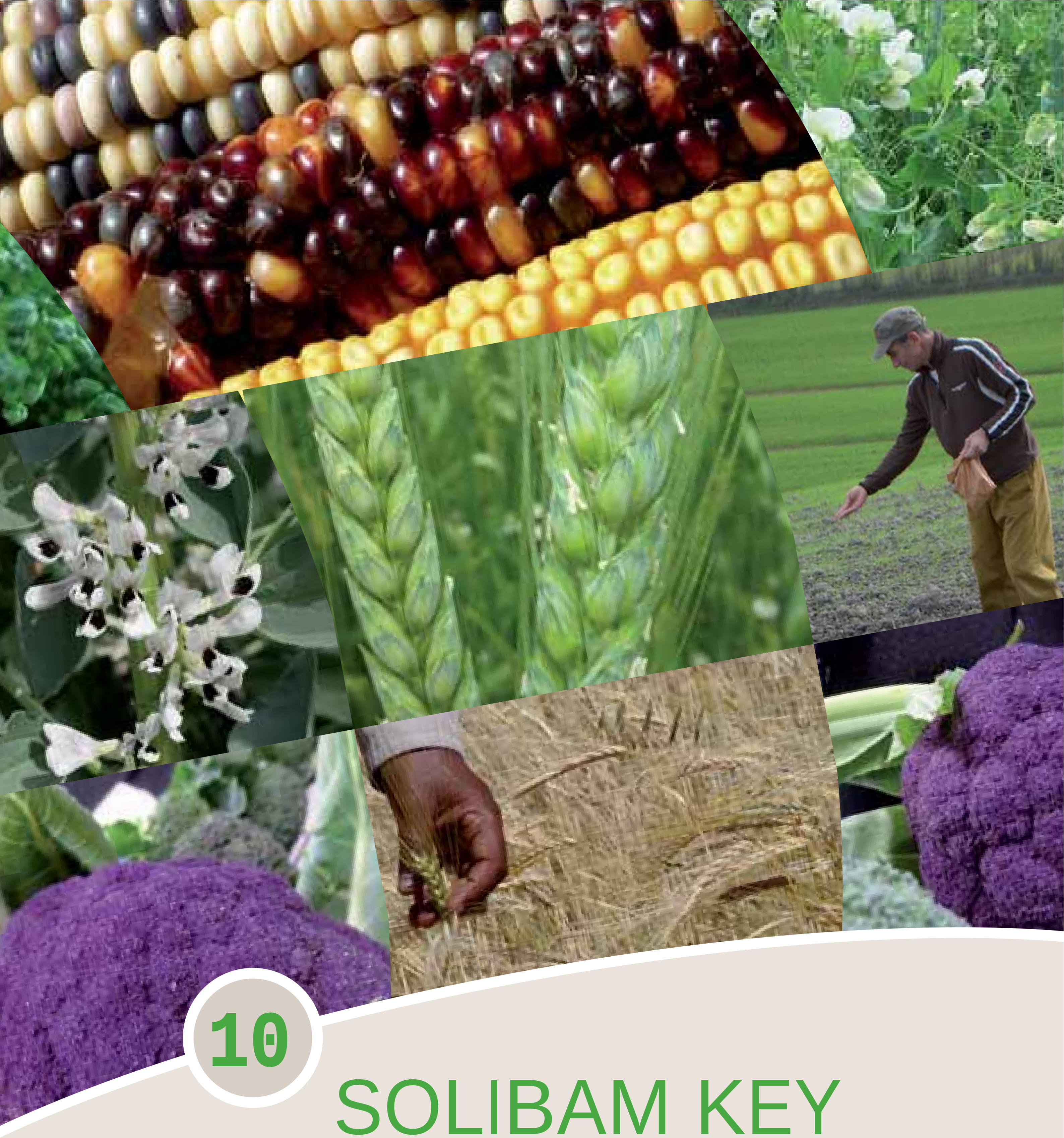


10

SOLIBAM KEY INNOVATIONS

Cultivating diversity

Solibam

Sommaire

Introduction

SOLIBAM: from multi-actor and transdisciplinary research to innovation

SOLIBAM has designed and tested innovative strategies to develop specific and novel breeding approaches integrated with management practices to improve the performance, quality, sustainability and stability of crops adapted to organic and low-input systems, in their diversity in Europe and taking into account small-scale farms in Africa, mostly in Ethiopia. **SOLIBAM** is a research programme which combines many disciplines and values with the aim of increasing system diversity and thus measuring impacts at multiple levels of agricultural production, from genetic aspects to environmental and socio-economical dimensions.

The **SOLIBAM** project has been carried out within the context of a lack of adapted varieties specifically for organic and low-input agriculture. A fundamental characteristic of these farming approaches is a wide range of variability within the farming system, combined with a wide range of environmental variation. Having a choice of adapted plants and practices is the only means to build a sustainable farming system which is characterised by a complexity of interactions. As a basis, we therefore aimed to develop tools and methodologies to improve understanding and management of complexity.

More than 50 field trials have been performed in 12 countries, in which innovations have been tested for at least 3 seasons between 2010 and 2014 on the model species of **SOLIBAM**: wheat, barley, maize, faba beans, common beans, tomato and broccoli. The experiments were organised to enable evaluation of the farming system and crop "performance" according to ten concepts defined to encompass the **SOLIBAM** objectives: (1) Resilience, (2) Robustness, (3) Functional biodiversity, (4) Yield stability, (5) Adaptability, (6) Intercropping*, (7) Sustainability, (8) Evolutionary processes, (9) Organoleptic quality, and (10) Participatory research (see the Layman booklet "10 **SOLIBAM** key concepts-cultivating diversity"). Several competences within the consortium, including genetics, plant breeding, agronomy, ecology, food science, statistics, sociology and economics, have little by little brought complementary knowledge to establish these concepts.

In addition to activities devoted to field and crop studies, the overall farm system has been assessed at three system levels: the cropping system, the farm and the chain from breeder to farmer (plant breeding and legal aspects) and to consumer (the food supply system).

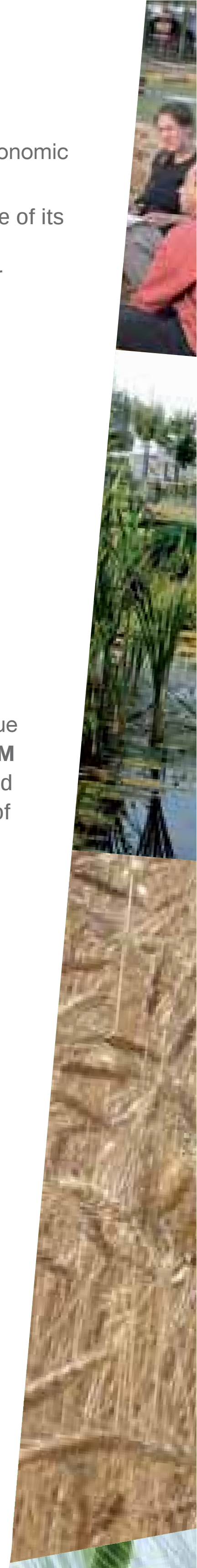
* see glossary page 26

There was a specific focus on resource use efficiency, environmental impacts and socio-economic assessments in case studies from the UK, France, Italy and Portugal.

Thus, **SOLIBAM** has developed various agro-ecological innovations which are at the core of its strategies:

- new approaches to plant breeding and development which simultaneously consider diversity and quality, performance and stability, co-breeding for intercropping*, or crop-pollinator interactions;
- new food products with improved quality properties;
- new tools for participatory plant breeding and management (PPBM) which farmers, researchers and other stakeholders designed together: 1) new breeding methods for decentralized programmes, 2) tools for resource and trial management, and for the statistical analysis of results, 3) integrating methodologies to improve selection for appetising products;
- social innovation and collective action for decentralised and participatory research;
- new modelling tools to improve understand and assessment of the resilience, viability and sustainability of farms;
- new propositions for policy makers so as to adapt seed regulations to accommodate diverse genetic resources.

This user-friendly booklet describes 10 **SOLIBAM** KEY innovations dealing with the issue of diversity at multiple levels, from the field to the plate. For each of them, **SOLIBAM** partners describe the background, the related activities performed during the project and the resulting new ideas (product, practice, service, production process or a new way of organisation) that were developed.



What is innovation?

According to guidelines of the new European Partnerships for Innovation, the innovation is often described as a new idea that proves successful in practice. The new idea can be a new product, practice, service, production process or a new way of organising things, etc. Such a new idea turns into an innovation only if it is widely adopted and proves its usefulness in practice.

Becoming mainstream will not only depend on the solidity of a creative idea, it also depends on the market possibilities, the willingness of the sector to take it up, cost- effectiveness, knowledge and perceptions, accidental external factors etc. It is impossible to predict how these factors work together to turn a new idea into an innovation. Therefore, one can only determine afterwards whether a new idea has led to a real innovation.

Innovations can be “additional”, with incremental improvements (sometimes at the margin) that do not drastically alter the previous system, or «radical», where they involve reconfiguration of the system. In addition, the INSIGHT project proposed a typology of innovations, which included (1) technological innovations; (2) knowledge based innovations and (3) organizational and social innovations.

* see glossary page 26

#1

Performance stability through genetic diversity knowledge on populations

Summary

Performance stability (e.g. yield stability) is the ability of a ‘variety’ to perform consistently in different environments in space and time. Because environmental variation is large, unpredictable and increasing, the ‘variety’ needs to have a large inbuilt capacity to deal with all variables. This is impossible to achieve with a single crop genotype. SOLIBAM therefore develops and tests alternative solutions including variety mixtures and composite cross populations* (CCPs), all containing high levels of genetic diversity. SOLIBAM tests these solutions for performance and stability in cereals and other crops across Europe.

Background

Pure line, genetically uniform crop varieties are bred for optimal performance in environments made more predictable by artificial inputs. However, in the variable environments of organic and low-input systems - and under increasingly unstable local and global weather - pure lines do not have the capacity to respond or adapt. Adaptation is crucial in providing crops with the ability to buffer against such environmental variation, which depends on much greater genetic diversity within the crops and in the agricultural systems. SOLIBAM trials focus on the advantages and disadvantages of crops containing different levels of diversity so as to identify key traits, breeding approaches and management options best suited to achieving stable performance for yield and quality in changeable and varied agronomic settings.

Activities

Diversity is a theme central to SOLIBAM and all field trials focus on using defined facets of diversity to improve crop performance and stability, both between and within species.
Between species, one example looks at how diversity in cropping systems can be managed in combination with crop variety choice, to reduce the need for external inputs while promoting yield stability. For example, tomato crops are preceded by a legume cover crop to provide fertility and then sown with accompanying wild flower strips to encourage pollinators. Intercrop trials have also been carried out to assess if and how genetic diversity in the species used can improve their associations through enhanced complementarity. For example, cereals which differ in their levels of diversity are grown with different species of legume.

* see glossary page 26

#1

Performance stability through genetic diversity knowledge on populations

The impact of within-species diversity is evaluated in a range of arable and vegetable crops (wheat, barley, maize, common bean, broccoli and tomatoes) through comparative trials across several geographical locations. Genetic resources vary from modern pedigree lines to landraces*, mixtures and populations. Some trials include novel synthetic populations which bring together genomes for which there is no known previous record, while others compare established or early generation populations with pure line controls and physical seed mixtures. One approach mixes populations with pedigree lines to try to maximise the benefits of each. Trials are carried out in different systems (conventional, low-input and organic) to determine the potential extent of their application.

Description of the innovation

Diversity underpins stable crop performance in heterogeneous conditions. This innovation track provides a solid baseline of information to guide the future development of new approaches specifically for organic and low-input crop breeding in a period of rapid environmental change. The broad scope of the trials means that results will be of value to a wide range of stakeholders, including breeders, researchers, farmers and growers.

The performance of mixtures and populations compared with pure lines gives information on how best to develop and to use crop diversity in organic and low-input systems. The approach of combining populations with pure lines in a mixture remains untried until now and allows for the possibility of simultaneous exploitation of the high diversity in populations with the high yield performance of pedigree lines. By testing different breeding strategies for arable and vegetable crops in a number of locations, we can identify which are the most appropriate for a given species and breeding goal. A key outcome is investigating the extent to which the level of diversity in a crop enables it to act in compensatory or complementary ways under environmental stress, leading to increased performance stability. Following SOLIBAM activities, the EU has agreed to a 'temporary experiment' to test marketing and maintenance of wheat populations on an EU farm scale (see innovation n°10).

Where: UK, Hungary, France, Italy, Portugal, Ethiopia, Austria.
When: 2010-1014
Who: ORC, HAS, INRA, ITAB, AIAB, UNIPG, EASC, ICARDA, Gautier, Donau Arcoiris
Contact: sally.h@organicresearchcentre.com

* see glossary page 26

#2

A crop-pollinator inter-play approach to develop faba bean varieties for low-input farming

Summary

Over the last few years, the significant decline in bee populations has led to increased interest in faba bean's ecological services, since a group of bee species is associated with their flowers. There is considerable potential to improve faba bean yield and resilience by strengthening interactions with bee pollinators for the purposes of crossing. Information on how the inter-play between crop and pollinator contributes to crop performance is explored to develop ecosystems services and improved open-pollinated varieties (OPVs) for low-input farming (LI).

Background

Creating OPVs based on diversified germplasm and using pollinators to mediate crossing, should be considered as an opportunity to improve farmers' income in a sustainable way. Open pollination is a method of crossing well adapted to farmer management as well as to site-specific requirements. To manage pollinators at the field level, the crop-design approach has been proposed whereby breeders and farmers developed faba bean cultivars with enhanced diversity (heterozygosity and heterogeneity). These cultivars provided greater floral resources within the crop, supporting bee pollinator populations. This approach is a promising strategy to connect small-scale agriculture with biodiversity conservation tasks.

Activities

Six faba bean gene-pools, derived from genetic materials selected to ensure that there was wide phenotypic diversity among them, were cultivated to develop locally adapted OPVs that take advantage of the observed benefit of low-input (LI) farming for pollinator density and diversity. Bee pollinators intensify selection for floral traits important in discovery, attraction and reward, but their behaviour may also select for traits that enhance seed production patterns through outcrossing and aided selfing. Two pollination environments (open-pollination vs. pollinator-exclusion) were used: 1) to examine the impact of natural selection in crop performance and how pollinator-mediated selection determines gene-pool changes and dynamic adaptation, and 2) to explore the relationships between floral traits relevant for the crop-pollinator interactions and each seed production component, gene-pool and pollination environment. Different levels of heterogeneity have been described using a range of statistical techniques.

#2

A crop-pollinator inter-play approach to develop faba bean varieties for low-input farming

Description of the innovation

Taking into account that LI farming relies largely on locally available resources such as bees, this work emphasised the relevance of traits enhancing an inter-play crop-pollinator system that contributes to realising the full potential of LI farming systems.

We have outlined a series of floral mechanisms under pollinator-mediated selection by which substantial variation in seed production patterns can accrue, especially between gene-pools evolving under different pollination environments.

The response to selection under different pollination environments is characterised by a series of plant architecture and flower structural changes that may result in mismatches between crop and pollinator. This would threaten to decrease the ecological services provided by faba beans and consequently reduce the plant's ability to benefit from pollinators increasing genetic diversity. The experiments conducted in the framework of SOLIBAM provide new tools to avoid such mismatches.

Our work has also given us a better understanding of the pollinators' influence:
Critical traits in the performance of faba bean crops, such as seed dimensions and weight, are under pollinator-mediated selection through functional floral traits. Pollinators are crucial for higher a number of seeds per plant, which are the main predictors of crop yield. Further studies focused on additional floral traits related to distant and local bee recruitment must be carried out in order to understand better the beneficial effects of pollinators on seed number.

Where: Spain
When: 2010-2014
Who: IAS-CSIC (Maria Jose Suso)
Contact: ge1susom@uco.es; mjsuso@ias.csic.es

#3 Development of novel organic winter bread wheat breeding lines

Summary

There is an increasing need among organic farmers to have resilient, robust and resistant bread wheat varieties selected especially for organic agriculture, which generally represents diverse growing conditions. Therefore, one of the important goals of organic breeding in Hungary is to improve the stability of variety performance by introducing diverse populations into the breeding process. This has been carried out in different management systems and has resulted in novel organic wheat lines that might be introduced into official Value in Cultivation and Use (VCU) tests. .

In addition, a molecular marker was used to select segregating wheat breeding material for bunt resistance in Austria. One breeding line from this program, SZD 5356, entered official organic VCU tests in Austria in autumn 2013. Field tests for bunt resistance by Austrian Authority AGES for VCU and by IFA Tulln are on-going within the COBRA - Core Organic - project.

Background

It is important to increase the adaptability of new organic varieties in order to cope with abiotic and biotic stresses that threaten Hungarian agriculture and that of other European countries. Organic breeding, i.e. starting the breeding process on organic land with diverse composite or single cross populations might be an effective strategy in developing new varieties with enhanced adaptability and stability for these cropping environments.

In recent years, both common bunt (Tilletia caries) and dwarf bunt (Tilletia controversa) have caused severe problems for some organic farmers across Europe. One main reason for bunt problems is the use of farm-saved seed without sufficient quality checks. This has been a particular problem in Austria, where the most widely grown organic wheat varieties are bunt susceptible. When combined with specific weather conditions, for example, long snow cover and a late vegetative growth in spring (as was the case in 2013), bunt spores on the seed or in the soil can cause severe infections of the wheat crop.

#3

Development of novel organic winter bread wheat breeding lines

Activities

Selection trials were established by the Centre for Agricultural Research of the Hungarian Academy of Sciences (MTA ATK) at the beginning of SOLIBAM to examine whether winter bread wheat lines with the same ancestral origin could evolve differently under different selection environments (organic and low input conventional fields). As a major outcome, organic wheat lines originating both from single crossed hybrids and organic composite cross populations* were developed. Some of these promising lines are expected to be the first organic bread wheat varieties bred and registered in Hungary.

In Austria, Saatzucht Donau made 23 cross combinations with the bunt resistance source variety "Weston" in order to incorporate bunt resistance into adapted winter wheat germplasm. Breeding lines were pre-selected beforehand for their major agronomic characters such as foliar disease resistance and quality. Bunt resistance gene Bt10 was detected by molecular marker analysis. 148 young breeding lines are now being screened for yield and quality in an organic field and in several conventional fields using observation plots.

Description of the innovation

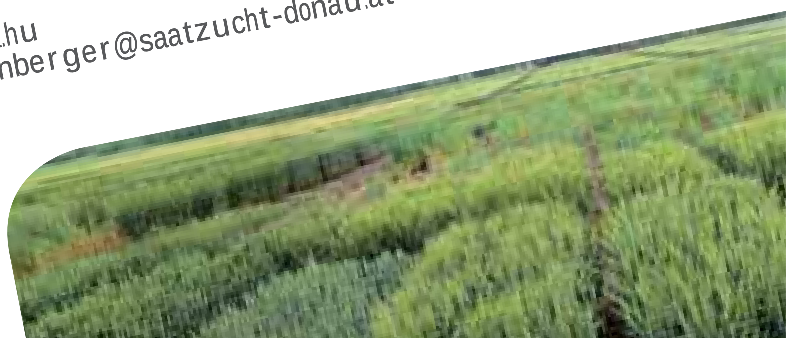
New organic winter bread wheat lines have been selected in Hungary and Austria within the framework of SOLIBAM.

After screening three generations within the framework of SOLIBAM, new organic winter bread wheat lines have been selected in Hungary for performance tests. These identified a couple of promising breeding lines that surpassed the wheat variety control (Mv Emese) not only in organic, but also under low input conditions. These lines mainly originated from composite cross populations* after the implementation of very strict spike-row selection, although some were established from a normal elite variety cross. This proves the need to put greater emphasis on the utilization of complex populations in organic wheat breeding. Selected lines are planned to be introduced into multi-environment trials, and the best ones will be applied for official registration as the first organic winter bread wheat varieties in Hungary.

The innovation developed by Saatzucht Donau lies in the use of molecular tools as a basis for the successful selection of new organic varieties. The company performed molecular analysis for the bunt resistance gene, Bt10. On average, 12% of the preselected material contained the resistance gene. This means that selection for agronomic characters acts against bunt resistance. By use of the molecular marker we retained 148 bunt resistant breeding lines, which are now being tested in the field. A preliminary field test for dwarf bunt resistance by IFA Tulln revealed that some of the breeding lines containing Bt10 showed good resistance to dwarf bunt.

The Saatzucht Donau wheat variety Amicus, cultivated in Hungary, Croatia and Serbia, showed good preliminary dwarf bunt resistance results, although it does not contain Bt10. The resistance donor of Saatzucht Donau Amicus was its parent variety Globus, which was the only common bunt resistant variety according to the Austrian National Descriptive List in 2013. A large number of new crosses have been performed using cv. Amicus. It is expected that new bunt resistant breeding material well-adapted to organic agriculture will result in the future.

Where: Hungary and Austria
When: from 2009 until variety registration
Who: MTA ATK (Hungary) and Saatzucht Donau (Austria)
Contact: miko.peter@agrar.mta.hu and franziska.loeschenberger@saatzucht-donau.at



* see glossary page 26

#4 Intercropping and associated crops

Summary

The main concepts behind this "innovation" are the design, development and testing of innovative arable and vegetable cropping systems based on a high level of agro-biodiversity (i.e. higher diversification within and between crop species, management and habitat), coupled with the use and development of genetically diverse germplasm. These are all strategies which may improve the performance, quality, resilience and sustainability of cropping systems. Increased diversity of species through the use of living mulch and the implementation of intercropping* has given good results in some of our experimental activities, and is a promising strategy for organic and low input farming systems.

Background

There is a need to design innovative cropping strategies for farmers working in organic or low-input systems, since they are restricted in the use of input options available to them (e.g. the prohibited use of herbicides) and thus need efficient alternatives to those commonly adopted in conventional farming. The main hypothesis is that a well-planned "more diversified cropping system" supported by tools adapted to local farming conditions may prove to be sustainable in the long-term regarding production quality and quantity (yield stability) and would increase resilience against stresses due to extreme climatic conditions.

Activities

Living mulches were tested in Europe in two different locations (Italy and Germany) in order to account for different environmental conditions. Subterranean clover (Trifolium subterraneum) was used as a living mulch in common wheat (Triticum aestivum L.) plots. While this approach performed poorly under Mediterranean organic conditions (central Italy), it proved to be a potential solution for controlling moderate weed infestations in continental European low-input systems (Germany). In this case particular attention has to be paid to the spatial arrangement of both species, i.e. the distance between wheat and clover rows must guarantee that competition between the two components in the earliest stages will not occur.

* see glossary page 26

#4

Intercropping and associated crops

In the Tigray region (Northern Ethiopia), where rainfed farming prevails, the erratic nature of the rainfall often results in crop failures and food insecurity. The intercropping* of cereals such as wheat and barley (traditionally called hanfets) then appears to be an important strategy.
In this region, mixtures of different varieties of barley and wheat were compared to their sole crops. Results showed that a mixture always performed better than the sole crops in terms of yield and weed suppression. The maximum yield was obtained using 50:50 proportions of barley and wheat.

Description of the innovation

In continental conditions, the intercropping* of wheat and subclover can be a successful strategy for weed control in low-input systems. In this case, the seeding density of both species has to be carefully evaluated. The same method in Mediterranean conditions is problematic, as it may affect the wheat yield. Further research should be directed towards the fine tuning of seeding density and sowing schemes for these species.
Cultivation of Hanfets (a wheat and barley mixture) has proven to be an effective cropping strategy, which leads to increased yield. In this case the optimisation (i.e. choice) of appropriate varietal components in the mixture is expected to further increase grain yield. On-going data evaluation will indicate whether the level of disease in hanfets is also reduced. At the moment, no clear conclusions can be drawn concerning the expected higher yield stability from hanfets.

Where: Italy - Germany - Ethiopia
When: 2011-2014
Who: SSSUP, TUM, MU, ICARDA
Contact: g.bocci@sssup.it), a.costanzo@sssup.it

* see glossary page 26

#5

Tools for Participatory Plant Breeding and Management

Summary

A methodology of Participatory Plant Breeding and Management (PPBM) was developed within SOLIBAM, based on real cases studies involving farmers, facilitators from farmers' organisations and researchers. Although we set up our method for particular cases, we also focused on making it as general as possible so that it can be used by a broad range of actors. Hence several tools have been created and divided into the following 3 categories: (i) collaborative trait definition and trait effect assessment, (ii) statistics and trials design for on farm trials and (iii) databases for PPBM program data, resources and trial management.

Background

A wheat PPBM programme started in France in 2005. It was based on a collaboration between the DEAP (Diversity Evolution and Adaptation of Population) team at INRA Le Moulon and a French farmers' seed network (Réseau Semences Paysannes). This project had 3 objectives: i) to create population-varieties adapted to farmers' practices; (ii) to develop methods and tools for on-farm breeding and diversity management and (iii) to strengthen learning and autonomy of farmers in breeding and diversity management. In order to reach these objectives, this project focused on a PPBM methodology following three main approaches: (i) co-construction between project actors, (ii) data analysis and (iii) data management. In order to deal with such different approaches, we based our work on trans-disciplinary research bringing together disciplines such as agronomy, quantitative and population genetics, sociology, bio-informatics and statistics.

Activities

The methodology consisted of three main activities: (i) co-construction between project actors, (ii) data analysis and (iii) data management.

I. co-construction between project actors. Co-construction between farmers, facilitators from farmers' organisations and researchers, is at the basis of the project. Two activities can be distinguished. The first corresponds to steps discussed throughout the project, i.e. to set up a charter, define objectives, formulate questions and hypotheses, develop experimental designs and choose analysis methods. The second corresponds to steps discussed in relation to the cycle of the plant, i.e. the choice of genetic resources, seed distribution, sowing, observations, farm visits, selection, harvest and discussion of the results.

II. data analysis. Based on the co-construction process, experimental designs have been set up on farms so that farmers can carry out the selection themselves. Each farmer participating in the project conducted their own experiment and chose which variety to sow. This approach results in unbalanced designs with few residual degrees of freedom and about 95% of variety x environment combinations missing on the network of farms. To deal with such data we have developed two hierarchical Bayesian models in order to (i) compare on-farm means and (ii) study variety x environment interactions. Both models gave satisfactory results as long as a large number of farms were analysed and each farm had at least one replicated control.
III. data management. In order to optimise use of data collected, a data-base is under construction called SHiNeMaS (Seed History and Network Management System). This data-base stores two kinds of data, the first concerns the farm network, including information on seed-lot histories and farmers practices (who has what, how many mass selections have been carried out, etc.). The second concerns, phenotypic and molecular data on the behaviours of the populations on farms.

Description of the innovation

I. co-construction between project actors. The co-construction process is not a "ready for use" method, but rather an example of how co-construction between actors can be developed. The method's guidelines have been published in a PhD thesis of which an English version is under construction.
II. data analysis. Simulation studies are in progress in order to assess how different levels of disequilibrium in the network affect the reliability of such analyses. An "R package*" to run these analyses is under development. By taking such an approach, we provide new tools to deal with on-farm decentralized breeding that can be implemented for a large range of species as long as the experimental design is kept and there are a large number of farms.
III. data management. A first version of SHiNeMaS should be available in 2015. An R package* allowing analysis at the network level and at the agronomic level is under development. Testing with facilitator associations was carried out in order to trial the database and to improve it. New developments have been completed in order to adapt the database to perennial species such as trees or grass forage.

Where: in France
When: 2010-2014
Who: INRA
Contact: pierre.riviere@moulon.inra.fr

* see glossary page 26

#6 Social innovation and collective action for a decentralised and participatory research

Summary

This innovation is related to new forms of interaction between management and actors in society. It also includes improved decision making through new ways of scientific assessment and public participation. The creation of networks in which no hierarchical relations exist and farmers, researchers, policy makers and citizens have an equal role in producing knowledge represents an example of social innovation. Innovative solutions for commercial activities that can contribute to the creation of synergies between different actors also represent a type of organisational innovation. The concept of social innovation is highly relevant to agriculture, and organic agriculture in particular, because of the wider public good expectations, for example in the area of ecosystems services and integrated rural development.

Background

Working in networks is becoming increasingly recognised as a valuable approach to conserve and use Plant Genetic Resources for Food and Agriculture (PGRFA) in a sustainable way (Da Vià, 2012). Within this framework, “local seed exchange networks are essential to the conservation of agrobiodiversity, because they permit access to seed and the maintenance of landraces* in agro-ecosystems throughout the world, despite the trend towards more uniform seed material flowing through formal, commercial seed systems (Pautasso et al., 2012). The sustainable use of PGRFA implies dynamic conservation that still permits the creation of new diversity in farmers’ fields. In this regard, informal and formal seed systems should be considered as a continuous flow of plant genetic resources plus their associated knowledge, and agricultural research is playing a key role in both systems. In particular, promoting and sustaining innovation behind networking and informal seed systems implies a restructuring of agricultural research in two complementary directions: participation and decentralization. Participatory research in the agricultural context brings together several actors sharing a common vision of concepts, methods and means for designing new food systems, based on the strong interrelationship between multidisciplinary scientific knowledge and the know-how of practitioners. Research actions are performed jointly from conception through to dissemination.

Activities

SOLIBAM supports on-farm participatory plant breeding and management (PPBM) for practice-oriented research to enhance and evaluate diversity as a way to increase food system sustainability and performance as well as product quality. Participatory plant breeding aims to enrich the crop genetic background to allow adaptation to diverse environments and practices, and to create new farmers’ varieties. In this participatory research process, SOLIBAM also involved citizens/consumers who have to use and consume the research results.Quality assessments have been developed to receive input from farmers, end-users, consumers and researchers. SOLIBAM deve-

* see glossary page 26

#6

Social innovation and collective action for a decentralised and participatory research

loped specific activities to promote PPBM in Italy, France, Portugal and Ethiopia by introducing segregating populations of durum/soft wheat and barley in farmers' fields. In the case of vegetables, a new tomato population has been developed during the project, using a selection of the best landraces* from Italy, France and Spain as parents. This PPBM programme also leads to a novel methodology for selection, which is based on new social organisation between researchers, technicians, farmers and their organisations. This social organisation focusing on decentralising plot trials in farmers' fields will increase the cultivated diversity in time and space.

Description of the innovation

Involving users (farmers, consumers or processors) in the research chain was shown to be a good way to improve plant breeding efficiency, simultaneously increasing diversity at farm level and in the entire food chain. This approach will also increase the resilience of agriculture systems and their capacity to cope with climate change. With particular regard to organic and low-input farming, decentralised and participatory research seems to be the best way to improve these systems, integrating local and tacit knowledge with scientific expertise. The SOLIBAM recommendations will suggest how to promote this new social organisation favouring the collective action of different actors and stakeholders. Currently, several limitations are blocking this innovation and need to be overcome in the near future. For example, seed policies and laws still consider farmers only as passive recipients of research and new varieties, the Common Agriculture Policy supports more individual than collective action and there is in general a lack of recognition of the paramount role that informal seed systems play, even in Europe, for preserving and creating new diversity. This evolving diversity can also be used as raw material in plant breeding programmes. The new approaches developed by the European Innovation Partnerships (EIPs) seems to be valuable and appropriate tools which need to be implemented by Member States in the right way to sustain social organisation and collective action. In fact EIPs, bringing together research and innovation, are thought to be challenge-driven, focusing on societal benefits and promoting networking at a local level for different actors.

Where: France, Italy, Portugal, UK.
When: 2010-2014
Who: AIAB, Italy; INRA and ITAB, France; ORC, UK; ESAC, Portugal
Contact: Riccardo Bocci (r.bocci@aiab.it)

Da Vià Elisa. Seed Diversity, Farmers' Rights, and the Politics of Re- peasantization. 1–14 (2012).
Pautasso, M. Challenges in the conservation and sustainable use of genetic resources. in Biol. Lett. 8, 321–323 (2012).

* see glossary page 26

#7 Integrative breeding methodologies to improve sensory qualities

Summary

Quality is a multi-faceted concept as it can refer to hygienic, sanitary, technological, nutritional and sensorial properties. However, the consumer's satisfaction remains the ultimate goal. In order to improve sensory quality and understand mechanisms which improve food product quality, SOLIBAM has developed 2 strategies.

The first concerned maize. It relied on the correlation between instrumental, chemical-physical, organoleptic and rheological variables and aimed at finding quality markers to predict the end-use quality. Good correlation between instrumental and sensorial analysis has been detected for some of the quality parameters and easier to measure approaches have been set up to select for improved quality maize, especially in participatory breeding programs.

The second strategy focused on wheat and aimed to adapt sensory tests to specific socio-cultural contexts in a participatory scheme. A bread-making methodology optimising the bread taste to ease cultivar screening on sensory criteria has been proposed. In combination with an appropriate experimental design, this protocol provides an integrative methodology to develop decentralized participatory plant breeding initiatives with a strong focus on sensory quality improvement.

Background

Nowadays, consumer preferences are decisive commercial factors. Producers and consumers are tending to become more concerned about products' sensory qualities and environmental-friendly practices. Until recently, plant breeders' efforts have focused mainly on improving production while largely neglecting such sensory traits. However, traditional cereal varieties have great potential for nutritional, organoleptic quality as well as technological improvement. To perpetuate the use of traditional varieties and to reach new market opportunities, innovative plant breeding methodologies to improve sensory qualities are increasingly needed. Consumers' preferences, in particular taste and aroma, as well as parameters influencing farmers and processors acceptance need to be investigated simultaneously. Nevertheless, the lack of fast and reliable screening tools for the most valued consumer quality traits has hampered this breeding objective.

In the case of wheat, the industrialisation of the bread sector has led to homogenization of the market, from the cultivated varieties (pure lines) to the end product. Over the last ten years, some countries in the EU have witnessed the emergence of a new artisanal sector of farmer-bakers. They make bread from their own wheat production, so the bread quality relies directly on the harvested wheat quality, which itself varies depending on the year and genotypes. Farmer-bakers need to know how to adapt their breeding and baking practices to produce bread of good and stable quality.

#7

Integrative breeding methodologies to improve sensory qualities

Activities

To predict the maize end-use quality, extensive chemical-physical, organoleptic and rheological analyses have been applied to a collection of 51 Portuguese traditional maize varieties. This has led to the identification of sources of high nutritional, health-benefitting or organoleptic components that might influence taste or aroma, such as phenolic or volatile compounds – a criterion to incorporate in breeding programs. Additionally, more than 50 assessors took part in the consumer sensorial analysis of breads obtained from 11 selected maize varieties. It helped to strengthen our knowledge of Portuguese traditional maize bread, our understanding of the influence of the maize variety, and to develop specific consumer sensory descriptors (appearance, aroma, texture and flavour) for this type of bread. The correlation between both instrumental and sensorial evaluation allowed the most important quality components valued by consumers and how they could influence consumer preferences to be teased out.
To integrate sensory criteria in the breeding process of bread wheat, two experiments have been conducted. The first aimed at evaluating the relative effect of the environmental, genetic and bakery factors on end-use qualities. Three genetic structures (a pure line, a population and a mix of populations) have been cultivated on four farms and compared. The quick and reliable Napping method has been used for sensory assessments (8 test sessions in 2 years). It relies on the identification of the global sensory distance of products (similarities/dissimilarities) and offers greater flexibility, as no trained panel is needed. The second experiment focused on plant breeding. In order to identify and characterize genotypes of sensory interest, farmer's knowledge and practices have been questioned in the light of sensory analyses (i.e. a sensory profile by a trained panel). Empirical knowledge has been gathered from 11 grain farmers (farmer-bakers) via semi-structured interviews aimed at identifying breeding strategies linked to end-use quality. The morphological and sensory characterization of wheat from several farmers has then been used to validate the patterns identified in the interviews.

Description of the innovation

The main innovation of the maize case study is the development of fast and convenient methods to improve the sensory qualities of products (maize bread) in a participatory breeding context. These promising methods combine instrumental and sensorial evaluations through the integration of consumer analyses when defining new quality breeding objectives/approaches. In addition, this integrative approach has contributed to the identification of beneficial components among Portuguese traditional maize varieties, making some of them eligible for quality certification (Protected Geographical Indication). In the future, an improved instrumental analysis will help detect sources of nutrient and organoleptic components as well as processing characteristics. But a new breeding method, based on both qualitative and sensorial criteria will surely sustain the demand for fine products such as the farm's maize bread, thus leading to financial benefits.
Concerning the wheat breeding strategy, an "improved" Napping test and a bread-making methodology optimising the bread taste have been developed to ease the cultivar screening on sensory criteria. This protocol – coupled with experimental design - provides a cross-cutting approach to develop decentralized participatory plant breeding initiatives with a strong focus on sensory quality improvement. A technical booklet with guidelines (from the experimental design to the sensory evaluation, including baking process) is about to be published for stakeholders. Plant breeding should also be a promising way to make bread with specific sensory qualities (taste). That is why farmer-bakers should mobilize the environmental, genetic and baking process levers to improve the sensory qualities of bread. Phenotypic markers of quality, such as the kernel colour, can help farmers to identify genotypes of interest in their field. On the other hand, environmental factors appear to modify essentially textural properties.

Where: Portugal, France
When: 2011-2014
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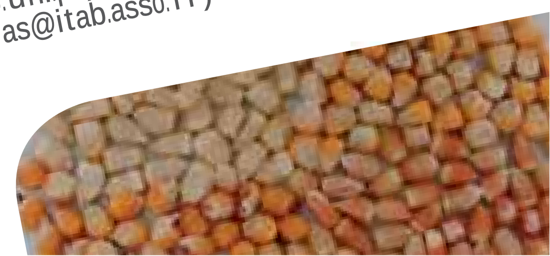

#8

New products with improved quality properties

Summary

High dietary fibre wheat lines are usually not appropriate for the production of traditional bread or other bakery products in themselves, as the presence of the fibre could influence the water binding capacity and therefore other processing properties of the wheat flour. However, blending high-fibre flour with normal flour in a certain ratio could be an excellent solution for the production of a new type of flour suitable for bread making, with an increased level of dietary fibre in the food at the same time. Research also focused on maize and common bean antioxidant compounds. Their raw seed flour, rich in phenolic compounds, can also be incorporated in bakery products. Our results have helped to identify cereal and bean genotypes presenting an increased level of bioactive components in the flour which contribute to the overall improvement of the human diet.

Background

The major dietary fibre (DF) components in wheat grain are the cell wall polysaccharides, arabinoxylan (AX) and β-glucan. They occur in soluble and insoluble forms, which may differ in their health benefits. Insoluble DF lowers transit time and increases faecal bulk, defecation frequency, and binding of carcinogens, while soluble DF reduces the risk of coronary heart disease and type II diabetes. DF components, in particular AX, also affect the processing properties of wheat i.e. breadmaking, gluten-starch separation, the quality of livestock feed and fermentation to produce alcohol for beverages and biofuel. That is why searching for high-fibre genetic resources is a key focus of cereal research.

Recently, researchers and consumers have also become interested in the presence of minor components in cereals and common bean which are claimed to possess antioxidant activity, thus contributing to the prevention of some diseases such as colon cancer and diabetes. A group of these compounds, known as phytochemicals (phenolic compounds), are mostly present as bound forms in plant cell walls or bound to macromolecular structures such as protein or starch. Several factors influence their quantity in the seed and flour, such as the plant genotype, the cropping environment, the storage conditions, the processing and the final product preparation. Therefore studies on antioxidants are another important focus of recent research related to the enhancement of healthier consumption practices.

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New products with improved quality properties

Activities

The physical, compositional and processing qualities of 16 variety mixtures and 10 composite-cross populations, produced in Hungary, Austria and the UK, were investigated in three consecutive years (2011-2013) within the framework of the SOLIBAM project (WP7). The aim was to identify new genetic resources with high dietary fibre content for organic farming purposes and to examine the effect of these components on the end-use qualities of flour.

As a result of our work, a new population (Elite-Composite) and a variety mixture (Mv-Suba: Elite-Composite, 1:2) have been identified containing significantly higher water extractable arabinoxylan (WE-AX) content in the flour (8.1; 10, respectively), than most of the studied samples and the wheat average. The increased WE-AX content had a significant effect on the water binding capacity of the flour (r 5%=0.55*) too.

The Phenolic Composition (TPC) and antioxidant activity (AA) of 32 different common bean varieties and 67 different maize varieties cropped in the central region of Portugal were also analysed through spectrophotometric and chromatographic assays. Different families of phenolic compounds were identified in beans (mainly hydroxycinnamic acids and flavonoids) and in maize (hydroxycinnamic acids). In maize, TPC ranged from 100.30 ± 4.81 to 206.83 ± 9.55 mg of gallic acid equivalents/ 100g DW (dry weight) and in common beans the total phenolic content ranged from 1 to 7 mg of gallic acid equivalents/g. For common beans a positive correlation (Pearson's coefficient of 0.909) has been found between TPC and AA measured by ORAC (Oxygen Radical Absorbance Capacity).

Description of the innovation

The innovation here consists in the possibility of blending high-fibre flour with commercial flour in order to produce healthier (or tastier) bakery products while maintaining the processing quality.

Cereal and bean genotypes have been analysed in the framework of SOLIBAM to determine their bioactive components (dietary fibre, antioxidants) and their processing quality. Consequently, a new wheat population and a wheat variety mixture with high dietary fibre (arabinoxylan) content in the flour have been identified. These populations were found to be appropriate for organic farming purposes, but had weaker processing quality when traditional bread and bakery products were produced. Taking advantage of the qualitative and quantitative diversity of antioxidant compounds present in common bean and maize genotypes, an increase in quality of bakery products (e.g. biscuits, breads, cakes) is expected after incorporating a mixture of common bean and maize raw seed flour as food ingredients.

Further experiments are needed to confirm such advances. Consumer acceptance of the product should be assessed through sensorial analyses and market studies; final new products should undergo quality testing to ensure a high level of fibre and phenolic compounds; positive health effects of the new bakery products should also be investigated hereafter to confirm the local influence of bioactive components in intestinal microbiota and human intestinal cells.

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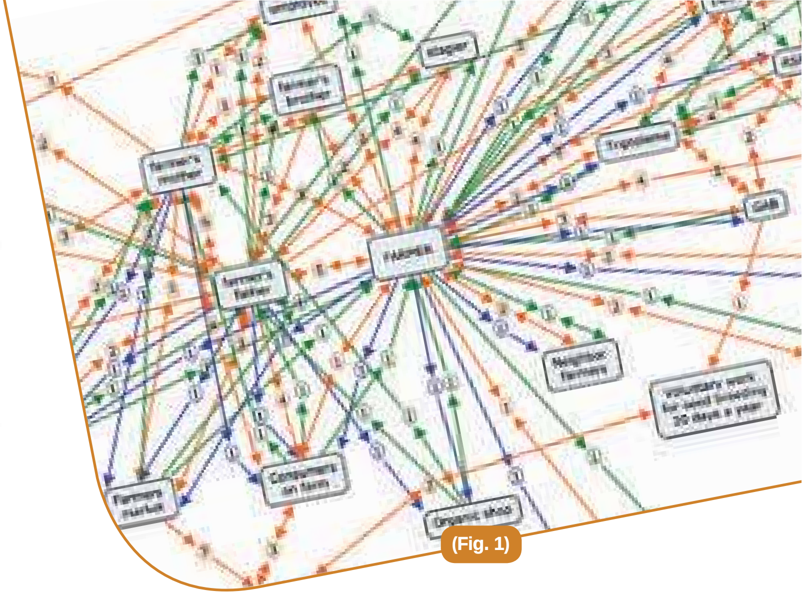
* see glossary page 26

#9 Modelling tools to assess and improve environmental and socio-economic sustainability of farms



(Fig. 1)

Summary

Farm management strategies to decrease environmental impacts may be improved by stronger interactions within the local community. The use of local renewable resources makes a farm more autonomous and less dependent on the global market's volatile prices. To assess the potential for improvement, SOLIBAM developed a number of innovative modelling tools e.g. i) Network analyses to unravel the interaction of farmers and factors influencing their actions; ii) Quantitative measures of autonomy accounting for the use of freely available natural resources as well as the use of resources from society; iii) Integrative design of farming systems based on environmental life cycle assessments in collaboration between scientists and farmers.

Background

Interactions with the local environment and society in a mutually beneficial sphere of innovation and local development may be a way to increase stability and resilience of farming systems. This may be obtained by increasing diversity at several levels and by focusing on locally available, natural resources and having a multifunctional production process, which also protects local environments.

In this context, there is a need for tools to evaluate how farmers are connected to, and interact with, the greater global economy and how autonomous they are by using local renewable resources. At the management level, tools for evaluating and designing farm-specific management interventions aimed at improving resource use and eco-efficiency are needed. The development of these tools requires a strong involvement of farmers and experts.

Activities

The three tools mentioned apply a broad spectrum of methods from environmental and socio-economic sustainability assessments and have been developed in a multidisciplinary collaboration of researchers and farmers. We have applied the different tools on detailed inventory data collected from eight selected relatively autonomous and low-input farms in France, UK, Portugal and Italy.

Farmers interactions with the local actors they consider relevant for their activity and innovation development have been assessed by creating a network diagram together with the farmer (Fig. 1). The centrality measures of network analysis are used to determine the role of different actors in the network of a farmer, thus giving important information on farmers interaction with society. This tool is a promising way of assessing social sustainability.

Other measures of farms' autonomy are based on emergy indicators accounting for all available energy used directly or indirectly to make the products of the farm. Specific focus has been put on renewability (the fraction of energy and material flows directly provided by the sun, the tide or geothermal heat) and geographical origin of inputs. On the basis of that information, it is possible to assess how a farm is supported by local

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Modelling tools to assess and improve environmental and socio-economic sustainability of farms

energy and material flows and how much it depends on external inputs, i.e., from the global economy.

Finally, product life cycle assessments (LCAs) have been performed to quantify the eco-efficiency of the study farms. For two bread producers from France, SOLIBAM scientists have co-developed improvement scenarios with the farmers using LCA as a decision support tool. With the use of the method, potential improvements have been revealed that allow some of the impacts to be almost halved without compromising cropping system diversity or distinctive product characteristics.

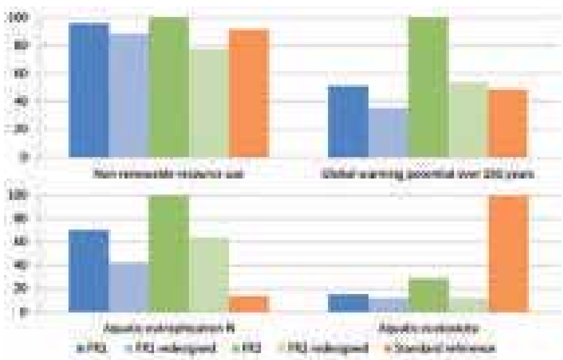
Description of the innovation

The network analysis shows that the individual farmer's connection to the environment, society, local and global economy is an important factor for the capacity of a farmer to increase farm stability and management innovations. The flows of materials and money may result in an inflow of innovation and knowledge. Therefore, local exchange of products may be a valuable source to also increase the effect of valuable tacit knowledge and innovations made by, for example, other farmers and scientists. Network analysis represents an innovative method for farm community analysis, which can be used to scale up innovations that could be further analysed in a micro-economic assessment.

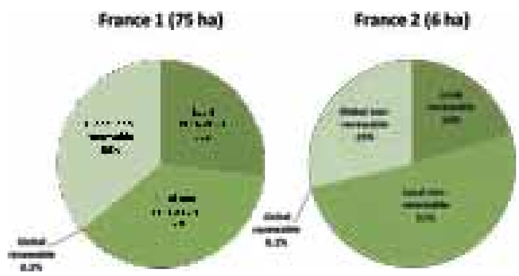
The emergy assessment made it possible to assess the interactions between farmers concerning use of resources from local society as well as each farmer's use of natural renewable resources. The specific information has been obtained by identifying the origin of inputs to the food production system. As an example, the emergy assessment from the French farms has shown that energy and material flows from the local area represented 64-71% of total resource use, and that about 20-27% of the total resource use was renewable (Fig. 2). This indicated a high level of interaction with the local environment but also a large amount of non-renewable resources coming from society.

LCA studies based on individual farms revealed a large variability of eco-efficiency within individual countries and even from year to year within individual farms (Fig. 3). It highlights the importance of individual management decisions. The application of integrative design with LCA for the two case study systems from France have shown i) that a low-input and diverse cropping system can be relatively eco-efficient with a proper organisation, ii) that it is possible to improve the eco-efficiency of such systems without compromising their distinctive properties such as local production and diversity and iii) that large improvement potentials suggest a lack of knowledge on eco-efficient cropping system management can be a key limiting factor for environmental sustainability.

Fig 1: Network diagram for farm FR1. Blue lines show material flows, orange lines show information flows and green lines show money flows.
Fig 2: Distribution of resource use on renewability and origin of inputs.
Fig 3: Relative environmental impacts of bread from the case FR1 (baseline), simulated bread from the case FR1 after the application of management improvements (FR1 redesigned), bread from the case FR 2 (baseline), simulated bread from the case FR2 after the application of management improvements (FR2 redesigned) and the standard reference (REF-FR). Functional Unit: 1 kg of bread at the consumer's home.



(Fig. 3)



(Fig. 2)

Where: Switzerland, Denmark, France, Italy, Portugal, UK.
When: Data from years 2008-2012 are collected in the years 2010-2014
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#10 Seed System Adaptation

Summary

For two centuries, cereal breeders have bred only true breeding line varieties*, which are convenient and simple; their use is enshrined in an international legal system. Such varieties cannot carry all the genes necessary for high yields in increasingly variable environments; their use can be maintained only by applying expensive inputs. The alternative is to increase massively within-crop diversity by using populations in which all plants are genetically different. However, marketing of population seed is illegal. SOLIBAM has helped to show that populations can be high yielding and stable across environments and it has now persuaded the EU of the need to develop a suitable protocol for marketing populations.

Background

Pedigree line breeding became important a century ago to help farmers know what they were growing. More recently it has enabled breeders to protect ownership of varieties. During this time, global cereal demand exploded, but the monocultures used lack the genetic potential to cope with environmental variation caused by increasing climate instability and declining resources. One solution is to increase within-crop genetic diversity by using physical mixtures of varieties, or Composite Cross Populations* developed from segregating F2 populations of varietal intercrosses*. Their productivity and stability has been confirmed in trials against leading varieties. However, marketing population seed is illegal, so it was necessary to disseminate information about the performance of populations, and to develop a way for legalising their use.

Activities

Partners have been involved in generating populations in a number of crops and testing their performance against standard pedigree line varieties or hybrids. Populations generally show acceptable yields and control of diseases, pests and weeds. However, in addition to the standard traits that have been measured, one of the most important has been to test for stability across different environments, both within and among countries. As expected, populations show predictable stability of performance relative to single varieties. Genetic analysis shows that this is largely due to changes in gene frequencies; few genes are lost from the populations. The genes that are lost appear to be those that reduce inter-plant competitiveness, such as dwarfing genes.

* see glossary page 26

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Seed System Adaptation

As predicted, there are indications that populations are also more stable than variety mixtures, particularly under more challenging conditions. However, it has not been possible to determine the occurrence or extent of local adaptation, probably because of large annual variations in climate and weather. Trials also show the potential for using diversity in different ways. For example, single varieties with useful characters such as high yield or quality can be mixed into populations. This has the potential for gaining from the required character while protecting the variety involved, at least to some degree. Performance from such mixtures appears to be predictable, depending on the proportions of variety and population. A further possibility is to select desirable lines from a population and then grow a mixture of the selected lines. This has the positive effect of removing some of the apparently weaker genotypes from a population while improving performance.

Description of the innovation track

Despite the positive results for the many ways in which genetic diversity can be used to advantage in cropping systems, those advantages are limited by the total genetic diversity available. That genetic diversity should be increased however, through the outputs from the FP7 project WHEALBI. A potentially valuable character related to such diversity is resistance to seed-borne diseases, particularly bunt, because of the advantages of retaining population seed for use in particular localities under organic management.

Despite the positive results, progress has been hindered by the international legal seed system based on the distinctness, uniformity and stability (D.U.S.) criteria for true breeding pure lines. This system prevents full exploitation of diversity at a time when it is increasingly needed. Mixtures of pure line varieties are allowed, but only if the mixture contains new seed of those varieties; the seed produced from mixtures cannot be traded. The legislation currently prevents development of the population breeding approach and the potential positive developments outlined above. This amounts to an artificial constraint on the possible means to deal with problems affecting secure, long-term provision of human nutrition. Fortunately, however, as a result of SOLIBAM's trials and representations, the EU has agreed to a limited temporary experiment which will allow a population protocol to be trialled, based on total transparency of the origin and cultivation history of marketed cereal populations. There is a need for widespread support for this development to ensure that the EU experiment allows population cultivation and observation in a wide range of different environments, with comprehensive feedback to underline the case for providing farmers with a greater opportunity to make practical and profitable use of greatly increased crop diversity.

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Glossary

Composite Cross Population: for production of a Composite Cross Population exhibiting a wide range of phenotypic variation, a range of genetically different parents would be hybridised, perhaps in all combinations, to produce an F1 population (see «F1/F2 populations »). This would then be allowed to self so that all of the F1 crosses would segregate. Mixing the offspring of all of the crosses would then produce a highly complex F2 population.

F1/F2 populations: if two plants with different genotypes (usually homozygous) of a P (Parent) generation are hybridised, they produce F1 (Filial generation 1) offspring which are heterozygous (highly heterozygous if the parental genotypes are very different from each other). This is in contrast to the selfing (see « True breeding line varieties* »). The phenotype of the F1 plants represents the expression of the dominant alleles of the heterozygous genes together with the genes that are homozygous between the parents. The ratio of heterozygous to homozygous genes depends on how different the parents are from each other. If the F1 plants are now allowed to self, to produce the F2 generation plant population, the genes will segregate, allowing expression of homozygous recessive genes. At this point, there is a high degree of expression of phenotypic variation, depending on the size of the population and the degree of difference between the parents.

Intercropping is the practice of managing different crops simultaneously in the same field; different spatial arrangements ensure different levels of interaction among the crops being grown. The different crops cultivated are chosen to be complementary for their use of resources. This type of cultivation provides advantages for soil structure, productivity, quality and associated biodiversity. Different types of intercropping exist depending on the cropping objectives (e.g. two or more cash crops, cash crop plus living mulch, etc).

Landrace: local plant variety which has developed over time, by adaptation to the natural environment in which it grows. A landrace is usually more genetically and physically diverse than a modern variety.

Resilience is the capacity of an ecosystem to respond to a perturbation by resisting damage and recovering quickly. A resilient system will reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks. Thus resilience is linked to the adaptive capacity of a system in the face of change.

R package : R is a free software environment for statistical computing and graphics (http://www.r-project.org/). A package is a set of R functions.

Sustainability: Often sustainable development refers to satisfying present needs without reducing the possibility of future generations satisfying theirs. However, sustainable development requires further that resources should be used at a rate that allows their re-formation and wastes should be produced at a rate which allows the environment to absorb them. This is an ideal situation which we should aim at even though it is nearly impossible to obtain.

True breeding line varieties (also pedigree line varieties): these are varieties that pass down particular phenotypic traits to all of their offspring. This means that, in each generation, the hybridising parents must be genetically identical and homozygous for those traits. The terms often refer to crop varieties selected from self-fertile species such as wheat, barley, oats, triticale and rice among the cereals. Because of the high level of self-fertility and homozygosity, the offspring produced from the male and female flowers of one parent plant are identical to that parent, hence true breeding. The small amount of out-crossing that does occur will be mostly between the identical plants in the same stand which will not affect the subsequent generation.

Varietal intercrosses: if sample plants of two or more varieties are crossed or hybridised, this can be referred to as a varietal intercross. If a number of varieties are hybridised, for example in generating a Composite Cross Population, this may be referred to as varietal intercrossing.

Yield (preferably high) stability is the ability of a variety (pure line, mixture, population) to yield consistently in different environments. Stability may be Type 1 (‘static’ - constant yield across environments), Type 2 (‘dynamic’ - yield follows the potential in different environments), or Type 3 (consistent over time at one location).

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SOLIBAM KEY INNOVATIONS

Cultivating diversity

June 2014

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10 SOLIBAM KEY INNOVATIONS

Cultivating diversity

Abstract: *Based on "diversity", **SOLIBAM** has designed and tested innovative strategies to develop specific and novel breeding approaches integrated with management practices to improve the performance, quality, sustainability and stability of crops adapted to organic and low-input systems. Through more than 50 field experiments, case studies in 4 countries, 8 major crop models and several competences including genetics, plant breeding, agronomy, ecology, food science, statistics, sociology and economics, **SOLIBAM** has developed various agro-ecological innovations which are at the core of its strategies:*

- *new approaches to plant breeding and development which simultaneously consider diversity and quality, performance and stability, co-breeding for intercropping, or crop-pollinator interactions;*
- *new food products with improved quality properties;*
- *new tools for participatory plant breeding and management (PPBM) which farmers, researchers and other stakeholders design ed together: 1) new breeding methods for decentralized programmes, 2) tools for resource and trial management, and for the statistical analysis of results, 3) integrating methodologies to improve selection for appetising products.*
- *social innovation and collective action for decentralised and participatory research;*
- *new modelling tools to improve understand and assessment of the resilience, viability and sustainability of farms;*
- *new propositions for policy makers so as to adapt seed regulations to accommodate diverse genetic resources.*

*This user-friendly booklet describes 10 **SOLIBAM** KEY innovations dealing with the issue of diversity at multiple levels, from the field to the plate. For each of them, **SOLIBAM** partners describe the background, the related activities performed during the project and the resulting new ideas (product, practice, service, production process or a new way of organisation) that were developed.*

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SOLIBAM
Strategies for Organic and Low Input Integrated Breeding And Management
2010-2014

www.solibam.eu