOKU**	BOKU-05 GW6X-31-4-4
468	**BOKU**	BOKU-06 GT9X-19-1-5
469	**AGS**	CH22172 Obélix
470	**RAGT**	RGT STUMPA

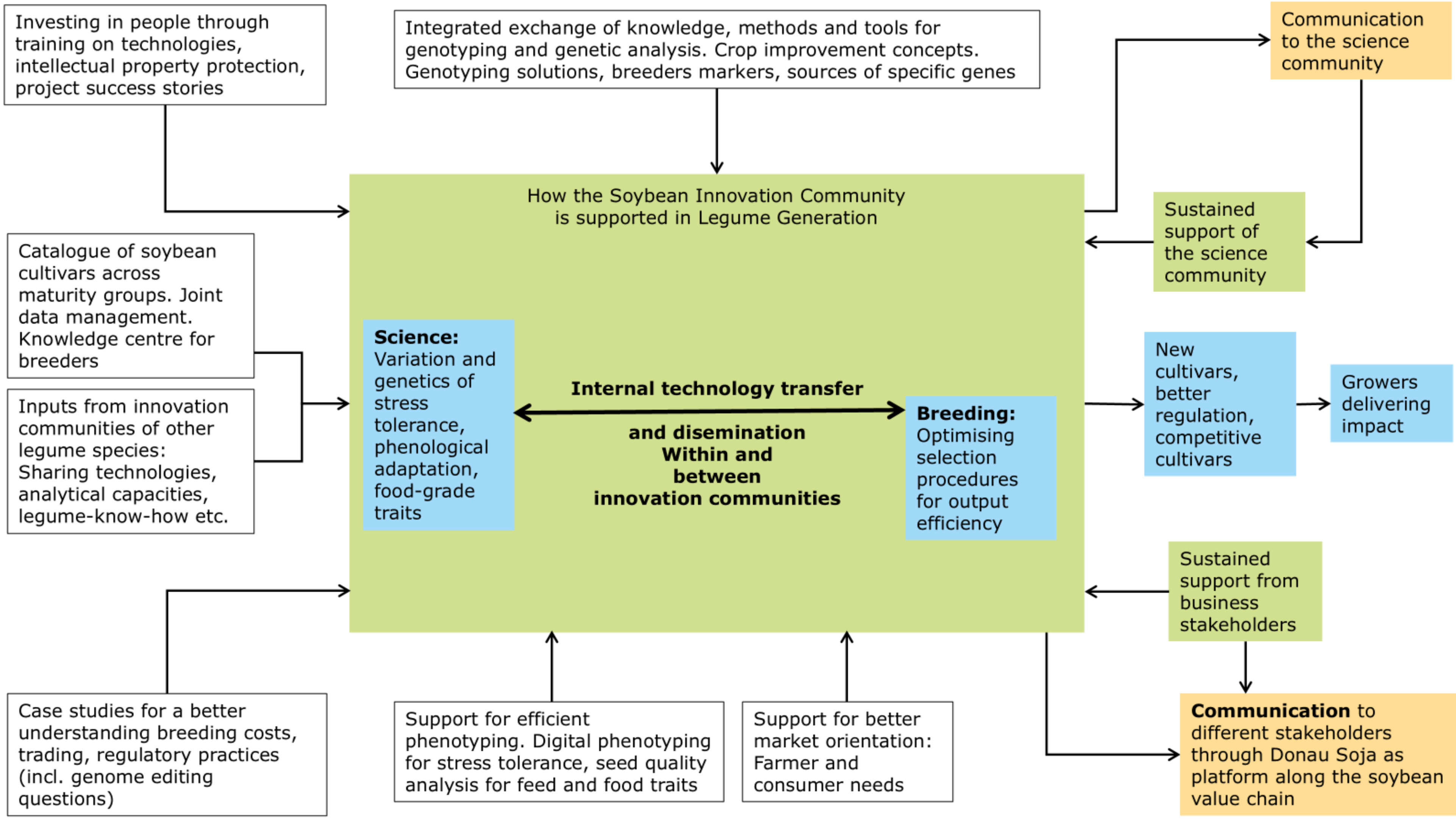

Figure 2 How the Soybean Innovation Community is supported in Legume Generation

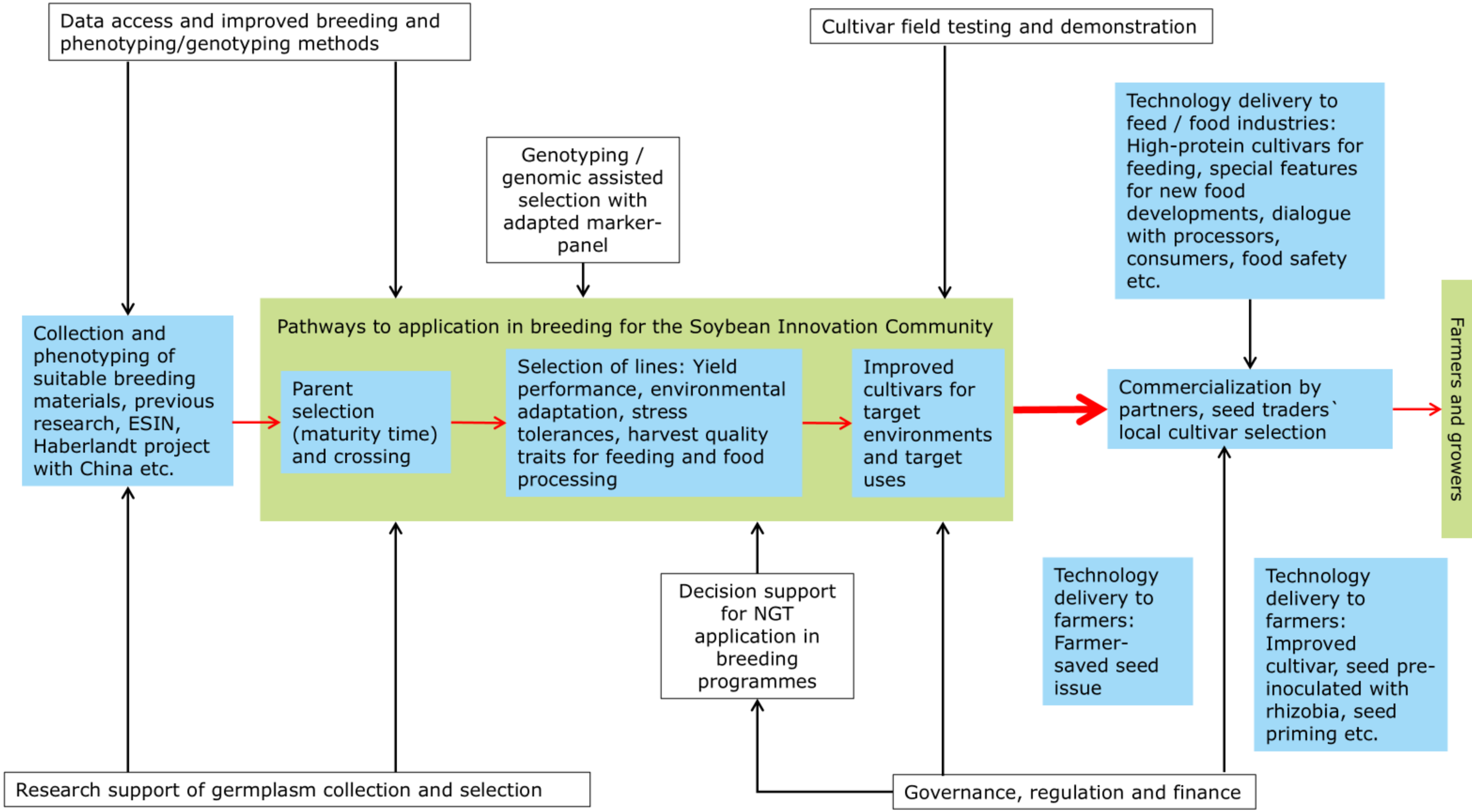

Figure 3 Pathways to innovation in breeding and to farmers for the Soybean Innovation Community