Ref. Ares(2021)6429758 - 20/10/2021

D 7.3 Production of materials for PPB and FPT evaluation training courses

ecobreed
IMPROVING CROPS

Funded by European Union
Horizon 2020
Grant agreement No 771367

SECURITY (DISSEMINATION LEVEL)	Public
CONTRACTUAL DATE OF DELIVERY	31.10.2019
ACTUAL DATE OF DELIVERY	20.10.2021
DELIVERABLE NUMBER	D 7.3.
TYPE	Deliverable
STATUS AND VERSION	Final
NUMBER OF PAGES	72
WP CONTRIBUTING TO THE DELIVERABLE	WP 7
LEAD BENEFICIARY	NATUR
OTHER CONTRIBUTORS	UNITUS, UNEW, KIS, CRI
AUTHOR(S)	Werner Vogt-Kaute, Janina Herrmann, Susanne Fittje, Sophie Egerer, Paul Bilsborrow, Mario Pagnotta, Marion Champailler, Leonidas Rempelos, Dagmar Janovská
KEYWORDS	Training material, Farmer Participatory Trials (FPT), participatory plant breeding (PPB)
ABSTRACT (FOR DISSEMINATION)	The training material is aimed at farmers, breeders and advisors in the EU to improve their crop evaluation skills to enhance farmer selection and seed production efforts in PPB for wheat, soybean, potato and buckwheat. Some of the training material will be distributed to participants and/or can be used for presentations at training events or meetings. It will be translated into different languages for meeting the target groups' needs (e.g. farmers). The document is divided into basic information and chapters with field sheets for each crop for data collection. Farmers conducting the trials and participants in the training courses will also receive some materials from the phenotypic data management system (DMS) for partners, in particular images for scoring/evaluation.
DOCUMENT ID	D 7.3 Materials for FPT and PPB training

Participatory Plant Breeding and Farmer Participatory Trial Evaluation Training Course

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Executive summary

This training material is addressed at farmers, growers and advisers in order to increase their skills in the evaluation and selection of lines/varieties for Farmer Participatory Trials and production efforts in participatory plant breeding. Specific chapters focus on wheat, soybean, potato and buckwheat.

The training material will provide a background of information to distribute attendees at the training events and/or can be used for presentations at training events, field days or meetings. The document is divided into chapters with basic information together with field sheets for data recording in each crop. Farmers conducting the trials and participants of training courses will also get material from the phenotypic DMS used by partners for phenotyping, especially pictures for scoring.

In the ECOBREED project farmers and breeders work and communicate together which encompasses the expertise of both groups. Farmer Participatory Trials provide an opportunity to evaluate genotypes under "real-life" organic conditions i.e. the conditions the genotypes are intended to be used in. Farmers are actively involved in the breeding process and can influence breeders in their decisions in particular in the identification of traits that are of particular interest and relevance to them.

Up till now, in most cases, organic farmers are not particularly interested and involved in the plant breeding process. Farmers are usually looking for the best variety that would fulfil the needs of their farms and therefore used conventionally bred varieties that are available on the seed market. It is often not necessary that organic farmers start their own breeding programme. But in some cases, it can make sense that farmers start saving, selecting or crossing generally because the number of varieties available for organic growers is often limited. For example: existing varieties often do not fit the organic farmer's requirement as they are bred and selected for under high input conditions but also because the use of hybrids is becoming more common in conventional production systems across Europe.

For starting activities relating to breeding, including selection and evaluation at a farm level some basic knowledge is necessary: knowledge about genetics (for example: self-pollinating and cross-pollinating crops, hybrids and composite cross populations), breeding schemes, seed quality, seeds laws in the EU, breeders' and farmers' rights in EU etc.

An important activity in Farmer Participatory Trials is which traits to evaluate and identify a suitable scoring system to be used. This training material (D 7.3) gives suggestions for traits particularly important for organic growers, but farmers can

add other criteria which are important for them and with that improve the training material.

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Introduction

The history of domestication of our crop plants is also the history of plant breeding. Through many generations of laborious selection, wild plants became usable for agriculture. Farmers were the first plant breeders selecting the highest-yielding, largest or best-quality material to use in future seasons.

Prior to the advent of plant breeding crop genetic diversity was higher because crops were not uniform. Farmers worked with populations/landraces rather than pure homozygous lines. In the second half of the 19th century seed companies often originating from farms and the first varieties were developed from landraces. Over time, seed companies enlarged from a regional base to a position where several large international companies tend have tended to dominate the conventional breeding sector in many countries across Europe. Breeding of uniform varieties/pure lines and later hybrids has brought an increase in yields, quality and other agricultural traits e.g. disease resistance.

Nevertheless, modern varieties bred for conventional farmers with a focus on large amounts of inputs (pesticides and fertilisers) often do not the meet requirements of organic farmers. International companies often develop hybrids which can be produced much quicker, but it means that farmers need to buy new seed each year. Many of the large conventional plant breeding companies don't breed for the organic sector or only have small breeding programmes devoted to it.

In some regions organic farmers say that they are the better breeders. This can happen if breeding programmes of companies focus on traits that are too far away from organic farmers' needs e.g. the breeding of short-straw varieties. Collaboration between farmers and breeders has the potential to develop varieties better suited for organic farming. Participatory plant breeding (PPB) is an effective breeding method well suited to organic farming as much of the work and evaluations are carried out in farmers' fields. There is a wide range of possibilities for PPB from researcher-led to farmer-led where the different systems have different benefits.

In the ECOBREED project, farmers and breeders work together and communicate which encompasses the expertise of both groups. Farmers can influence breeders in their decisions. Farmers can develop their activities especially in the field of composite cross populations (CCP). In the ECOBREED project both Farmer Participatory Trials (FPT) and demonstration events are planned. Meetings are also being held with participating farmers with respect to the monitoring, evaluation and data recording for the trials which are supported by researchers from partner organisations. Scoring will be done (depending on crop) on; field emergence, date of heading/flowering, plant height, canopy closure, lodging, disease levels, insect damage, maturity, yield and quality. Farmers can help to decide which are the relevant characteristics/ traits of interest for them. It is not to be expected that every farmer will start to be a breeder, but a better awareness/understanding of organic plant breeding helps farmers to improve their decisions on choice of varieties instead of using the same varieties as conventional farmers. The farmer's conducting trials and participants of training courses will also get material from the phenotypic DMS for partners, especially pictures used for scoring.

1. Participatory plant breeding (PPB)

Crop research has had an important impact on the development of rural society, nutritional value, food systems, etc. (Westengen and Winge; 2020). One of the examples is the implication or inclusion of farmers in crop research (Almekinders and Elings, 2001). This is a real change in paradigm for agricultural development policies and public research that promote the emergence of innovative actors e.g. in organic agriculture (Ortolani et al., 2017), because "competent innovators, often trying seeds and practices" (Van Etten et al., 2016; Johnson, 1972; Sumberg and Okali, 1997).

In the literature, we can find different designations of research programs/activities with the participation of farmers:

- **Participatory Plant Breeding (PPB)** is part of breeding programs that include stakeholders such as farmers within research or breeding programs for varietal selection and/or breeding: The term 'participatory plant breeding' does not refer to a single, clearly defined method of genetic improvement but rather to a set of breeding approaches characterised by differing levels of interaction between farmers and breeders. These differing levels of interaction aim to shift the focus of genetic improvement to a more local level by directly involving the farmer in the breeding process (Moris and Bellon, 2004). Furthermore, Almekinders and Elings (2001) wrote about **Participatory Crop Improvement** which we consider to be the same as PPB.
- **Farmer Participatory Trials (FPT)** can be a part of PPB or an approach to dealing with other objectives not linked to plant breeding, e.g. plant conservation, farm management and practices.
- **Participatory Varietal Selection (PVS)** is a specific part of PPB where multi-stakeholders are included to evaluate varieties according to different traits or to choose and rank varieties for specific requirements, soils, systems, environments, etc.

Among these different approaches we will focus on PPB since it is aligned with the ECOBREED projects objectives:

(1) **History and definitions of PPB** Different examples of PPB within recent decades are presented.

(2) **Methodology and role of stakeholders in PPB.** We will present differences between the role of stakeholders, methods PPB, goals, relations/exchange of information during trials etc.

(3) **PPB in organic agriculture? Why?** To look at the potential for adoption in organic plant breeding.

(4) Conclusion: the strengths and weaknesses of PPB

1.1 History and definitions of PPB

The first description of PPB was in the early 1950's in developing countries by programs focused on the fight against hunger and poverty. They were initiated by the Consultative Group for International Agricultural Research (CGIAR). Some cases failed because farmers' needs were not considered while choosing varieties (according to taste, texture, colour, etc.). For example, Shelton and Tracy (2016) cited an example where a high yielding hybrid variety of corn was proposed to farmers but was not adopted by them to replace low-yield traditional varieties (Apodaca, 1952).

The literature describes newer generation of PPB programs in the early 1990s across Europe and North America initiated by Non-Governmental (NGO) and farmers' organizations. Shelton and Tracy (2016) identified several projects of organic farming PPB programs in different countries.

For example, Desclaux et al. (2006) and Dawson et al. (2011) conducted a PPB program on durum and bread wheat in France and the USA respectively, Ceccarelli (2015) on barley in Syria and several were done in the USA on vegetable breeding (Mendum and Glenna, 2010).

Step by step, PPB was becoming recognised by different institutions. By 2000, a recommendation made to the CGIAR Technical Advisory Committee suggested "that PPB become an integral part of each CGIAR center's plant breeding program" (Shelton and Tracy 2016). A World Development report of 2008 presented PPB as "complementary institutional development" for traditional crop improvement programs (World Bank, 2007).

The literature survey of Ceccarelli and Grando (2020) found 254 publications dealing with participatory approaches to plant breeding during the last 4 decades. In this, 69 countries (10 developed and 59 developing) experimented on PPB with 47 crops including self-pollinated, cross-pollinated, and vegetatively propagated crops.

1.1.1 The goals of PPB

In the literature, there are 3 target approaches to PPB i.e. **economic, technological, and environmental.**

- The first goal focuses on **farmers' skills and empowerment.** Even though they are essential stakeholders in food chains, farmers were not considered in agricultural development during the Green Revolution. PPB offers a possibility for their inclusion in crop breeding and permits the inclusion and targeting of their requirements, needs and judgments. This co-operation increases the curiosity of all participants and creates a network or community of knowledge exchange between farmer and researcher/breeder (Sumberg and Okali, 1997; Westengen and Winge, 2020). Chiffoleau et al. (2006) state that "PPB can be interpreted as an innovative socio-technical network" that encourages human and biological diversity by empowering otherwise silent actors. Mendum and Glenna (2010) go even further by suggesting that "applying participatory plant breeding methods to a U.S. context could be understood as a radical act of democratisation".

- The second goal of PPB is the improvement of productivity or efficiency of varieties with high potential. With **climate change** this goal is reinforced with a greater focus on factors such as resilience against the impacts of weather which is the second important goal. Even though varieties with high potential yield are not always the target to address the key challenges of climate change (Morris and Bellon, 2004).
- The cultivation of an increasing diversity of varieties with the objective of **genetic conservation** is the 3rd goals of PPB. Farmers' needs and their conditions of production are diversified and heterogeneous. Therefore, adapted varieties are needed to ensure a satisfactory yield in diverse environments and in response to extreme weather events. Recently, most pure line varieties being bred under high pesticide and fertiliser inputs are not adapted to heterogeneous conditions of production e.g. organic and low-input conditions whereby PPB could be a way to adapt varieties to diverse farming environments (Murphy et al., 2007; Wolfe et al., 2008; Reid et al., 2011). On the other hand, Morris and Bellon (2004) present a negative exception where PPB methods could cause the loss of genetic diversity if just few genetically similar populations are chosen and grown by farmers that displace an array of more diverse populations.

1.1.2 Who are farmers-participants?

In PPB literature farmers are described according to different characteristics e.g. farm means, soil quality, production system (e.g. with low-input or not), background, community inclusion, community identity, links or relationship with institutions, commercial and culinary uses of production, interest in innovations, biodiversity, market issues and others (Zimmerer and Douches, 1991).

Some articles present common characteristics of farmers included in organic agriculture PPB programs: they are known as innovators by local advisors or dynamic members of professional groups, farmers' associations or communities. Moreover, they are recognised to have best practices in their region and have developed networks with strong and diverse links and are interested to acquire knowledge and potential innovations. These characteristics and enthusiasm are important for effective participation and uptake of PPB (Ortolani et al., 2017, De Sousa et al., 2021).

1.2 Methodology and role of stakeholders in PPB.

Numerous articles have analysed the methodology and characteristics of PPB (Morris and Bellon, 2004; Shelton and Tracy, 2016; Tveitereid Westegen and Winge, 2020; Van de Fliert and Braun, 2002).

Morris and Bellon (2004) defined 3 types of PPB trials which are differentiated by their governance, design and goals i.e. Type 1 trials, the aim of which is to assess the biophysical properties of different materials which are researcher-designed and researcher-managed; Type 2 trials, are researcher-designed and farmer-managed are designed to elicit farmer perceptions about different materials; and finally Type 3 trials, whose aims are to determine the acceptability of different materials and/or promote farmer innovation, are farmer-designed and farmer-managed.

In practice, PPB has a combination of these types. From the governance perspective PPB that are driven by seed breeders/ researchers are termed as “formal-led PPB” or “farmer-led PPB” (Sperling et al., 2001). Moreover, Shelton and Tracy (2016) describe farmers’ role in PPB as a continuum at 5 levels from least involved to the most involved defined by 5 tasks: seed production, seed distribution, evaluation, selection among progeny, initial crosses and determination of breeding goals. Morris and Bellon (2004) defined 3 models of co-operation between farmers and breeders in PPB according to different tasks: “Complete participatory breeding”, Efficient participatory breeding” and “Participatory variety selection”. These models depend on the responsibility for different tasks. For example, choosing germplasm in the beginning and how to obtain it, evaluation of plots with formal or original traits.

Participatory Plant Breeding is an inclusive approach that requires clear methodology, division of tasks and responsibility. Numerous technical PPB articles and books exist to assist researchers, breeders and farmers with technical methodology (Organic Seed Alliance, 2012). Conception of protocols requires different dimensions (Steinke et al., 2017; Van de Fliert and Braun, 2002; Organic Seed Alliance, 2012). To define protocol characteristics essential questions must be answered.

- **Location:** What are the locations? Is it a centralised or decentralised trial? in a single or different environments? Are there potential conflicts with daily tasks carried out by farmers?
- **Germplasm and traits:** Use of commercial varieties or breeding lines? Are the varieties or material selected and if yes by whom? How many different

varieties/lines to include in the trials? Plot size and dimensions? What are the traits to be evaluated? How were they chosen and by whom? Who will evaluate them farmer or researcher? and how? Is the trait easily measurable with objective attributes e.g. % of lodging?

- **Do we need formal descriptors or a triadic approach?** How many repetitions should be done or if no repetition how many times should the measurement be repeated? Will subjective evaluation of attributes be needed? (Triatic comparison of tricot approach: it means to compare 3 varieties for example to limit the difficulties of farmers' estimation and evaluation. This PPB approach was used often with success in development programs even with farmers dealing with difficulties of communication and illiteracy (Van Etten et al., 2016, Van Etten, 2011).
- **Farm management:** Are the cultivation methods/controls (e.g. against weeds, diseases and pests) decided by the farmer or breeder? What is the limit to solicitation of farmers? Work and time commitment of a farmer? Should farmer participation be compensated? as this is likely to lead to greater engagement and a greater willingness to carry out tasks ensuring a good balance between the objectives of the trial and the input needed from a farmer.
- **Communication:** How should observations and evaluations be used: papers, presentation at conferences/scientific meetings, faming press, etc.?

Clear guidelines must be made by the researchers and communicated with the participating farmers.

1.3 PPB in organic agriculture? Why?

After success of PPB all over the world, it was adopted by organic farmers (Shelton and Tracy, 2016). Difficulties with access to organic seeds in quantity and quality, of materials available which is likely to have had little adaptation and evaluation under varying environmental conditions (e.g. abiotic and biotic stresses), are key drivers for farmer participation in PPB (Shelton and Tracy, 2016; Murphy et al., 2005).

- **The lack of organic seed adapted to farmer needs in organic farming: according to quantity and quality**

  The European project LIVESEED i.e. "Improving the performance of organic agriculture by boosting organic seed and plant breeding efforts across Europe" have carried out a number of surveys and analyses of stakeholders with respect to organic seed production and consumption and the use of derogations for seed material. They presented a complete appraisal of organic seed in Europe (Soldanelli et al., 2021) with information from companies, farmers and certification bodies. They underlined that only a joint effort from all stakeholders could reach the target for 100% of organic seed use by farmers with no derogations for conventional seed use permitted. Additionally, the necessity to test varieties/lines under organic conditions is supported together with the establishment of organic variety lists for use by organic farmers and growers.

The context is similar in the USA where Shelton and Tracy (2016) analysed limits of the resources available for investment in research and development for new varieties in organic agriculture as a consequence of external (e.g. investments by the breeding industry, budget for research) and self-imposed restrictions (e.g. standards and practices). Therefore, organic farmers cannot access crop varieties suitable for their heterogeneous environmental conditions.

This lack of quantity and quality of organic genetic material is caused by a limited number of companies and individuals participating in organic breeding activities (Desclaux et al., 2006).

- **Lack of organic seed regarding to farmer needs**

  Cultivars that perform well in conventional production systems are not necessarily high performers in organic agriculture. This non-adaptation of conventional varieties for organic agriculture is described in detail by Murphy et al. (2007), Wolfe et al. (2008) and Reid et al. (2011). In this context, the BRESOV project, "Breeding for resilient, efficient and sustainable organic vegetable production" also targets increasing the competitiveness of three important vegetable crops (broccoli, green beans and tomatoes) by providing climate resilient cultivars selected for suitability for organic vegetable production systems (EUCARPIA, 2021).

- **Lack of different organic agriculture resources in institutional experimental platforms**

  Almekinders and Elings (2001) paid attention to the Genotype x Environment interaction in PPB because it as an important issue in plant breeding particularly suited to PPB where selection occurs in diverse local environments (Morris and Bellon 2004) with specific management conditions that are relevant to each participating farmer.

  Growing conditions on organic farms also can be vastly different than those found on high-input, conventional farms/breeding stations (Drinkwater et al. 1995; Bengtsson et al., 2005). The application on organic farms and their management seems to be worthwhile to find varieties able to adapt to organic systems and organic management practices (Shelton and Tracy, 2016, Desclaux et al., 2006). Therefore, Ceccarelli (2006) recommended the decentralisation of trials and PPB in heterogeneous environments to meet requirements of users where not only traditional criteria (e.g. yield and stability) should be used.

1.4 Overview of impacts and strengths of PPB despite limits

Despite limits PPB received only researchers' and breeders' disapproval. Some solutions to face difficulties are reported in several studies:

- PPB is at crossroads between agronomy and sociology, a lot of questions are raised about its accuracy and representativeness. Van Etten et al. (2016) subscribed to the theory of "Wisdom of crowds principle" as defined by Surowieckim (2005), who analysed the diversity of points of view, independence of observations, uses of technologies as well as the accuracy reliability and validity of results. Under such conditions, the "Wisdom of crowds principle" explains that the average value from a large collection of noisy but independent measurements tends to give the correct answer and so PPB is suitable (Steinke et al., 2017).
- PPB must not be used just for the legitimisation of breeding programs. Van de Fliert and Braun (2002) reported that early approaches at farmer engagement treated them more as research subjects, rather than true collaborators. Jones et al. (2014) analysed projects of PPB according to 2 axes: the type of participation (from consultative, to collaborative and collegial approach) and the outcomes of participation (from manipulative, instrumental to empowering).
- The Organic Seed Alliance on Participatory Plant Breeding Toolkit (2012) underlined that PPB, projects can be sabotaged by unspoken and unrealistic expectations, unmet needs and unclear responsibilities. The prioritisation of targets must be set as well as potential conflicts between goals be clearly identified. Goals must be clear at the beginning for all stakeholders. They advised that a breeding project should not attempt to actively select more than five traits at once. Van Etten et al. (2016) and Van Etten (2011) recommend the Triadic comparisons for exchange of observations which means the comparison of only 3 varieties to limit the difficulties of farmers estimation and evaluation. This PPB approach was used often with success in development programs even when farmers were dealing with difficulties of communication or illiteracy.

Expected impacts of PPB are potential costs reduction, early adaptation of genetic material, adoption of materials, creation of new networks of farmers and stakeholders and creation of a community of knowledge.

- Van Etten et al. (2016) and Morris and Bellon (2004) considered the costs of PPB. Significant cost reduction could be done because field staff time costs are reduced thanks to many tasks being potentially carried out by farmers. But the management of a group of farmers together with the communication and exchange of information with farmers can be time consuming. The diversity of programs, climate and crops are some of factors which can considerably affect costs of PPB in different situations.

- PPB can have an accelerating effect on breeding programs. Earlier cooperation with farmers/produces enables an adaptation of early lines and an adoption of materials adapted for farm conditions (Morris and Bellon, 2004; Joshi et al., 2014). Long-term programs are often most powerful for adoption of innovations, but PPB can be done within a relatively shorter period in comparison with traditional breeding and can accelerate the adoption of innovation and of adapted varieties (Witcombe et al., 2003; Joshy et al., 2001).
- One key outcome of PPB is the establishment of operational networks between farmers, researchers and breeders. A good relationship together with developing a common framework of shared goals is essential for the success of PPB. Desclaux et al. (2006) reported unexpected requests of farmers to learn more about breeding and the managing of biodiversity.
- Morris and Bellon (2004) presented different papers that analysed the issues of PPB in the context of accepted plant breeding theory (e.g. Atlin et al., 2001; Witcombe and Virk, 2001) which could draw on the experience gained through formal plant breeding to strengthen PPB methods (e.g. Bänziger and Cooper, 2001; van Eeuwijk et al., 2001). Whereby the potential of PPB has not been fully explored but is likely to create more positive impacts and results in coming years.

2. Why we perform farmer participatory trials (FPT)?

On-farm trials have always been a component of agricultural production as many farmers when looking at a new variety, fertiliser product or pesticide will grow a small area/block within a field and observe differences in growth, yield, disease resistance, etc. in comparison to their other varieties/management practices. This then enables a farmer to assess the performance of that variety/product under his/her specific growing conditions with minimal risk. Though farmers observe and experiment with a unique set of conditions each time they grow a crop, the scientific requirement to control variation for statistical analysis has meant that many farmers therefore carry out non-scientific demonstration and non-replicated trials, i.e. single plot. There exists the potential of developing innovative on-farm research using FPT, which enables an understanding of farmers' goals and constraints while incorporating and using their technical and practical knowledge. The essential basis of farmer-participatory research is collaboration between farmer and researcher to address issues in agriculture with the goal of increasing research output/impact. Collaborative research is a key component of developing sustainable agricultural systems to meet the demands of population growth and FPT provide a clear opportunity for farmers and researchers to work together to address practical issues and challenges.

A primary advantage of farmer-participatory research is the opportunity to evaluate agricultural practices under conditions in which they are ultimately intended to be used i.e. a farmer's field. Cultivars, inputs and management strategies that are effective at researcher trial sites under controlled conditions – often on good soils - may react differently on a commercial farm. FPT allow for analysis under realistic farm conditions at a relevant scale for commercial production with the potential to carry out on-farm economic and environmental evaluations. Farmers often question how applicable data and information from small-plot experiments is to their farm where conditions and management practices are often very different. Farmer-participatory research also provides insight into site-specific effects, which allow researchers to evaluate techniques outside of experimental fields which can help farmers improve their understanding of practices that best suit their farm conditions.

Farmer-participatory research also facilitates networking and collaboration between farmers and researchers. Trials focused on a particular aspect of crop production bring interested stakeholders together to exchange ideas and experiences and provides opportunities for stakeholder networking and demonstration of best practice. This type of participatory research encourages broader knowledge exchange between growers and researchers, as new practices and products can be widely disseminated through online resources. Farmers are likely to adopt new practices through participation in on-farm trials, especially after experiencing a productivity increase or other agronomic benefit on their own site.

While farmer-participatory trials have considerable potential there are several limitations as farmers are wary of the time and resource requirements while researchers have concerns over their ability to control experimental conditions. Farmer-participatory trials often require farmer time and resources which results in additional costs to the farmer. To produce publishable research from participatory trial studies, robust trial monitoring, record-keeping and data collection needs to meet scientific research standards which means that much more time and effort is required than for typical production operations. Yield data is of particular interest in farmer-trials, yet harvest is a very disruptive time, as farmers rush to complete harvest within a restricted timeframe and farmers are generally concerned about reduced yields and/or poorer Gross Margins based on experimental conditions. For the success of FPT a balance needs to be struck to allow for reliable and robust data collection and management with minimal disruption to normal commercial farm activities.

The complexity of managing multi-site FPT is often a concern for experimental design and management. If on-farm data collection is intended to be the responsibility of the farmer, simpler designs are preferred by farmers to reduce the risks of incomplete and inaccurate record-keeping. While simple non-replicated trial designs are easier for farmers, they generally lack the accuracy/robustness to draw reliable conclusions which often results in a conflict between researcher and farmer. Researchers are generally focused on creating robust experimental designs to enable statistical analysis while farmers are more concerned with a simple evaluation/comparison concerned with profitability. A successful FPT therefore needs to provide a balance between the needs of farmers and researchers, striking a balance between experimental complexity and practical operation.

In the ECOBREED breeders/researchers and farmers plan and evaluate the FPT together. Researchers suggest a number of varieties to be evaluated in the trials based on their past performances while farmers suggest additional varieties which are often ones they are currently growing to enable a clear comparison of variety performance. Some varieties should be grown on all farms with similar climatic conditions to enable statistical analysis where individual farms can be used as replicates. The new thing for farmers is the international exchange of varieties. For example, Austrian farmers growing varieties from Slovakia and Slovakian farmers growing varieties from Austria that they had no previous knowledge or experience of. Another new aspect for farmers is the inclusion of heterogeneous populations.

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The number of farms within an individual country in the ECOBREED project is between 4 and 6 per crop which enables exchange of knowledge both within and between countries. Another possible strategy for FPT is working with more farmers but less genotypes per farm (crowd sourcing field trials).

Everybody can order seeds from national genebanks. However, the number of seeds is usually very small (e.g.10 – 20 seeds) which causes difficulties in agricultural crops and a considerable amount of time is required to multiply the seed. A farmer who wants to evaluate genetic resources on his farm should start to work by hand with special plot machines. After some years there is enough seed to be able to sow with his usual farm equipment. Therefore, ordering seeds from a genebank is often not a feasible option for many farmers in the EU. Associations for maintenance of old varieties like VERN or Arche Noah can support farmers by multiplying first generations, evaluating and maintaining the varieties.

Traditional knowledge, activities of stakeholders, availability of genotypes and satisfaction of the farmers with the situation is different from crop to crop and from country to country. In some crops like wheat varieties from conventional breeding programmes, organic breeding programmes, old varieties/landraces and new heterogeneous populations are already available.

Not all assessments take place in the field. After harvest assessments, such as protein content or other quality aspects have to done. These criteria are also important for choice of variety for farmers. All the results are discussed intensively with participating farmers and stakeholders.

3. Do I need to breed? Saving, selecting or crossing varieties?

In most cases it is not necessary that organic farmers start their own breeding programmes. If a farmer likes a variety that is not available in the market anymore and as a result has not been protected for some year's they can save the variety on their farm or with colleagues. It is possible to register the variety as a 'conservation variety' if the farmer wants to sell the seed in future. For saving seed it is also necessary to have smaller plots/areas to maintain the original characteristics constant from year to year. Original characteristics could be improved by removing unwanted plants e.g. ones with high disease levels. It is also necessary to intensively check seed quality every year.

Susceptible varieties (e.g. disease), which produce high quality crops (e.g. high grain protein) could be mixed with others varieties (varietal mixtures) to hide the weakness of an individual. A mixture of many different crosses is a population. Self-pollinated crops should be crossed to get a population; however, in cross-pollinated crops this occurs naturally. Plants of preference can be selected and this is an important part of the breeding process.

If existing varieties on the market do not fit farmer's requirements, crosses to recombine the traits of interest should be made. Before crossing there is a need to know very well the traits of parent plants. For example, if a variety which combines the traits of malting quality and long straw for barley is needed, while all the available varieties have either long straw or brewing quality the contrasting lines trying to find recombinants which include both characters should be crossed. This would be very difficult if the loci involved in the traits are associated (close on the same chromosome) and to increase the chance to have a recombinant, the progeny should be wide.

The target environment should always be considered. A variety from big company (often multi-national) is supposed to work in many regions. However, if breeding/selection is targeting a specific farm or region the suitable variety only needs to be adapted to the local environmental conditions. Furthermore, varieties bred/selected under good environmental conditions (good soil, mild weather, good nutrient supply) sometimes fail under more difficult heterogeneous organic conditions.

Rule 1: Take a look at what already exists

Rule 2: Reflect on what you want

4. Seed regulations in the EU

4.1. Variety protection, variety registration, organic varieties and organic heterogenous material

Seeds of protected varieties have to be multiplied under national seed laws. This usually includes a certain distance from fields with the same species, one or several field visits to the multiplication site by an authorised inspector and requirements on purity, germination and absence of diseases. Seed quality has to be checked by an official certified laboratory.

Plant breeders' rights are the rights that give the plant breeder the exclusive control over the propagation of a variety for several years. For getting this right the variety has to be new and has to fulfil DUS (Distinctness, Uniformity, Stability) criteria. The variety has to be distinct from all other known varieties in at least one botanical characteristic e.g. plant height, disease resistance, etc. It has to be uniform i.e. plant characters are the same on all plants and have to be stable from generation to generation. This has to be proven in an official registration/evaluation process that lasts for 2 or 3 years. For some crops in this registration process also the VCU (Value for Cultivation and Use) criteria have to be fulfilled. That means that at least one characteristic, e.g. disease resistance, has to be better than the varieties already registered. For some crops with small areas of production e.g. buckwheat protection is possible without the registration process. In some countries the registration process is also carried out under organic conditions for some crops. The breeder gives the variety a name that must be used by anyone who markets the variety.

Conservation varieties (old varieties) can be registered but not protected. For conservation varieties the quantity of seed that is sold can be limited at a national level. For seeds to be "organic" multiplication has to be done for a minimum of one year under organic certification conditions for annual crops. Organic seed of a variety can come from a conventional or from an organic breeding programme. If a variety was tested during registration under organic VCU conditions the variety can be called "tested in organic".

The new **organic regulation** (848/2018) starting in 2022 is introducing new categories of varieties for organic agriculture: organic varieties and organic heterogenous material. An organic variety must be developed under organic conditions and it needs to have high genetic diversity. So, a new DUS procedure will be needed for organic varieties. The criteria for the first crops will be developed in seven-year experiments starting 2022. Organic heterogenous material (OHM) is not a variety. OHM also has to be multiplied under organic conditions at least for one year. OHM can be registered but cannot be protected. For organic varieties it is not yet clear whether they can be protected.

4.2. Breeder and farmers rights in the EU

“Plant breeders’ rights” are the rights that give a plant breeder the exclusive control over the propagation, and selling or earning a compensation, of a variety for a set time, often 20 or 25 years. For getting this right the variety should be new and fulfil DUS and VCU criteria (for more information see Pedersen et al., 2021). There are exemptions for breeders who may use protected varieties to create new varieties, for research purposes and non-commercial use and patents could hinder this (Rutz, 2010).

“Farmers’ rights” are not only the rights of a farmer to save, use, exchange and sell seed that they have produced i.e. farm-saved seed. Farmers rights also include the right of farmers to participate in decision making, protection of traditional knowledge and the right to participate in sharing benefits arising from the use of plant genetic resources (Andersen, 2010). In the ITPGRFA (International Treaty on Plant Genetic Resources for Food) Farmers’ Rights are an important cornerstone linked to maintenance of crop genetic resources and crop genetic diversity (Andersen, 2010).

Farmers may use their own seeds of a protected variety (except from hybrids or synthetic varieties) (Rutz, 2010) however, the crop must be on a positive list (EU 2100/94, Art 14). For example, soya or white lupins are not on this list. It is also possible that the farmer pays a fee to the breeder for using his seed if the variety is protected. Some breeders have started to prohibit the use of their own seed in a private contract with the farmer (e.g. new varieties of emmer). A farmer must not sell seed of a protected or registered variety from the species directory of crops to another farmer (Rutz, 2010). Seed multiplication and exchange of a protected and registered variety from the species directory (EU plant variety database) should always be done within the framework of the seed laws. A variety can be registered without protection. For some minor crops (e.g. buckwheat, emmer) which are not listed on the species directory a variety can be protected but not registered and a farmer would be able to sell the seed. A farmer or seed company can apply for a volunteer seed certificate. It is possible that there are different interpretations on this in different EU member states.

Farmers’ activities should concentrate on older varieties/conservation varieties (without protection) and populations. Populations/OHM cannot be protected but it is possible that the breeder makes a contract with the farmer on the use of their varieties in developing a population. Populations of wheat, barley, oats and maize can be registered for experimental use at the moment. From 2022 onwards the organic EU regulation will permit the registration of populations (organic heterogenous material). The conditions have been published in a delegated regulation (EU C/2021/3163) but only one year of multiplication under organic conditions is mentioned. While, a minimum number of crosses (e.g. for composite cross populations) is not mentioned.

In the ECOBREED project, farmers communicate with breeders, but they can also develop their own activities, while in some cases farmers work with old landraces which are often similar to populations (e.g. wheat in Greece). However, most of the work is devoted to the new composite cross populations (CCP) which over time will slowly adapt to regional conditions. As previously explained, during the development of CCP farmers will discard susceptible plants (e.g. high disease levels) and select the resistant ones. This is one of the topics that will be discussed at meetings with farmers and in the training events.

There is the further possibility of internal use by a farmer or a farmers group if the breeder agrees. It has to be done on a contract base and it is not permitted to sell the seeds. Internal use of a “club variety” could be interesting for a small crop or a specific regional use because of certain traits. But still the sale of seed is only possible in the EU for crops not on the species directory list of crops for seed production e.g. buckwheat. A farmer or a group of farmers can collaborate and can find a company to start multiplication of seeds within the seed laws. They can also build up their own community or farmers’ seedbank.

There are also initiatives for alternative concepts like the ‘open source seed licence’ initiative. Like in computer programmes the variety is free but the user has to agree that the entire outcome remains freely available. But a variety has to be registered to be introduced in such a system.

There are some international regulations on access and benefit sharing of genetic resources. Key pieces of legislation are the CBD (Convention of Biological Diversity), the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from the Utilisation to the ITPGRFA. As countries sign these agreements, they are establishing national systems to implement them (Vernooy *et al.*, 2019).

5. Basic terms of plant breeding

5.1 Method of crop plant reproduction

Self-pollinated crops: The flowers of self-pollinated crops have evolved strategies to exclude pollen from other plants to prevent cross-pollination, such that the offspring are identical to their parents. Self-pollination does not require wind or insects to aid pollination and it is much easier to maintain a self-pollinated crop. Examples of self-pollinated crops are the major cereals wheat and barley, but also soybean and potato.

Cross-pollinated crops: Cross pollination is the opposite of self-pollination, where pollen in transferred between plants of the same species such that the offspring are genetically different from each parent plant. Producing and maintaining homogeneous cross-pollinated crops is more difficult as the plants need to be isolated by either distance or by cages. You need much more distance or effort for isolation. But the central advantage of cross-pollinating plants is that they can adapt to different environments. Examples of cross pollinated crops are rye and buckwheat. There are also crops which exhibit both self-pollination and cross pollination, e.g. fava beans.

Vegetative propagated: Plants that propagate vegetatively, as potato, have advantages directly in the second generation. After a cross of two parents a single plant with good characteristics could be selected and maintained by cloning it.

5.2 Chromosomes, genes and alleles

In plants, animals and humans, DNA is bundled together into ***chromosomes*** which contain many genes (Fig. 1). Most crop species are diploid, meaning they have two sets of chromosomes: one set from their mother and one from their father. Some crops have even more sets of chromosomes, e.g. durum wheat has four sets (tetraploid), bread wheat and spelt have six sets (hexaploid). Cultivated potato landraces can range from diploids (2n = 2x = 24) to pentaploid (2n = 5x = 60). In the meiosis chromosome sets are split. Sperm and egg cells carry only one set of chromosomes such that half of genes will come from the father and half from the mother. A **gene** is a small DNA section that carries information for the expression of a trait. Usually, there are several genes involved in the expression of one trait e.g. flower colour. An **allele** is a variant form of a given gene. The gene carries the information about a trait (e.g. flower colour) whereas the allele determines the possible variants of that trait e.g. flower colour could be red, white, blue, etc. An allele is either dominant or recessive. Dominant alleles are by convention indicated with upper-case letters (e.g. “A”), recessive alleles with lower-case letters (e.g. “a”).

5.3 Heterosis

The term heterosis describes the phenomenon that the offspring is superior to its parents (Fig. 1). Heterosis is often used in hybrid breeding and therefore is also known as hybrid vigour.

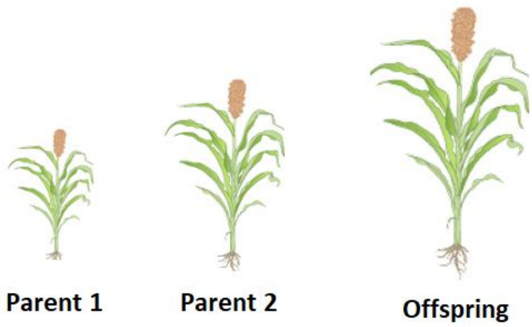


Fig. 1 Heterosis where the offspring exhibits hybrid vigour i.e. superior to both of its parents (Sophie Egerer)

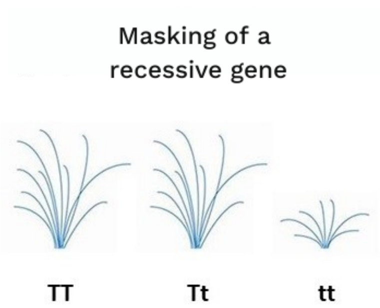
Why can this happen? Two loci that are responsible for plant height are linked. For example, Parent 1 has AAbb and parent 2 has aaBB. The offspring has AaBb where A and B are dominant to a and b. Often traits relate to many genes.

5.4 Inbreeding depression

Inbreeding depression is the reverse of ***heterosis***. It results from the accumulation of ***homozygous*** pairs of rare and detrimental ***recessive alleles*** due to continued self-pollination or crossing similar plants.

5.5 Homozygous and heterozygous

If a plant has got two copies of an allele one can be dominant (A) giving the dominant phenotype regardless of the situation at the other allele. You cannot determine in the phenotype whether it is homozygous (AA) or heterozygous (Aa). When crossing two parents with Aa some of the offspring can have the combination aa i.e. exhibit the recessive trait (Fig. 2).



Self polination in a homozygous plant

Parental alleles	T	T
T	TT tall	TT tall
T	TT tall	TT tall

Self pollination in a heterozygous plant

Parental alleles	T	t
T	TT tall	Tt tall
t	tT Tall	tt short

Fig. 2 Possible combinations of dominant and recessive alleles (adapted from White and Connolly, 2011)

5.6 Dominant or recessive genes

Recessive genes can be masked and can appear by crossing.

5.7 Selection

In mass selection individual plants are selected in a population and decisions are made based on the phenotype. But be aware of the risks: environmental factors can have a major influence on the phenotype of some traits, e.g. differences in soil or soil fertility can result in different phenotypes of plants (such as plant height) and furthermore it is not known if undesirable ***recessive*** genes may be carried by the selected plants in a hidden ***heterozygous*** state. It can be useful to divide the field into several sections (reps) and choose an equal number of plants from each section (positive selection). Negative selection can also be done by eliminating undesirable plants.

5.8 Crossing

Crossing of a self-pollinated crop involves two major steps. The first step is emasculation where the anthers of the female parent are removed to prevent self-pollination. Depending on crop this can happen before the flower starts to open. Some days later a second step is crossing whereby pollen from the male parent is applied usually via a small paint brush to the stigma of the female parent, which is then maintained in a bag to prevent further pollen transfer.

5.9 Heritability

Heritability is the likelihood that a trait present in a parental plant also appears in the offspring. Some traits are greatly influenced by the environment and have a low heritability (e.g. stress, heat or drought tolerance). Breeders aim to select for traits that have a high heritability and only a small influence from the environment. It is difficult to select for traits that have a high environmental component e.g. HFN in wheat.

5.10 Bottleneck

For crop improvement it is necessary to have variability in the parents. In some crops genetic diversity is low so that the resulting lines are quite similar (bottleneck). Breeders try to increase variability by crossing with landraces, wild relatives of crop species or by causing mutations (use of radiation, chemicals, Crispr-Cas). Some of these methods for causing mutations are seen negatively within organic agriculture. Another problem of low genetic diversity is that a disease can cause great damage e.g. *Phytophthora infestans* on potatoes in Ireland in 1845. Diversity can also get lost when focussing on single traits over a longer time period e.g. higher yield.

5.11 General scheme: Breeding of lines

The breeding of new varieties is carried out using several different schemes/techniques of which the Pedigree method is the most common one in use (Fig. 3). In this system selection is carried out in early generations F2-F6 where heterozygosity is at its highest. This starts by the crossing of two selected parents:

- F1 harvest of seed (no selection due to uniformity of the offspring)
- F2 selection of best single plants
- F3 single row based on single F2 harvested ear + further selection
- F4 non replicated small plot (6-12 rows) + further selection
- F5 replicated and randomised field trials

Bulk breeding: All seed from the early generations is retained with selection occurring during later generations i.e. F5-F7 where the bulk population has had time to adapt to the environment.

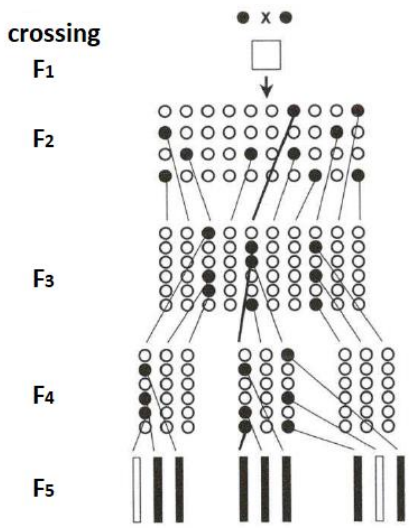


Fig. 3 Selection scheme for the Pedigree breeding system (adapted from White and Connolly, 2011)

5.12 Breeding of populations

A population is more than a mixture of varieties. Old landraces often are genetically heterogenous populations (www.diversyfood.eu). A population/organic heterogenous material is not stable and therefore the current methods of uniformity and stability used for variety registration are not appropriate (C2021/3163). They cannot be described easily, every plant can look different and the next generation can be different from the original one. But the particular characteristics have to be described for registration (C/2021/3163).

For cross pollinated crops population varieties are a usual strategy. You can choose certain plants from a population. The plants of a population variety look similar and generations are relatively stable so they can be described by the DUS criteria. But a cross pollinated population will always look more heterogenous than a pure-line variety of a self-pollinated crop or a F1 hybrid.

Composite cross populations (CCP) consist of crossing several parents (any type of varieties) during one or several consecutive generations. The more crossings that are made, the more recombination events and possibilities for new genotypes to be generated (www.diversifood.eu). For self-pollinated crops you have to cross by hand, whereas cross-pollinated crops randomly mate easily.

5.13 Resistance and tolerance

If resistance is linked to a single gene, it is most often not permanent and can break down easily this is the case for many fungal diseases of plants where resistance to the disease can break down quickly. Pathogens can mutate and produce new races which overcome the resistance easily. In polygenic resistance many genes are interacting against the disease such that the resistance is more durable. But it needs a very large number of plants to create polygenic resistance. In some cases, it is not necessary to have complete resistance against a disease while it is better to have plants that can tolerate the disease.

5.14 Field design

Be aware that the conditions within a field can be different. It is important to use plots that are not too small to limit the effects of this variation.

5.15 Seed quality

If enough seed is available seed quality should always be checked. Bunt (*Tilletia*) is an important disease which is common in wheat and its relatives and is generally effectively controlled by seed treatments in conventional agriculture which are not available to organic growers. The number of spores per seed should be <10, better close to 0. Bunt spores are on the surface of the seed and can be removed e.g. by brushing or steam. Seed germination should also be checked at 10°C. One of the ECOBREED projects aim is to identify and evaluate bunt tolerant varieties suited to organic production.

5.16 Scoring

Scoring of characteristics e.g. diseases, length, maturity, is often done using a numerical scale from 1 to 9. Generally, 1 means low, short or early while 9 means high, long or late. Crop development can be expressed with days after sowing

(DAS). In the next sessions scoring methodologies for wheat, potato, soyabean and buckwheat are outlined.

6. Farmer Participatory Trials for variety selection; Defining important crop traits in a participatory way

As previously explained, Farmer Participatory Trials (FPT) will ensure that varieties will be evaluated under "real life" conditions. In order to select important traits for the various crops that match the specific requirements of organic farmers, prior to conduction of on-farm trials participating farmers are asked to assign levels of importance to a list of traits pre-selected by breeders/researchers as well as to add not listed traits (see examples of list in the Appendix). Ratings are added up to create cumulative weights for each trait in the selection index. Breeders/researchers then identify the traits of importance that will be measured in the field and/or lab. Results of trials have to be discussed with farmers and stakeholders for further decisions.

6.1 Wheat

Fig. 4 ECOBREED organic wheat trial

Wheat with an area of 2.18 M ha is one of the most important crops worldwide. Some of its relatives the ancient wheats Einkorn (*Triticum monococcom*) and Emmer (*Triticum turgidum* ssp. *dicoccum*) were developed about 10,000 years ago in the south of Turkey and/or Sinai. Hexaploid wheat (*Triticum aestivum*) appeared about 8,000 years ago. There are some relatives with four pairs of chromosomes (durum wheat, Kamut) and six pairs of chromosomes (spelt). Wheat is a self-pollinating crop. As wheat is an important crop in most countries of the EU many varieties are available. However, most modern wheat varieties are semi-dwarf which provides a higher potential yield under a high input environment but have negative effects because of reduced competitiveness against weeds and increased sensitivity to Septoria tritici and Fusarium spp. (Hilton et al., 1999: Simon et al., 2004).This increases the need for herbicide and fungicide inputs in conventional production systems but reduces yield potential in organic systems where such inputs are not permitted. Important traits could therfore be yield, baking quality, disease resistance, standing ability, winter hardiness, drought tolerance and further quality parameters (durum for pasta production).

Often organic seed is available and in some countries the use of organic seed is mandatory. Organic seed can be derived from conventional breeding programmes, conventional breeding programmes with selection under organic conditions, organic breeding programmes, old varieties/landraces and populations. Whereas good quantities of older varieties are available in some countries the production of populations is a relatively new option. There are already some populations (composite cross populations) available so trials with populations in wheat will start in2020-21. These populations often look different. Whereas ears of the “Liocharls” population from Dottenfelder Hof in Germany look very different while ears of the “MV elite CCP” from Hungry look similar. There is a wide range of characteristics available in the EU, for example drought tolerant varieties with early maturity and more recently some varieties with good resistance to common bunt. There are few problems in production of organic wheat in the EU. New varieties from conventional breeding programmes have often very short straw which can cause problems with weed suppression. A new tendency is that conventional breeders focus more on developing wheat hybrid varieties. For these varieties farmers cannot use their own seed anymore. Furthermore, farmers used to save their own seed, however this is now restricted due to the absence of cleaning facilities and the appearance of diseases (such as bunt, fusarium etc). Some new varieties from organic breeding offer good resistance against bunt.

Wheat phenotypic traits selected for ECOBREED FPT:
Winter hardiness
Ground cover
Heading
Plant height at flowering
Stem Lodging
Maturity
Grain yield
Insect damage
Foliar and ear diseases important to various countries

Descriptors for the collection of background climatic and agronomic information and phenotypic traits for ECOBREED Wheat (*Triticum* L.) FPT trials are presented in Appendix II. Examples of data recording sheets for wheat FPT are presented in Appendix III.

6.2 Potato

Fig. 5 Potato field in Austria

Potato is the fourth most important crop for human consumption after wheat, maize and rice with over 19 M ha worldwide. The yield gap between organic and conventional potato production systems is much greater (up to 60% lower yields in organic systems) and has been mainly attributed to inadequate control of pests and diseases that can be effectively controlled by fungicides, particularly late blight caused by *Phytophthora infestans*. The potential future exclusion of copper fungicides from organic potato production is likely to have further negative effects on late blight control and yields, while low nutrient use efficiency and sub-optimal fertilisation regimes have also been reported to contribute to lower yields.

The origin of potatoes is South America with the oldest traces of wild potatoes being 13,000 years old. Multiplication potato is done vegetatively by tubers but also can be done by seeds. Potatoes are predominantly a self-pollinating crop where not all varieties produce berries and some of them lose the flowers after pollination. Potatoes are an important crop in most countries of the EU where many varieties are available. Often organic seed is available, while in some countries use of organic seed is mandatory. There are many different varieties available with differences in maturity, taste and many other criteria, new and old ones. There is no organic breeding programme for new potato varieties in the EU up to now. There is some maintenance of old varieties on some farms and some initiatives. Potato multiplication at a larger scale is in the hand of specialised farms because it is not easy to do. As a result of vegetative multiplication, it is important to remove diseased plants, especially in the case of virus infections.

ECOBREED project is not planning to develop populations of potatoes because farmers and consumers are not in favour with each plant having different characteristics e.g. taste. The ECOBREED project has given early lines to farmers (about 10 tubers per line) for evaluation of performance in the field. Important traits in breeding are yield, disease resistance and tolerance, quality, taste while the focus in ECOBREED project is the development of late blight resistant varieties. Late blight causes heave losses in organic farming in many European countries.

Potato phenotypic traits selected for ECOBREED FPT:
Days to emergence
Canopy closure
Disease levels
Insect damage
Days to maturity
Yield
Tuber size and number
External and internal tuber defects (such as secondary growth, growth cracking, hallow heart, black heart, tuber rots, *Rhizoctonia solani*, scab, silver scurf)
Cooking quality (such as mealiness, flavour)

Descriptors for the collection of background climatic and agronomic information and phenotypic traits for ECOBREED potato FPT trials are presented in Appendix II. Example of data recording sheets are presented in Appendix III.

6.3 Soybean

Fig. 6 Soybean production in Germany

Soya is a very important crop worldwide with 125 M ha planted with a large proportion of that being genetically modified (GM) varieties. Soya is used both for animal feed and human consumption and use as an arable crop has been known in Japan for 5000 years and in Korea and China for 3500 years. Production worldwide has increased substantially since the 1960s. Increased organic soybean production in Europe requires development of genotypes with increased; drought and cold tolerance, competitiveness against weeds, capacity for symbiotic N fixation, and resistance/tolerance to pests and economically important diseases. Particular emphasis should be on developing resistance/tolerance to diseases such as *Macrophomina phaseolina* (charcoal rot) and *Diaporthe* spp. and pests which are thought to expand their geographical range e.g. two spotted spider mite (*Tetranychus urticae*) and southern green stink bug (*Nezara viridula*). Soybean production for human consumption accounts for a small fraction of the soybean market globally, but the soy food industry is growing.

Soya is a self-pollinated crop and with breeding for earlier maturity soya having reached more northern countries like Canada and Germany. Often organic seed is available. There are a few organic breeding programmes for new soya varieties which are mainly linked to special traits for processors, e.g. quality for tofu production. As breeding for earlier maturity is a relatively new development there are no older varieties with early maturity available. Many companies and universities started breeding soya as it is expected that production in the EU will increase and expand into regions with a colder climate.

A soybean population will be developed within the ECOBREED project and will be evaluated in the second year of FPT.

Soybean phenotypic traits selected for ECOBREED FPT:
Time to emergence
Plant density
Time to flowering
Height of the lowest pod to soil
Plant height
Disease levels
Insect damage
Canopy closure
Time to maturity
Pod shattering at maturity
Yield

Descriptors for the collection of background climatic and agronomic information and phenotypic traits for ECOBREED Soybean FPT trials are presented in Appendix II. Example of data recording sheets for wheat FPT are presented in Appendix III.

6.4 Buckwheat

Fig. 7 Buckwheat trials in Italy

The first buckwheat production was most likely in China. Oldest traces in the Black Sea region are about 9000 years old. The most important time of buckwheat cultivation in Middle Europe was in the Middle Ages before potatoes were introduced. In spite its name, Buckwheat is not a relative of wheat but is a pseudo-cereal rather than a true cereal. It was grown widely in the past, but recently has been identified as having clear nutritional benefits and being suitable for the manufacture of gluten-free products. The demand for buckwheat, and in particular organic buckwheat has increased rapidly in recent years and is largely met by imports from outside the EU, particularly from Russia and China. Buckwheat has a range of agronomic benefits suited to an organic environment including high nutrient use efficiency and weed competitiveness/ allelopathy when compared with modern wheat cultivars. There has been a clear decline in the presence of insect pollinator groups in recent years with potential impacts on the future sustainability of crop production. Buckwheat has the potential to increase the presence of important pollinator species in agriculture, a key strength of organic production (Taki et al., 2009). There are very few climatic constraints on buckwheat, which means that it can be grown in most European countries, although the availability of buckwheat varieties is a key factor limiting this potential growth. Buckwheat is a cross-pollinated crop. Buckwheat is not covered by the EU seed laws for seed certification, but a variety can be protected. Dehulling of seeds is complicated and only few companies offer this service.

The amount of buckwheat varieties with seeds available in the EU is limited, maximum of 20 and organic seed is often not available. Breeding activities in the EU have been low in recent decades. But there has been an increase of production in recent years. Buckwheat is also used as an inter-crop after harvest of cereals, also in mixtures with other species for use as cover crops. So, some farmers could produce buckwheat seed for their own inter-crop mixture. The main problem of buckwheat production is the low uniformity of flowering and maturity.

A population will be developed in the ECOBREED project and will be evaluated in the second year of FPT.

As buckwheat is not at present on the species directory of crops in the moment, farmers may sell seed of not protected varieties to other farmers in most EU countries. In some EU countries there are national regulations on buckwheat seed.

Buckwheat phenotypic traits selected for ECOBREED FPT:
Days to emergence
Days to flowering
Plant height
Lodging
Branching
Days to maturity
Yield

Descriptors for the collection of background climatic and agronomic information and phenotypic traits for ECOBREED Wheat buckwheat FPT trials are presented in Appendix II. Example of data recording sheets for wheat FPT are presented in Appendix III.

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Appendix I: Draft questionnaires for trait selection

1. Wheat

What are the important traits for you?

Trait	Yes	No	Not sure
Yield			
Yield stability			
Quality			
Disease resistance, examples			
Other			

What are the key challenges for organic compared to conventional production in your region?

Trait	Reason	Yes	No	Not sure
Yield	Less nitrogen			
Yield stability	Varieties			
Weed suppression	No herbicides			
Baking quality	Less nitrogen			
Other				

2. Soybean

Which are the most important traits for your crop?

Trait	Yes	No	Not sure
Yield			
Yield stability			
Quality			
Height of lowest pod			
Lodging			
Maturity			
Other			

Which are the key challenges for organic compared to conventional production in your region?

Trait	Reason	Yes	No	Not sure
Weed suppression	No herbicides			
Vegetative growth and canopy formation	Varieties			
Suitability for human consumption	Varieties			
Other				

3. Potato

Which are the most important traits for your crop?

Trait	Yes	No	Not sure
Yield			
Yield stability			
Disease resistance e.g.			
Taste			
Other			

Which are the key challenges for organic compared to conventional production in your region?

Trait	Reason	Yes	No	Not sure
Yield	Less nitrogen			
Late blight	No fungicides			
Other diseases	No fungicides			
Viruses	No insecticides			
Tuber size	Less nitrogen			
Other				

4. Buckwheat

Which are the most important traits for your crop?

Trait	Yes	No	Not sure
Yield			
Yield stability			
Quality, e.g. seed size			
Processing quality			
Other			

Which are the key challenges for organic compared to conventional farming in your region?

Trait	Reason	Yes	No	Not sure
Yield	Less nitrogen			
Yield stability	Varieties			
Uniformity of maturity	No desiccants			
Other				

Appendix II: Descriptors for the collection of background climatic, agronomic information and phenotypic traits for ECOBREED FPT trials

1. Descriptors for the collection of background climatic and agronomic information for ECOBREED FPT trials

Climatic parameter	Unit	Notes
Average air temperature	^{o}C	Daily averages from planting to harvest
Total precipitation	mm	
Solar radiation	MJ $m^{-2}d^{-1}$	
Relative humidity	%	
Soil temperature	^{o}C	
Agronomy	**Unit**	**Notes**
Soil type		
P K pH		
Available N (NH_4; NO_3)		
Planting/ drilling	Date	
Crop emergence	Number of plants	
	emerged	
Harvest	Date	
Fertilisation	Dates, rates	Types, rates etc (nutrient content of
		fertiliser, if known), other minerals if
		Applied
Weed control	Dates, method	Types etc
Crop protection treatments	Dates, rates	Types, rates etc
Defoliation	Date, method / product	
	used	
Ridging (potato)	Dates, method	

2. Phenotypic descriptors for Wheat (*Triticum* spp.) FPT trials

Acronym	Trait	Trait category
1 WINT	**WINTER RESPONSE/WINTER HARDINESS**	**Abiotic stress**

Observation of winter damage (1-9 scale):
1 = <10% damage; 5 = 50% damage; 9 = >90% damage

Variation in winter hardiness of a winter wheat variety trial: in the foreground and background plots with about 1/3 winter damage (score 3), left and right completely destroyed plots (score 9).

Photo credit: E. Cramer, Pflanzenschutzdienst Gießen

Superficial leaf freeze damage will have no effect on grain yield (score 1).

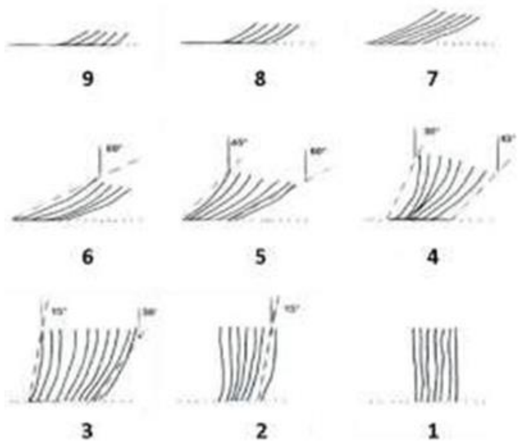
Photo credit: J. Edwards, Oklahoma State University, Extension Service

Freeze damage of about half the wheat foliage. Damage before stem elongation (BBCH 30) will have no major effect on grain yield. Reduction of grain yield depends on the amount of damaged, already elongated stems.

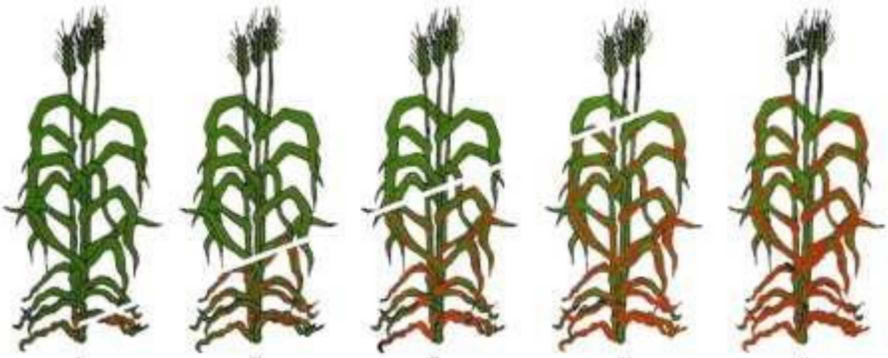
Photo credit: S. Harrision, Louisiana State University, AgCenter

Almost completely damaged wheat plants which will hardly recover and/or produce fertile stems (score 9).

Photo credit: Pflanzenschutzdienst Gießen

Acronym	Trait	Trait category
2 GCOV	**GROUND COVER** Measurement of ground surface covered by the plant in % (or on a corresponding 1-9 scale); measured during stem elongation (BBCH30-39); score all plots on the same day and record simultaneously the BBCH stage	Agronomic
3 HEAD	**HEADING** Date of BBCH growth stage 55 (middle of heading; half of the inflorescence emerged in 50% of the plants). For convenience the date of HEAD should be recorded as “days after 30 April”, e.g. 28 May = 28, 5 June = 36. For statistical analysis the date is finally converted into days after sowing.	Agronomic
4 HGHT	**PLANT HEIGHT** Height (cm) of plant at maturity, measured from ground to top of the spike (excluding awns). Measurement should be carried out at normally developed plants; border plants have to be ignored.	Agronomic
5 LO01, LO02	**LODGING**  Intensity of lodging (1-9 scale) of the majority of plants measured at (a)) heading/flowering or at an appropriate date after heading, e.g. two days after a heavy rainfall causing lodging (LO01) and (b) maturity (before harvest) (LO02). Border plants should be ignored. 1 = no lodging; 9 = completely lodged	Agronomic

Acronym	Trait	Trait category
6 PM01, PM02	**POWDERY MILDEW** Scoring of the disease (1-9 scale) at (a) end of stem elongation and/or early heading (PM01) and (b) early grain filling and/or milk dough stage (PM02); modified after Saari and Prescott (1975); it is recommended to record at the same date the BBCH growth stage	Biotic stress



Score	Description
1	A few isolated lesions on only the lowest leaves
2	Scattered lesions on the 2nd set of leaves with 1st leaves lightly infected
3	Light infection of lower ⅓ of plant; lowermost leaves infected at moderate to severe levels
4	Moderate infection of lower leaves with scattered to light infection extending to the leaf immediately below the middle of the plant
5	Severe infection of lower leaves; moderate to light infection extending only to the middle of the plant
6	Severe infection on lower ⅓ of plant, moderate infection on middle leaves and scattered lesions beyond the middle of the plant
7	Lesions severe on lower and middle leaves with infection extending to the leaf below the flag leaf, or with trace infection on the flag leaf
8	Lesions severe on lower and middle leaves; moderate to severe infection of upper ⅓ of plant; flag leaf infected in amounts more than a trace
9	Severe infection on all leaves; spike also infected to some degree

Severe powdery mildew (*Blumeria graminis* f.sp. *tritici*) infection on the lower to medium part of the plant (score 6).

Photo credit: H. Grausgruber, BOKU

Acronym	Trait	Trait category
7 LR01-LR03	**LEAF (BROWN) RUST**	Biotic stress
8 YR01-YR02	**YELLOW (STRIPE) RUST**	Biotic stress

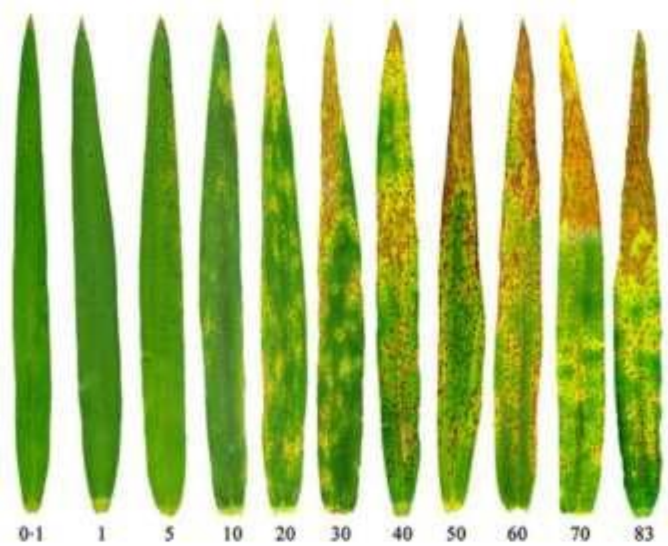
Scoring of the rust disease (1-9 scale) at (a) end of stem elongation/early heading (LR01, YR01) and at (b) early grain filling/milk dough stage (LR02, YR02); if suitable more scoring dates can be applied; it is recommended to record at the same date the BBCH growth stage; in case that some lower leaves are already dead due to e.g. leaf senescence or powdery mildew infection, only the top 4 leaves should be evaluated; use scoring system as outlined

Score	Description
1	No infection observed
2	One chlorotic spot/stripe per tiller
3	Two spots/stripes per leave
4	Most tillers infected but some top leaves uninfected
5	All leaves infected but leaves appear green overall
6	Leaves appear half infected and half green
7	Leaves appear more infected than green
8	Very little green leaf tissue left
9	Leaves dead (no green tissue left)

Severe leaf rust (*Puccinia triticina*) infection of winter wheat (score 8) on the left, yellow rust (*P. striiformis*) infection (score 6) on the right.

Photo credit: H. Grausgruber, BOKU

Acronym	Trait	Trait category
9 LB01, LB02	LEAF SPOT and BLOTCH DISEASES Scoring of leaf spot and blotch disease complex (tan spot – *Pyrenophora tritici- repentis*, leaf blotch – *Staganospora nodorum*, *Septoria tritici*) (1-9 scale); scoring should be carried out up to 2 times at appropriate dates; it is recommended to record at the same date the BBCH growth stage; scoring should be carried out between heading (BBCH55) and medium milk stage of the grain (BBCH75) and concentrated on the uppermost leaves (flag leaf + 3 leaves); scale and image of severity see below	Biotic



Spot blotch severity on wheat leaves: numbers represent percentage (%) of leaf area showing symptoms (necrosis and chlorosis) of spot blotch.

Photo credit: Domiciano et al. (2014)

	Range in % severity on indicated leaf			
Score	Flag leaf	Flag leaf - 1	Flag leaf - 2	Flag leaf - 3
1				<5
2				<20
3				<50
4			<10	<75
5		<5	<20	<90
6		<20	<50	100
7	<5	<50	<75	100
8	<20	<75	100	100
9	<75	100	100	100

Tan spot (*P. tritici-repentis*)

Photo credit: Friskop and Liu (2016)

Septoria tritici leaf blotch (STB)

Photo credit: Maccheek, Wikipedia

Acronym	Trait	Trait category
10 SR01	**STEM RUST** Scoring of stem rust (1-9 scale); scoring should be carried out once during grain filling; it is recommended to record at the same date the BBCH growth stage; scale and image of severity see below	**Biotic stress**

2 4 6 7 9

Photo credits: Z. Pretorius, University of Free State

Acronym	Trait	Trait category
11 GB01, GB02*	**SEPTORIA GLUME BLOTCH**	**Biotic stress**

Scoring of glume blotch (1-9 scale); scoring should be carried out at appropriate date (preferably before ripening/harvest) when symptoms are readily visible; if necessary GB can be carried out twice (GB01, GB02); it is recommended to record at the same date the BBCH growth stage; score should combine disease incidence and severity (% glume area diseased)

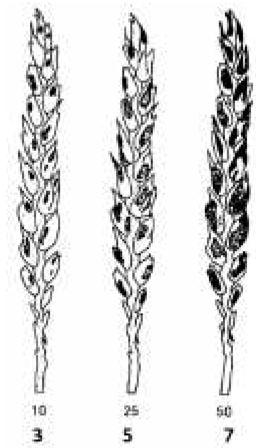


Photo credit: K. Wise, Purdue Extension

1 = no infection

3 = low infection on >50% of the spikes

5 = moderate infection on >50% of the spikes 7 = high infection on <50% of the spikes

9 = high infection on >80% of the spikes

Intermediate scores can be used if appropriate, e.g. 2 = low infection on <50% of the spikes

Acronym	Trait	Trait category
12 GYLD	**GRAIN YIELD**	**Agronomic**

Yield of grains (g/plot). For statistical analysis GYLD is converted to g/m².

***Tilletia caries* (common bunt) and *Tilletia controversa* (dwarf bunt)**

Tilletia can cause heavy losses in organic wheat. Origin of an infection with common bunt and dwarf bunt can be seeds but also soil. Amounts of spores on seeds of wheat must be checked before sowing. Recommendations of threshold are between 10 and 20 per seed.

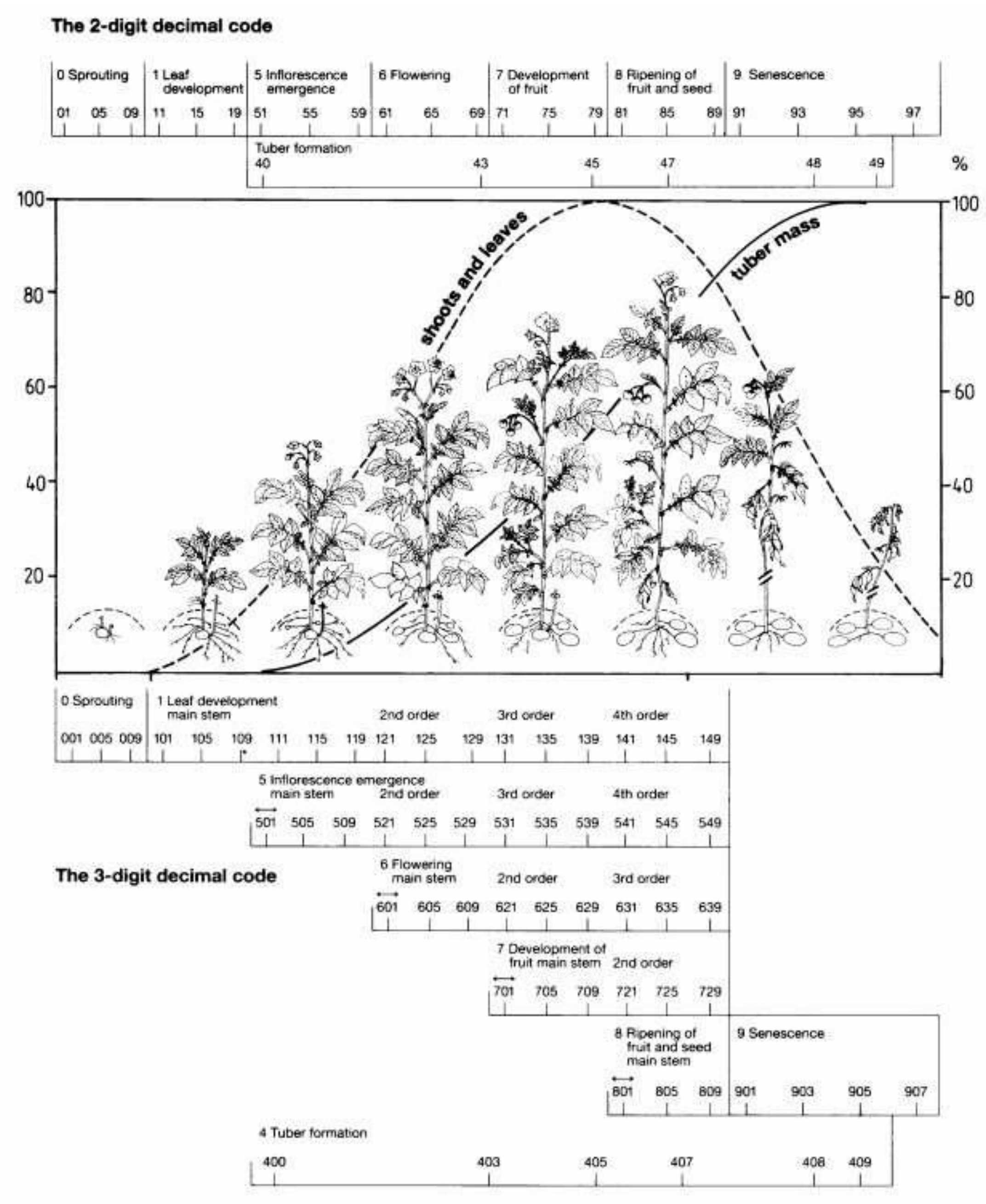
Field inspection: Check ears between one and two weeks before harvest. Most affected plants are little bit shorter, have a greener colour (not black) and the ears look scrubby. Instead of a seed you will find black spores smelling like fish. Plants with dwarf bunt are shorter.

Photo credit: Biologische Bundesanstalt Darmstadt

3. Phenotypic descriptors for Potato (*Solanum tuberosum* L.) FPT trials

	Potato Trait	Trait category
1	**Potato Phenological growth stages**	***Agronomic***

Potato Phenological growth stages should be assessed weekly by using the BBCH growth stage identification key (Hack et al. 1993). Ideally the following (foliar) stages should be recorded Emergence Leaf development (GS11); Inflorescence development (GS51); Flowering (GS61); Fruit development (GS71); Ripening (GS81); Onset of senescence (GS91).



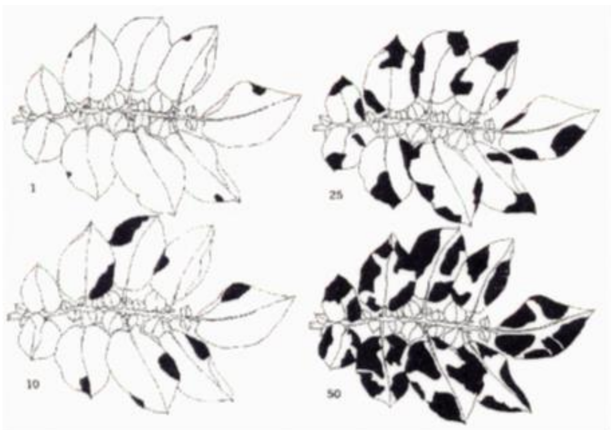
	Potato Trait	Trait category

2 **Late blight caused by *Phytophthora infestans*** — *Biotic stress*

The typical late blight symptoms are brownish or blackish water-soaked lesions on the leaves or stems. Down-side of the leaves manifest the necrosis, and the whitish sporulation (mycelium) is usually observed (Figure 8). The sporulation can also be observed on the upper side of the leaf on the margin of the lesion. Once late blight appears in the experimental field, all the varieties are assessed in a weekly interval.

Late blight symptoms

The degree of infection of each plot will be expressed as percentage of late blight-symptomatic canopy (Figure 9) and in scores using the 1-9 scale (Table 3).



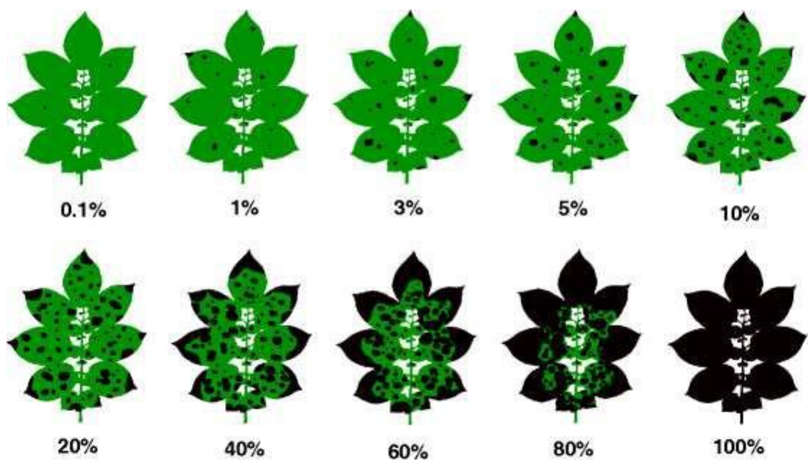
Score	Symptoms of infection	Infection % range	Infection % mean
9	No symptoms, occasional necrotic spots	0.0 – 0.5	0.2
8	Occasional spots on individual plants, 2 leaves infected	0.6 – 2.3	1.1
7	Slight infection on 9 leaves	2.4 – 9.5	4.7
6	All plants infected, about 20% leaves blighted	9.6 – 32.1	18.3
5	50% of leaves blighted, petioles infected	32.2 – 67.9	50.0
4	80% of leaves blighted, petioles and stems infected	68.0 – 90.4	81.7

3	Heavy infection, about 9 leaves healthy	90.5 – 97.7	95.3
2	Very heavy infection, individual leaves green	97.8 – 99.5	98.9
1	Plants completely blighted, occasional parts of steams non infected	99.6 – 100.0	99.8

Source: Sieczka, 2001

	Potato Trait	Trait category
3	**Early blight caused by *Alternaria solani***	***Biotic stress***

Alternaria solani is a fungal pathogen, which plant causes a disease called early blight. The pathogen produces distinctive "bullseye" patterned leaf spots and can also cause stem lesions and fruit rot and tuber blight on potato. Despite the name "early," foliar symptoms usually occur on older leaves. In potato, primary damage by *A. solani* is attributed to premature defoliation of potato plants, which results in tuber yield reduction. Initial infection occurs on older leaves, with concentric dark brown spots developing mainly in the leaf center. The disease progresses during the period of potato vegetation, and infected leaves turn yellow and either dry out or fall off the stem. On stems, spots are gaunt with no clear contours (as compared to leaf spots).



Area diagrams for early blight scoring

The degree of Alternaria solani infection will be expressed in a percentage scale according to Figure 10. The evaluation will be done during the season. Standard area diagrams for early blight (*Alternaria solani*) severity on potato (*Solanum tuberosum* L.) leaves. The numbers represent percent (%) leaf area showing symptoms of the disease.

	Trait	Trait category
4	**Potato virus Y (PVY)**	***Biotic stress***

PVY is the most prevalent and economically important virus in potatoes. Infection of potato field with PVY may results in 10 – 100% loss in yield. Typically, infection with PVY results in easily visible mottling (Figure 11), but some strains are able to evoke necrotic symptoms on leaves and/or on tubers (Potato Tuber Necrotic Ringspot Disease, PTNRD, caused by NTN or some N strains of PVY – Figure …

Mosaics symptoms on leaves of potato caused by PVY

The degree of infection of each plot will be expressed as percentage of symptomatic canopy (Figure …) and in scores using the 1-9 scale (Table 3).

5	**Potato leafroll virus (PLRV)**	***Biotic stress***

PLRV belongs to genus Polerovirus of Luteoviridae family. The virus is transmitted by aphids feeding on the plant sap in persistent manner. Symptoms of primary infection (infection in the growing season), occurs on the youngest leaves. Leaf margins become necrotic, turning brown and purplish and curl inwards towards the centre of the leaf. Secondary infection, which starts from infected potato tubers, produces more severe symptoms. Leaf rolling is more apparent and the entire leaf can become chlorotic and sometimes also has a purple discoloration (Fig. 12) (Khurana, 2004).

Leafroll symptoms on leaves of potato caused by PLRV

	Trait	Trait category
6	**Colorado potato beetle damage (% of defoliation)**	***Biotic stress***

Colorado potato beetle (*Leptinotarsa decemlineata*) is the most important pest damaging potato crop during growth in continental Europe. Beetles overwinters 20 to 50 cm deep in the soil. They emerge in May and after that colonize the potato crop. Female may produce 300 to 800 eggs from which fleshy red to dark red colour larvae hatch (Fig. 13). In hot summers the cycle from egg to adult beetle takes only 35 days, in cold weather up to 80 days. Colorado potato beetle usually has two life cycles per season, in hot summers even three. Due to their fast multiplication rate, they can destroy potato foliage completely within one generation.

Colorado potato beetle damage of the potato foliage in the experiment will be visually estimated in % of leaf surface destroyed.

Colorado potato beetle – adult, eggs, larvae

	Trait	Trait category
7	**Collection of Potato samples**	***Agronomic***

Approximately 2 weeks prior to harvest potato plant canopy is removed and tubers are left in the ground for skin maturation. Plants of the whole plot should be harvested. Tubers need to be weighed and yields to be recorded (kg/plot). Tubers should be returned to the lab for further assessments.

After harvest tubers will be evaluated for the following yield traits: Yield; Marketable Yield; Number of tubers per plant; tuber size and tuber disorders; dry matter content; specific gravity; Cooking/baking quality; Skin color; Skin appearance 1-9.

8	**Tuber size grading**	***Quality***

Plot samples should be graded according to scales (>85mm; 65 – 85mm; 45 – 65mm; 25 – 45 mm; <25mm), and a weight taken of each scale per sample (number of tubers and tuber weight for each group).

	Trait	Trait category
9	**Assessment of tuber disorders and diseases**	***Quality***

Tuber samples should be graded for **external tuber disorders and diseases** such as: secondary growth; green tubers; mechanical damage; cracked; soft; hollow heart; black heart; Blight; Rhizotonia; Scab; Slug damage and Wireworm damage. Five types of secondary growth will be recognized: knobby tubes; bottlenecks; elongated tubers with pointed ends; chain-tuberization; sprouted tubers.

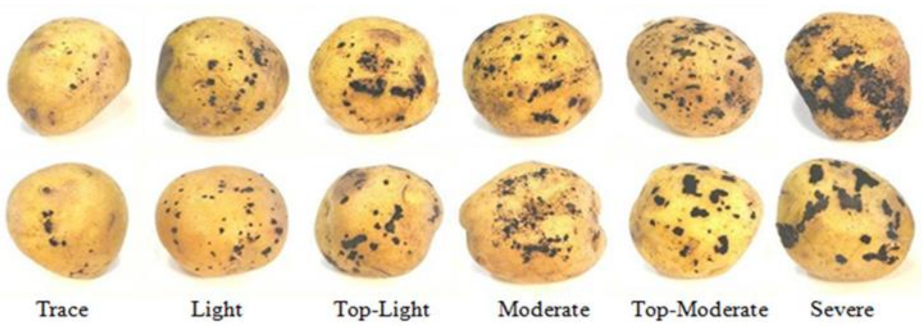
The number of destroyed tubers and their total tuber weight should be recorded for each disorder. If more than 10% of the assessed number of tubers is infected by specific disorder the damage (%) of each disorder on tuber surface % (Fig. 14) should be recorded (asses 100 tubers).

Each sample should then be stored and assesses every month for three months for any further examples of tuber disorders.

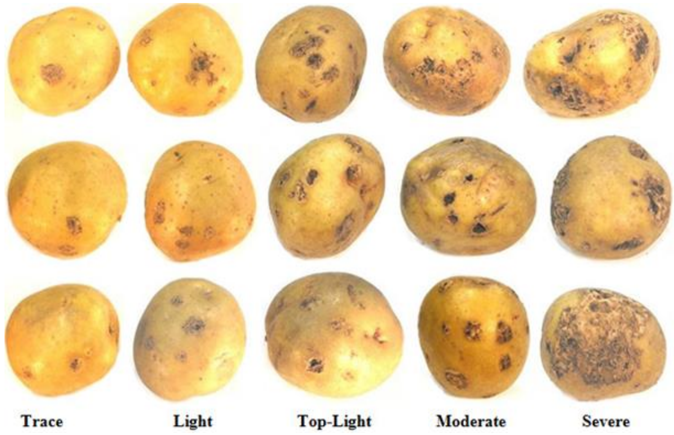
Disease Level	Percentage Coverage
Trace	0% - 1%
Light	>1% - 5%
Moderate	>5% - 10%
Severe	>10%

What the 10% of tuber surface area looks like (AHDB)

The most important **internal tubers defects** are: Internal rust spot; Vascular discoloration; Hollow heart; Black heart; Brown center; Internal rust spot; Vascular discoloration (Table 11). The defects of tuber flesh are determined in large tubers. The incidence of internal tubers defects will be expressed as percentage (%) of tubers in a 30 tuber sample. The tubers will be cat longitudinally.



Rhizoctonia solani



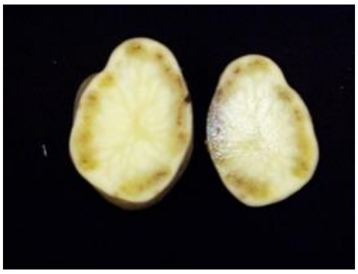
Common and netted scab

Secondary growth

Growth cracking

Hollow heart

Black heart



Brown center

Internal rust spot

Vascular discoloration

Silver scurf

Potato tubers rots

Symptoms of various external and internal diseases and disorders of potato tubers

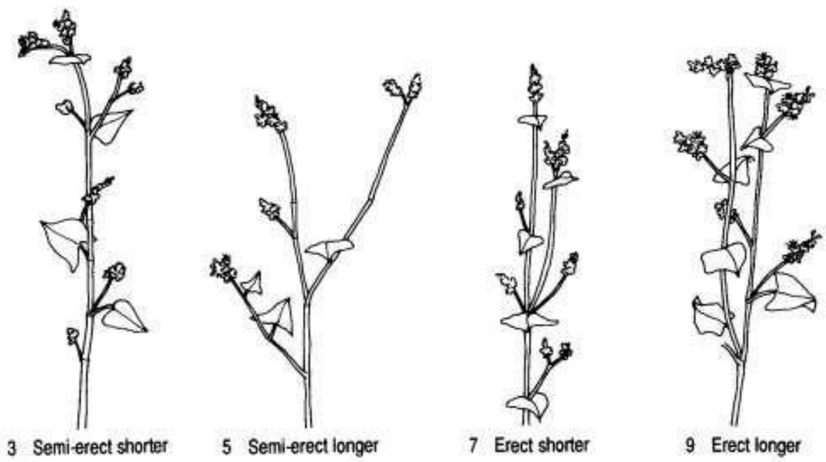
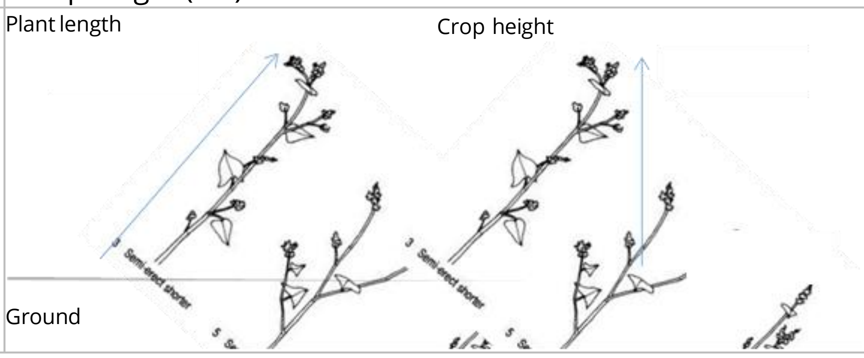
The British Agriculture and Horticulture Development board (AHDB) Online Toolbox contains useful information on the identification of potato Diseases (https://potatoes.ahdb.org.uk/gallery/potato-diseases) and Disorders (https://potatoes.ahdb.org.uk/gallery/potato-disorders)

4. Phenotypic descriptors for Soybean (*Glycine max* L.) FPT trials

	Soybean Trait	Trait category
1	**Days to emergence:** Date from sowing to emergence (when 50% seedlings emerge). Data: date (eg. 03.06.2020)	*Agronomy*
2	**Canopy closure** Data: canopy cover, two decimal places (eg. 50.25 %) Data: evaluation date (eg. 03.06.2020); Record canopy cover every week, from V1 till canopy closure. From multiple sampling dates, for each plot the canopy coverage will be calculated, as well as average canopy coverage Plots will be photographed every seven days till canopy closure. Each single plot should be photographed at each time interval. Based on fraction of green pixels, canopy coverage (average canopy closure, rate of canopy closure...) will be determinated. For canopy closure phone camera (application Canopeo) will be used. Detailed manual on how to use Canopeo is available at http://canopeoapp.com).	*Agronomy*
3	**Time to flowering:** Date when accession reach R1 (Fehr and Caviness 1977). Data: date (eg. 03.06.2020)	*Agronomy*
4	**Time to maturity:** Date when accession reach R8. (Fehr and Caviness 1977). Data: date (eg. 03.09.2020)	*Agronomy*
5	**Plant height at maturity:** Average plant height of 3-5 plants Data: units in centimeter, no decimal places (eg. 95 cm), single number per plot	*Agronomy*
6	**Pod shattering at maturity:** Score Description 1 No plants with shatter pods 2 Up to 10% of plants with shatter pods 3 11-40% of plants with shatter pods 4 41-80% of plants with shatter pods 5 Over 80% of plants with shatter pods Data: score, no decimal places (eg. 2)	*Agronomy*

	Soybean Trait	Trait category
7	**Yield:** Machine harvested yield per plot. Moisture content is obligate for calculation (data %, one decimal place) Data: grams per plot, no decimal places (eg. 3,250 g)	***Agronomy***
8	**Thousand seed weight:** Take a seed sub-sample from plot sample. Count and weight 4 x 50 seeds. Average value are calculated based on 1000 seeds Data: units in grams, one decimal place (eg. 186.2 g)	***Agronomy***
9	**Screening of genetic resources to stem canker and charcoal rot** Evaluation of stem canker severity will be conducted in field, between R6 and R7 growth stages by observing the presence of stem canker or charcoal rot. Observation of each variety will be conducted using a modified field scale provided by Backman et al. 1985. Rating Description 0 = No symptom 1 = 1-10% of diseased plants 2 = 11-25% of diseased plants 3 = 26-50% of diseased plants 4 = 51-75% of diseased plants 5 = 75-100% of diseased plants	***Biotic stress***
10	**Two spotted spider mite (*Tetranycus urticae*)** Mite's occurrence and intensity will be visually monitored at several localities every 10 to 15 days in July and August, since usually in this period comes to its intensive appearance and colonies development. Pest presence will be monitored at four spots in the field, at the edge, at 20, 40 and 60 meters from the edge of the field. At every spot, 25 leaves will be examined for mite's presence.	***Biotic stress***

5. Phenotypic descriptors for BUCKWHEAT (*Fagopyrum* spp.) FPT trials

	Trait		Trait category
1	**Growth and branch shoot habit**		*Agronomy*
	Angle of branch shoot and the highest tip branch longer or shorter than main shoot. At flowering stage		
	3	Semi-erect shorter	
	5	Semi-erect longer	
	7	Erect shorter	
	9	Erect longer	
			
2	Plant length (cm) *		*Agronomy*
	Mean height measured from the ground level to the highest tip of shoots of at least 10 randomly chosen plants at physiological maturity		
3	Crop height (cm) *		*Agronomy*
			

	Trait		Trait category
4	Lodging (all plants together) *		***Agronomy***
	Degree of lodging of plants assessed when seeds are mature		
	1	Very low (0%)	
	3	Low (25%)	
	5	Intermediate (50%)	
	7	High (75%)	
	9	Very high (100%)	
5	Plant branching*		***Agronomy***
	Average number of primary branches taken from randomly chosen five plants at physiological maturity		
	1	Very weak (no branch)	
	3	Weak (2 branches)	
	5	Intermediate (4 branches)	
	7	Strong (6 branches)	
	9	Very strong (8 branches)	
6	Days to flowering*		***Agronomy***
	Number of days from sowing to 50% of plants having fully open flowers		
7	Days to maturity*		***Agronomy***
	Actual number of days between sowing and physiological maturity (75% of seeds turned brown)		
	1	Very early (<60 days)	
	2	Early (60-75 days)	
	3	Intermediate (76-90 days)	
	4	Late (91-105 days)	
	5	Very late (> 106 days)	
8	Number of seeds per cyme*		***Agronomy***
	Average number of seeds per two representative cymes each from five different plants. Recorded when 75%.		

	Trait		Trait category
9	**1000-seed weight (g) ***		
10	**Crude protein content***		***Quality***
11	**Rutin content (achenes) ***		***Quality***
12	**Abiotic stresses***		
	At any stage of occurrence, it is devoted to the occurrence of any abiotic stress such as low temperature damage, frost damage, high temperature damage, high soil moisture, low soil moisture, high temperature during the flowering stage, low air moisture with high temperature etc.		
	1	Very low or no visible sign of susceptibility	
	3	Low	
	5	Intermediate	
	7	High	
	9	Very high	
13	**Biotic stresses ***		
	At any stage of occurrence, it is devoted to the occurrence of any abiotic stress such as fungi, pests, viruses etc. Each occurrence must be specified separately		
	1	Very low or no visible sign of susceptibility	
	3	Low	
	5	Intermediate	
	7	High	
	9	Very high	
14	**Seed yield (g) ***		
	Total seed weight from at least 0.25 m2. At moisture content 13%, at harvest time.		

Appendix III: Example data recording sheets for trait scoring on FPT

Example data recording sheet for wheat FPT										
wheat (location)	**Unit**	**dat e**	**variety 1**	**variety 2**	**variety 3**	**variety 4**	**variety 5**	**variety 6**	**variety 7**	**variety 8**
Sowing										
sowing density	seeds/m²									
disease 1 (name)	1 to 9									
disease 2 (name)	1 to 9									
disease 3 (name)	1 to 9									
pest 1 (name)	1 to 9									
pest 1 (name)	1 to 9									
plant height	cm									
Canopy	1 to 9									
Lodging	1 to 9									
harvest yield	t/ha									
Protein	percent									
Location:				**Notes:**						
Recorded by:										

Example data recording sheet for potato FPT										
potato (location)	**Unit**	**date**	**variety 1**	**variety 2**	**variety 3**	**variety 4**	**variety 5**	**variety 6**	**variety 7**	**variety 8**
sowing date	farmer									
sowing density seeds/m²	farmer									
date of emergence (BBCH 009)	farmer									
date of canopy closure (BBCH 39, if it was)	farmer									
date of canopy senescence (BBCH 91, first yellow leaves)	farmer									
plant height in cm	farmer									
Late blight severity (1-9)	farmer									
Early blight (1-9)	farmer									
Colorado potato beetle damage (1-9)	farmer									
harvested yield (t/ha)	farmer									
tuber size big > 65mm										
tuber size medium 45-65 mm										
tuber size small < 45 mm										
Rhisoctonia, silver scurf on tuber (1-9)										
tuber disorders (hollow heart, internal rust spot, tuber cracks) % of tubers										
dry matter (%)										
cooking type										
regularity of tuber shape										
depth of eyes										
tuber size										
% dry matter										
Discoloration of cooked tubers 10 min. and 24 h. after cooking										

Discoloration of potato flesh in raw state 4h after cutting										
Location:				**Notes:**						
Recorded by:										

Example data recording sheet for soyabean FPT										
soya (location)	**Unit**	**dat e**	**variety 1**	**variety 2**	**variety 3**	**variety 4**	**variety 5**	**variety 6**	**variety 7**	**variety 8**
Sowing										
sowing density	seeds/m²									
Emerge	plants/m ²									
Canopy	1 to 9									
disease 1 (name)	1 to 9									
disease 2 (name)	1 to 9									
disease 3 (name)	1 to 9									
pest 1 (name)	1 to 9									
plant height	cm									
Lodging	1 to 9									
maturity/water content	time/%									
harvest yield	dt/ha									
Protein	%									
Location:				**Notes:**						
Recorded by:										

Example data recording sheet for buckwheat FPT										
buckwheat (location)	**Unit**	**date**	**variety 1**	**variety 2**	**variety 3**	**variety 4**	**variety 5**	**variety 6**	**variety 7**	**variety 8**
Sowing	date									
sowing density	seeds/m²									
plant length	cm									
crop length	cm									
Lodging	1 to 9									
day to flowering	days									
days to maturity	days									
number of seed per cyme	number									
1000-seed weight	gramms									
crude protein content	%									
rutin content										
abiotic stresses										
biotic stresses										
seed yield	dt/ha									
harvest date	date									
Shattering	1 to 9									
moisture content (harvest time)	percent									
Location:				**Notes:**						
Recorded by:										