INTERNATIONAL CONGRESS

# DIVERSITY STRATEGIES

## for organic and low input agricultures and their food systems

7th • 9th July 2014

Nantes (France) I Oniris

Site de la Géraudière

Strategies for Organic and Low-Input Integrated Breeding and Management

# BOOK of ABSTRACTS

# Diversity strategies for organic and low input agricultures and their food systems

## Solibam final congress

**7th - 9th July 2014**

**Oniris-La Geraudière, Nantes (France)**

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# Foreword

## Diversity strategies for organic and low input agricultures and their food systems

## SOLIBAM final congress

### Strategies for Organic and Low-input Integrated Breeding and Management

7th - 9th July 2014
Oniris-La Géraudière, Nantes (France)

This event is the final congress of the SOLIBAM European project (2010-2014) which aimed to develop 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 Europe and Sub-Saharan Africa. Twelve countries and 23 organisations (research and development institutions and seed companies) are involved in the consortium.

**Organisation of the congress**

The congress takes place in the last year of the project so as to present most of our SOLIBAM outcomes, recommendations and strategies. Along with a widespread call for external contributions, this has resulted in a large programme devoted to diversity in agriculture. Partners from COBRA (Coordinating Organic plant BReeding Activities for diversity), a Core-organic II project, have joined the SOLIBAM team and participated as members of the scientific committee. There are joint poster areas for the two research programmes.
Keynotes speakers have been invited to enrich SOLIBAM points of view, and to open discussions into the future of agriculture.
The first evening will bring together several stakeholders in the project, highlighting the interactions between them, showing the multi-actor approach of SOLIBAM and providing an opportunity to try some “edible results” of our research activities. The event will be an occasion in which to share produce from farmers and taste recipes cooked by caterers engaged with the SOLIBAM team, clearly making visible the links between organic culture and agriculture.

**The congress title encapsulates the key-themes of SOLIBAM**


***Diversity***[1]*:*
Diversity is a fundamental principle throughout SOLIBAM. The underlying hypothesis is that diverse populations in organic and low-input systems are more resilient to stresses of various kinds and can therefore better adapt to environmental variations.” For plant breeding and management, agricultural diversity refers to the diversity of species cultivated for human food, animal feed, medicine, industrial uses etc., and even includes farmers’ associated knowledge. Agricultural biodiversity is the sum of the differences among species, among varieties within species and among individuals within varieties. Within the SOLIBAM research activities, we have extended diverse approaches to all levels from soil management to socio-economic aspects. In SOLIBAM we are combining many disciplines and values with the aims of increasing system diversity and participatory methods, developing methods and assessing quantitative and qualitative data, all of which are important in supporting transdisciplinary thinking

[1] SOLIBAM, deliverable 9.4 – booklet 3

***Strategies*[2]:**

Strategies have been developed to improve crop performance, produce quality and resilience/sustainability of cropping, farming and food systems through agroecological innovations. These are all based on improving and optimising the use of diversity in breeding and management, as well as reducing external inputs. One survey[3] has offered a broad picture of the farmers, susceptible to adopt SOLIBAM strategies, showing farms managed by women and early entrants, as well as family farms. The "multifunctional" criteria of organic farms is also noticeable with typical services provided by multi-functional farms being processing, agritourism, and education to environment. The source of information predominantly used by farmers comes from universities and other public services.

***Organic and low input agriculture*[4]:**

Within the umbrella activities of SOLIBAM, we tried to better define both forms of agriculture on which we were working. Health of ecosystems and natural processes are defining the central hypothesis of organic agriculture, whereas low-input farming is based on input reduction, rather than exclusion, and uses a wide range of methods, both mechanical and technological. Organic farming is managing farming systems thanks ecosystems services and don't use external solutions, as chemical inputs, which are reduced but not abandoned in LI farming systems.

In most definitions of organic agriculture, ecological health is central and farmers are aware that conversion from other farming systems can bring a decrease in income; however, low-input farming puts the economic argument as the main focus, although ecosystem health remains important.

The definition with the greatest consensus among SOLIBAM partners is proposed by J.F. Parr et al. (1990)[5]: low input farming systems are those which "seek to optimize the management and use of internal production inputs (i.e. on-farm resources)... and to minimize the use of [external] production inputs (i.e. off-farm resources), such as purchased fertilizers and pesticides, wherever and whenever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, and to increase both short- and long-term farm profitability."

***Food systems*[6]:**

We define a food supply system as consisting of the initial production on-farm, followed by processing and distribution to the customer. SOLIBAM has undertaken case studies of food supply systems, mainly on farms which are aiming to reduce their inputs and apply a large diversity of crops and varieties. In this way, these farms act as candidates for potential recommendations to define a 'SOLIBAM food supply system'. We have analysed the environmental impacts, resource use efficiency and economic feasibility of these case studies and benchmarked them against 'normal practice'. In addition, the data has been used to describe possible scenarios for how to increase the contribution food chains could make to the sustainable development of European agriculture. Sustainable development is often taken to refer to approaches that satisfy the needs of the present generation without reducing the possibility for future generations to satisfy theirs; however, sustainable development requires more than this. It also demands that resources should be used at a rate that allows their re-formation and waste should be produced at a rate which allows the environment to absorb it. This is an ideal situation which we can aim for, but which is nearly impossible to obtain.

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[2] Deliverable D1.8

[3] Milestone M8.11: Isabel Dinis, Livia Orttolani, Riccardo Bocci, Claudia Brites (2003) Organic agriculture and sustainable practices: towards a typology of farmers. In proceeding of: ESADR 2013, At Évora, Volume: C07 - Ambiente e Recursos Naturais:1673-1690

[4] Deliverable D1.4

[5] Parr JF et al. (1990) "Sustainable Agriculture in the United States," in *Sustainable Agricultural Systems*, ed. by Clive A. Edwards, et al. (Ankeny IA: Soil and Water Conservation Society

[6] Deliverable D8.4

# The Scientific Committee

It is composed by SOLIBAM 9 WP leaders and 3 COBRA (Coordinating Organic Plant Breeding Activities for Diversity) scientists.

CHABLE VÉRONIQUE, Inra, France
HOWLETT SALLY, Elm Farm, UK
GOLDRINGER ISABELLE, Inra, France
MENDES-MOREIRA PEDRO M.R., Esac, Portugal
ØSTERGÅRD Hanne, Riso-DTU, Denmark
BOCCI RICCARDO, AIAB, Italy
BARBERI PAOLO, SSSUP, Italy
MIKO PETER, HAS, Hungary
RAKSZEGI MARIANNA, HAS, Hungary
BORGEN ANDERS, Agrologica, Denmark
FINCKH MARIA, University of Kassel, Germany
PEDERSEN TOVE, Knowledge centre for agriculture, Denmark

**How to cite this document**

Chable V, Goldringer I, Howlett SA, Barberi P, Miko P, Mendes-Moreira PMR, Rakszegi M, Østergård H, Borgen A, Finckh MR, Pedersen T, Bocci R (Eds.) 2014. Diversity strategies for organic and low input agricultures and their food systems. Book of abstracts of Solibam final congress, Nantes, 7-9 July 2014.

# Solibam partners

We would like to acknowledge and thank all SOLIBAM partners for their contributions to the work described in abstracts marked with Solibam logo.

The project is a collaborative effort which relies on the input of all participants including farmers, advisors, researchers and breeders. The main beneficiary organisations involved are: Institut National de la Recherche Agronomique (INRA, France); Associazione Italiana per l'Agricoltura Biologica (AIAB, Italy); The Organic Research Centre, Elm Farm (ORC, UK); Technical University of Denmark (DTU, Denmark); Institut Technique de l'Agriculture Biologique (ITAB, France); Technical University of Munich (TUM, Germany); Instituto de Tecnologia Quimica e Biologica (ITQB, Portugal); Instituto de Agricultura Sostenible (IAS, Spain); Escuola Superior Agraria De Coimbra (ESAC, Portugal); Agricultural Research Institute of the Hungarian Academy of Sciences (HAS, Hungary); Scuola Superiore Sant'Anna (SSSUP, Italy); University of Perugia (UNIPG, Italy); Federal Department of Economic Affairs (FDEA-ART, Switzerland); Institute of Food and Resource Economics (UCPH, Denmark); INRA Transfert (IT, France); Saatzucht Donau (Austria); Gautier Semence (France); Agrovegetal (Spain); Arcoiris (Italy); International Centre for Agricultural Research in Dry Areas (ICARDA, International); Mekelle University (MU, Ethiopia).

# Programme

## Monday, July 7th

| | |
|---|---|
| **1 :00 pm** | Arrival and payment of lunch fees |
| ***Main lecture hall*** | **Plenary (the context) :Transdisciplinary research for organic and low-input agricultures** |
| **1 :30 pm** | Transdisciplinary research for organic and low-input agricultures : SOLIBAM aims at increasing diversity at all levels in farming and food systems<br>*Véronique Chable, Inra, France, Frédéric Rey, Itab, France, Pedro Mendes-Moreira, ESAC, Portugal* |
| **2 :15 pm** | Partnerships for transition in agriculture : Potentials and conditions of a transdisciplinary approach of innovation<br>*Philippe Baret, University of Louvain, Belgique* |
| ***3 :00 pm*** | *Coffee break* |
| **3 :30 pm** | Experimental design for PPB in farm network : When Bayesian statistics meet farmers'field<br>*Pierre Rivière, INRA − Univ Paris-Sud, France* |
| **3 :45 pm** | Towards a more community oriented and chain-based breeding<br>*Edwin Nuijten, Louis Bolk Institute, The Netherlands* |
| **4 :00 pm** | Cereal breeding: a more appropriate direction?<br>*Martin Wolfe, ORC, UK* |
| **4 :15 pm** | Discussion |
| **4 :45 pm *Entrance hall*** | Poster Session |
| **5 :45 pm** | Presentation of Oniris and meeting with local peasants |
| **7 :00 pm** | Welcome cocktail |
| **8 :00 pm** | We are experiencing a new renaissance: what are the stakes of this changes ?<br>*Yannick Roudaut, lecturer and author, France* |

## Tuesday, July 8th

| **Main lecture hall** | **Session A. Managing diversity for robustness, resilience and yield stability** | **Pink hall** | **Session C. Diversity for quality in organic systems 'soil to fork'** |
|---|---|---|---|
| **9 :00 am** | SOLIBAM approaches to promote strong crop performance in heterogeneous conditions<br>*Sally Howlett, Martin Wolfe, ORC/Elm Farm, UK and Paolo Barberi, SSSUP, Italy* | **9 :00 am** | GxExM effects on organoleptic, nutritional and end-use quality<br>*Mariann Rakszegi, Centre for Agricultural Research, Hungary, and Elsa Mecha,ITQB, Portugal* |
| **9 :45 am** | Breeding for Diversity: A review of 10 years of evolutionary participatory breeding, and a look ahead.<br>*Kevin Murphy, Washington State University, USA* | **9 :45 am** | Agro-biodiversity and preservation of traditional food: Functional properties and perspectives<br>*Giovanni Dinelli, DiPSA, University of Bologna, Italy* |
| ***10 :30 am*** | *Coffee break* | | |
| **11 :00 am** | Responses of bread wheat varieties to different environments : Differences among wheat traits in sensitivity to organic and low input growing conditions<br>*Peter Mikó, Centre for Agricultural Research, HAS, Hungary* | **11 :00 am** | Manipulating protein content in diverse populations using NIRS single seed sorting<br>*Anders Borgen, Agrologica, Denmark* |
| **11 :15 am** | Exploitation of diversity in grain Maize<br>*Nevena Nol, Scuola Superiore Sant'Anna, Italy* | **11 :15 am** | Processing and Baking Quality of Organic Winter Wheat in Switzerland<br>*Knapp Samuel, Agroscope, Institute for Plant Production Sciences, Switzerland* |
| **11 :30 am** | Breeding for improved nitrogen fixation<br>*Monika Messmer, FiBL, Switzerland* | **11 :30 am** | Peppers : soil dynamics, root architecture and fruit quality<br>*Adrian Rodriguez-Berruezo, Spain* |
| **11 :45 am** | Breeding winter peas in diversity for diversity<br>*Ulrich Quendt, Cereal Breeding Research Darzau, Germany* | **11 :45 am** | Integrative breeding strategies to improve sensory qualities of wheat bread<br>*Vindras-Fouillet Camille, Inra - Itab, France* |
| **12:00 pm** | Discussion | 12 :00 pm | Discussion |
| ***12:30 pm*** | *Organic buffet with local food* | | |

| Main lecture hall | Session B. Diversity for specific adaptation and evolutionary processes | Pink hall | Session D. Sustainable food supply systems from diversity |
|---|---|---|---|
| **2:00 pm** | Diversity for functional biodiversity, specific adaptation and evolutionary processes<br>*Goldringer Isabelle, Inra, France* | **2 :00 pm** | What is efficiency in sustainable food systems and how could it be measured?<br>*Bjorklund Johanna, Örebro University, Sweden* |
| **2:45 pm** | Diversity for specific adaptation and evolutionary processes : Improving Food Security by Cultivating Diversity<br>*Ceccarelli Salvatore, Icarda, Italy* | **2:45 pm** | Sustainable food supply systems from diversity : Integrated assessment of environmental and economic sustainability applied on case farms<br>*Østergård Hanne, Technical University of Denmark* |
| | | **3 :15 pm** | Integrative design. Resolving the conflict between diversity and efficiency.<br>*Kulak Michal, Institute of Sustainability Sciences, Agroscope, Switzerland* |
| ***3:30 pm*** | *Coffee break* | | |
| **4:00 pm** | Microbial communities associated to common bean seed<br>*Klaedtke Stephanie, Inra, France* | **4 :00 pm** | Economic sustainability of SOLIBAM food supply systems. A comparative analysis<br>*Morten Gylling, University of Copenhagen, Denmark* |
| **4:15 pm** | Performance of wheat composite crosses on-station and on-farm<br>*Maria Finckh, University of Kassel, Germany* | **4 :15 pm** | Discussion of results from case farms |
| **4:30 pm** | Using diversity of Ethiopian durum wheat to challenge climate change: a three-pronged approach<br>*Djene Kassahun Mengistu, Scuola Superiore Sant'Anna - Mekelle University, Italy & Ethiopia* | **4 :30 pm** | The role of learning networks in co-producing sustainability. The case of Crisoperla Association<br>*Adanella Rossi, University of Pisa, Italy* |
| **4:45 pm** | Building-up faba bean cultivars for low-input farming : A crop-pollinator inter-play approach<br>*Maria José Suso, Instituto de Agricultura Sostenible, Spain* | **4 :45 pm** | Is cultivated diversity a guarantee of stability?<br>*Estelle Serpolay-Besson, Itab, France* |
| **5:00 pm** | Discussion | **5 :00 pm** | Discussion of sustainable food systems |
| ***5:30 pm*** | *End of the day* | | |
| ***7:30 pm*** | *Cocktail and Gala dinner (optional)* | | |

## Wednesday, July 9th

| Main lecture hall | Plenary (for future) : Agriculture for a future society: challenging paradigms |
|---|---|
| **9:00 am** | Agriculture for a future society : challenging paradigms<br>*Riccardo Bocci, AIAB, Italy* |
| **9:45 am** | Jan Douwe Van der Ploeg, University of Wageningen, The Netherlands. Author of "The New Peasantries - Struggles for Autonomy and Sustainability in an Era of Empire and Globalization" Earthscan (London), 2008 |
| ***10:30 am*** | |
| **11:00 am** | Terry Marsden, University of Cardiff, UK. Co-editor with and A. S. Morley "Sustainable Food Systems: Building a new paradigm" Oxon: Routledge, 2012 |
| **11:45 am** | Discussion and conclusion |
| ***12:30 pm*** | *Organic picnic / organic buffet* |
| **2:00 pm** | Departure for the farm (please get to the bus before 2 pm!) |
| **7:00 pm** | Back in Nantes |

# Plenary

# The Context

# Transdisciplinary research for organic and low-input agricultures

# Partnerships for transition in agriculture : potentials and conditions of a transdisciplinary approach of innovation

BARET PHILIPPE[1]

[1]University of Louvain, Earth & Life Institute, Belgium, www.philagri.net, philippe.baret@uclouvain.be

**Key words:** agroecology, transition

**Summary:** Transition of agricultural systems is a complex and long process. New indicators, new practices, new networks will ease this process. In a agroecological framework, different sources of knowledge will merge to explore innovation and design pathways. Mode of interactions between actors is a key elements and in itself a subject of research in order to overcome enduring lock-ins and to build new alliances. An analysis of the present situation and an analysis of the diversity of the mode of organization may paves the way to more efficient and relevant partnerships.

# Transdisciplinary research for organic and low-input agricultures

## SOLIBAM aims at increasing diversity at all levels in farming and food systems.

VÉRONIQUE CHABLE[1], FRÉDÉRIC REY[2], PEDRO MENDES MOREIRA[3]

[1]INRA, Sciences for Action and Development, Rennes- Le Rheu, France, chable@rennes.inra.fr
[2]ITAB, French Research Institute of Organic Farming, France, www.itab.asso.fr, frederic.rey@itab.asso.fr
[3]ESAC, Portugal, www.esac.pt, pmm@esac.pt

**Key words:** multi-actor research, innovation, plant breeding, crop management, autonomy

**Summary:** Based on the hypothesis of “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. From more than 50 field experiments, case studies in 4 countries and 8 major crop models, several competences including genetics, plant breeding, agronomy, ecology, food science, statistics, sociology and economics, SOLIBAM has established 10 major concepts for cultivating diversity (resilience, robustness, functional biodiversity, yield stability, adaptability, intercropping, sustainability, evolutionary processes, organoleptic quality, participatory research), building strong transdisciplinarity in a dynamic process of knowledge integration.

### Introduction

The fundamental hypothesis of SOLIBAM is diversity. Diversity was studied and stimulated at multiple levels: from genetic diversity within cultivars to crop diversity on-farm, diversified crop management and diversity in food products. SOLIBAM started in 2010 under the auspices of the International Year for Biodiversity. The United Nations invited people to act all over the world “to safeguard this irreplaceable natural wealth and reduce biodiversity loss”. Diversity was considered “vital for current and future human wellbeing”.

Now, as SOLIBAM comes to an end in 2014, the United Nations has launched the International Year of Family Farming to emphasise the vast potential of family farmers to eradicate hunger and to preserve natural resources. The FAO stresses the huge productive potential of family farmers: "Nothing comes closer to the sustainable food production paradigm than family farming. Family farmers usually run non-specialized, diversified agricultural activities that give them a central role in securing environmental sustainability and preserving biodiversity."[7] SOLIBAM has taken into consideration many farm types dealing with diversity and held a workshop in 2013 which concluded that most of them could be qualified by their family dimension. This raised the question of what was the most appropriate way to describe them: peasant farming or family farming?

In the global context of these overall objectives for agriculture and food systems, 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 steps of agricultural production, from genetic aspects to environmental and socio-economical dimensions.

### From multidisciplinarity to transdisciplinarity

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 characterized by a complexity of interactions. As a basis, we therefore aimed to develop tools and methodologies to better understand and manage 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, (10) Participatory research (see deliverable D9.4/ 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.

Several examples will be given during the Congress to illustrate this research approach, which incorporate multiple concepts per trial. For example, breeding activities involving our model species have been integrated with management practices, including adaptation and evolutionary processes, taking into account soil fertility management, efficient root systems able to interact with beneficial soil micro-organisms, the ability to compete with weeds, to contribute to crop and seed health and to give good product quality. Assessing the performance of crops has necessitated a methodological approach: a set of traits was designed according the conditions and objectives for each model species. Traits specific to organic and low-input conditions were identified and assessed using a range of competences, but analysed according to our 10 concepts. In this way, a strong transdisciplinary approach was built which can be described as a dynamic process of knowledge integration.

[7] FAO Director-General José Graziano da Silva, speaking on behalf of FAO, which is the lead UN agency for the year, http://www.fao.org/news/story/en/item/207544/icode/

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). 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.

Part of SOLIBAM's research was participatory in nature, based on the experience and skills of a number of partners to better share knowledge and to involve several kinds of actors and their activities. In several cases, transdisciplinarity in SOLIBAM has allowed links to be made between scientific knowledge and practitioner 'know-how' in complementary ways.

**From multi-actor and transdisciplinary research to innovation**

SOLIBAM has developed various kind of 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) in 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 better select for tasty products ;

-social innovation and collective action for decentralised and participatory research;

-new modelling tools to better understand and assess resilience, viability and sustainability of farms;

-new propositions for policy makers so as to adapt seed regulations to accommodate diverse genetic resources.

**An example with maize to illustrate transdisciplinary and multi-actor research in SOLIBAM**

Maize is one crop which illustrates several of our SOLIBAM strategies. Two main countries were involved: France and Portugal. In Portugal, the participating farmers had been engaged in PPB for a long time, since Dr Silas Pego (Mendes-Moreira 2006) started VASO (Sousa Valley) – PPB in 1984. In France, farmers initiated on-farm breeding of maize in the South West at the beginning of 2000, when they organised themselves in networks to address the needs of organic and low input farming (Chable et al, 2014). In both countries, the aim was to better connect plant breeding and quality of the final products in their diversity. In Portugal, farmers and bakers were interested in maintaining traditional bread baking ("broa" bread), and in France, practitioners gathered together farmers, bakers and caterers (chefs or cooks) to innovate with new maize populations. SOLIBAM offered several types of approach for breeding methods with and for diversity, for exploring interactions between quality aspects (nutritional, sensorial and end-use characteristics) with breeding and management parameters (e.g. intercropping), and for raising new scientific questions as a result of SOLIBAM experiments. For example, quality evaluation is crucial to differentiate maize for food (human consumption) and feed (mainly provided by modern F1 hybrid varieties), and the integration of empirical knowledge (quality as defined by farmers and consumers) to technological and biochemical aspects is very important in determining breeding strategies and markets. In parallel, the connection between both French and Portuguese PPBM networks has enlarged farmers' 'know-how' by sharing organisational and practical knowledge. The farmers' experience with breeding for diversity and on-farm seed multiplication has given substance to recommendations and debates within DG SANCO in the framework of the seed regulations revision.

**An example of an organic farm where disciplines and competences meet**

The involvement of farmers also raised several other questions about the definition of SOLIBAM strategies and the sustainability of farming systems, from environmental and socio-economic points of view. For example, Florent Mercier's farm, which we will visit at the end of the congress, was first involved in PBB for bread wheat. He participated in the organisation of experiments from the grain to the final bread products, and provided several wheat populations previously selected on his farm from landraces. His farm has been converted to organic agriculture for several decades (two generations of farmers) and demonstrates a high level of autonomy. LCA and emergy assessment, involved in the study of environmental sustainability raised many questions about the relevance of the models and the criteria of sustainability at farm level. From a sociological point of view, apart from high crop diversity, SOLIBAM farms like Florent's are characterized by a desire for autonomy, cooperation and sustainability. Autonomy means increased stability by reducing dependency on external inputs and large markets on one hand and increasing interactions with social networks and nature on the other. Florent is member of "Réseau Semences Paysannes" in France, in which the name "peasant" is positively promoted. Peasant farmers consider themselves citizens as much as producers and are aware of their social and environmental responsibility. Rather than the 'best' price, they will target consumers who look for product and process quality and who engage in communication with the producer.

We have worked with several SOLIBAM farmers to show that diversity does not only cover crops species and varieties, but also production management and marketing channels. At all levels, SOLIBAM has tried to identify complementarities between diversified, non-dogmatic solutions from which choices can be made according to each farm's situation, within a cultural and environmental context.

**Conclusion**

SOLIBAM is characterized by a large number of trials aiming to illustrate the diversified conditions of organic and low-input agriculture in Europe. The objective was not to apply common methodologies but to share several strategies to expand and support our 10 concepts for cultivating diversity. SOLIBAM has focused on complex agricultural systems, with the goal of producing knowledge relevant to multiple stakeholders, bringing to farmers and consumers new tools, and renewing socio-economic choices.

**References**

Chable, V., Dawson, J., Bocci, R. and Goldringer, I., 2014. Seeds for Organic Agriculture: Development of Participatory Plant Breeding and Farmers' Networks in France In: Organic farming, prototype for sustainable agricultures, Bellon S. et Penvern S. (eds), Springer, Berlin, 383-400

Moreira P. M. (2006). Participatory maize breeding in Portugal. A Case Study. Acta Agronomica Hungarica, 54(4): 431-439.

# Experimental design for PPB in farm network

## When Bayesian statistics meet farmers'field

Pierre Rivière[1], Julie C. Dawson[2] , Isabelle Goldringer[3] , Olivier David[4]

[1] UMR de Génétique Végétale, INRA − Univ Paris-Sud – CNRS, Ferme du Moulon, F-91190 Gif-sur-Yvette, France. pierre.riviere@moulon.inra.fr
[2] Department of Horticulture, University of Wisconsin-Madison, 1575 Linden Dr. Madison, WI 53706, USA. dawson@hort.wisc.edu
[3] UMR de Génétique Végétale, INRA − Univ Paris-Sud – CNRS, Ferme du Moulon, F-91190 Gif-sur-Yvette, France. isa@moulon.inra.fr
[4] UR 341 de Mathématiques et Informatique Appliquées, INRA, Domaine de Vilvert F-78352 Jouy en Josas, France. Olivier.David@jouy.inra.fr

**Key words:** decentralized participatory plant breeding, unbalanced data, hierarchical model, bread wheat, Bayesian statistics

**Summary: :** In decentralized participatory plant breeding (PPB) selection is decentralized in the target environments and relies on collaboration between farmers, NGOs and researchers. In the wheat PPB project carried out in France, each farmer participating in the project has its own experiment and chooses which variety to sow. This leads to unbalanced designs with few residual degrees of freedom on farm and about 95% of variety x environment combination missing on the network of farms. To deal with such data we developed two hierarchical Bayesian models in order to (i) assess mean comparisons on farm and (ii) study variety x environment interaction. Both models gave satisfactory results as long as a large number of farms were analysed and each farm had at least one replicated control.

### Background

A wheat PPB programme started in France in 2005. It is based on collaboration between the DEAP (Diversity Evolution and Adaptation of Population) team at INRA Le Moulon and a French farmers' seed network (Réseau Semences Paysannes (RSP). Initially, 90 populations were created by crossing parents chosen by Jean Francois Berthellot, a farmer-baker. The goal of the PPB programme was to create varieties adapted to different environments while maintaining genetic diversity within the varieties. These 90 populations have been spread in 2008 in a network of farms from the RSP. As farmers participating in the project had organic systems spanning a large range of conditions, selection was decentralized in order to develop population-varieties (named population in the rest of the text) that would suit their requirements.

### Main chapter

The wheat PPB project carried out in France is based on a large network of farms: 25 farms ran experiments for three years. Following discussion between actors of the project, several measures have been recorded on farm by the research team: plant height, last leaf spike distance, spike weight, colour, awns, curve of spike on 25 plants per population and thousand kernel weight and protein content on the bulk of the 25 plants. One of farmers' objectives was to select populations adapted to their needs. Therefore, it was necessary to evaluate a wide range of populations on farm. When setting up the experimental design, the researchers required to replicate the populations in order to estimate effects properly. On the other hand, replication was a constraint for the farmers due to (i) the lack of space and time, (ii) the need to optimize space in order to evaluate as many populations as possible and (iii) the need for flexibility. The final design was a compromise between the number of populations evaluated on-farm and the number of replicated controls (Dawson et al 2011). Two types of farms were set according to their experimental designs: satellite farms with one control, Rouge du Roc, replicated twice and regional farms with four controls (including Rouge du Roc) replicated twice in two blocs (Figure 1). Over the three year, there has been 21 regional farms and 39 satellite farms. In the following the combination of a farm in a year will be considered as an environment.

| | | | |
|---|---|---|---|
| Rouge-du-Roc | pop1 | pop2 | pop3 |
| pop4 | pop5 | C21 | pop6 |
| pop7 | C14 | pop8 | pop9 |
| pop10 | pop11 | pop12 | Renan |

| | | | |
|---|---|---|---|
| pop13 | C21 | pop14 | pop15 |
| Renan | pop16 | pop17 | pop18 |
| pop19 | pop20 | pop21 | Rouge-du-Roc |
| pop22 | pop23 | C14 | pop24 |

| | |
|---|---|
| Rouge-du-Roc | pop1 |
| pop2 | pop3 |
| pop4 | pop5 |
| pop6 | pop7 |
| pop8 | Rouge-du-Roc |

Figure 1. Experimental design for regional farms (left) and satellite farms (right). The controls are in black boxes. "pop" refers to population chosen by the farmers.

At the farm level, this led to augmented designs with few replicated populations which made standard estimates of residual variances and population comparisons unstable (due to few residual degrees of freedom). At the network level, this led to 95% of missing population x environment combination which made estimation of population, environmental and interaction effects unstable.

To deal with such data, we developed two hierarchical Bayesian model (Robert, 2001). In both models, we restricted ourselves to analysing plot means. First, to assess mean comparisons at the within-farm level, model 1 assumes that residual variances of each farm follow a common distribution. The residual variance of a trial within a given environment is estimated using all the information available on the network rather than using the data from that particular trial only. Model 2 works at the network level to models population and environment effects and sensitivity of population to interaction using all information available on the network (Table 1). The models were run with JAGS in R (Plummer, 2003).

Table 1. Models used

| Model 1 at the farm level | Model 2 at the network level |
|---|---|
| The phenotypic value $Y_{ijk}$ for variable Y, population i, environment j and block k was modelled as :<br>$Y_{ijk} = \mu_{ij} + \beta_{jk} + \varepsilon_{ijk}$ ; $\varepsilon_{ijk} \sim N(0, \sigma^2_j)$ where<br>$\mu_{ij}$ was the mean of population i in environment j;<br>$\beta_{jk}$ was the effect of block k in environment j satisfying the constraint $\beta_{j2} = -\beta_{j1}$ ;<br>$\varepsilon_{ijk}$ was the residual error;<br>N (0, $\sigma^2_j$) denoted normal distribution centred on 0 with variance $\sigma^2_j$, which was specific to environment j.<br><br>We took advantage of the similar structure of the trials on each environment of the network to assume that trial residual variances came from a common distribution :<br>$\sigma^2_j \sim Gamma(\nu, \rho)$ where ν and ρ are unknown parameters.<br><br>The parameters $\mu_{ij}$ and $\beta_{j1}$ were assumed to follow vague prior distributions : $\mu_{ij} \sim N(\mu_{.j}, 10^6)$; $\beta_{j1} \sim N(0, 10^6)$<br>Then, we placed vague prior distributions on the hyperparameters ν and ρ :<br>$\nu \sim Uniform(2, 10)$; $\rho \sim Gamma(10^{-6}, 10^{-6})$. | $Y_{ij}$ , the phenotypic value for a given variable of population i and environment j, was written as :<br>$Y_{ij} = \alpha_i + \beta_i \theta_j + \varepsilon_{ij}$ ; $\varepsilon_{ij} \sim N(0, \sigma^2_e)$ where<br>$\alpha_i$ was the effect of population i<br>$\theta_j$ was the effect of environnment j<br>$\beta_i$ was the sensitivity of population i to environments.<br>$\varepsilon_{ij}$ was the residual<br><br>Each parameter of the model were taken from the following distributions :<br>$\alpha_i \sim N(\mu, \sigma^2_v)$; $\beta_i \sim N(1, \sigma^2_s)$; $\theta_j \sim N(0, \sigma^2_l)$;<br>$\sigma^{-2}_e \sim Gamma(10^{-6}, 10^{-6})$<br><br>A vague prior distribution was used for $\sigma^2_e$ . Then, we placed vague priors on hyperparmeters μ (which was the general mean of $\alpha_i$ ), $\sigma^2_v$ , $\sigma^2_s$ and $\sigma^2_l$ :<br>$\mu \sim N(\nu, \nu^2)$; $\sigma_v \sim Uniforme(0, \nu)$; $\sigma_s \sim Uniforme(0, 1)$;<br>$\sigma^2_l \sim Uniforme(0, \nu)$ where ν was the arithmetic mean of the data.<br>The distribution of variance were borned to 0 as variance are positive by definition. |

In both models, the hierarchical model tends to shrink extreme value leading to more robust estimation of the parameters. Nevertheless, such models gave satisfactory results as long as a large number of farms are analysed and each farm has at least one control replicated. For model 1, at least 20 farms were needed to give robust results. For model 2, a large unbalanced data-set was more accurate for parameters estimation than a smaller balanced data-set. Moreover, cross validation studies showed that model 2 was predictive with $r^2$ (predicted value versus real value) between 42 and 86% for the variables.

Those models are part of the PPB methodology. Model 1 estimates the effects of each population in each environment, therefore allowing for mean comparisons which are the base for farmers to select among population on their farm. Model 2 estimates global population effects, environment effects and sensitivity of populations to interaction effects. Based on the results, there were three options for the farmers to choose new populations as candidates on their farms. The first option was to choose populations that were less sensible to interaction and had an extreme effect for traits of interest. The second option was to find farms that have similar effect the farmers'own farm and then look for populations grown on this farm. This can be done based on mean comparisons from model 1. In addition, results in percentage of the common control Rouge-du-Roc, may add extra information for the farmers. The third option was to predict the behaviour that a population would have in a given environment based on model 2. For each variable, the five best populations could be proposed to each farmer.

Simulation studies are in progress in order to assess how different levels of disequilibrium in the network affect the reliability of such analyses. A R package to run these analyses is under development. By developing 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.

**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM.

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# Towards a more community oriented and chain-based breeding
## Understanding underlying principles for successful new models

Edwin Nuijten[1], Edith Lammerts van Bueren[2]

[1]Louis Bolk Institute www.louisbolk.org, e.nuijten@louisbolk.nl
[2]Louis Bolk Institute, www.louisbolk.org, e.lammerts@louisbolk.nl

**Key words**: breeding approaches, organisational models, organic agriculture, analytical framework, key-elements

**Summary:** New breeding approaches and organisational models are needed to stimulate breeding for organic agriculture. In order to achieve this, new concepts are needed. We propose a new analytical framework based on two axes: the level of diversity in breeding products and the level of access in the breeding model. This model combines ecological and socio-economic of breeding. With this framework, it is possible to understand the success of particular initiatives, and to understand what technical breeding approaches can be combined with which organisational models Such framework will also help understand how to stimulate the development of more community oriented and chain based breeding models.

Background

Various initiatives exist to develop new breeding approaches and models for organic and low input agriculture, often outside the formal sector, sometimes partly with the formal seed sector, and even from within the formal sector. For example, some initiatives focus to have more diversity within varieties, others to develop populations instead of varieties, to stimulate the use of traditional varieties (landraces), to stimulate collaborative approaches, to involve other chain partners in breeding, to integrate the use of molecular markers in breeding, or in extreme cases to argue that GM methods have benefits for organic agriculture. These initiatives each have different approaches and assumptions. Sometimes, certain approaches seem contradictory or even incompatible with each other. And some are more successful than others. To better understand how to move forward and identify solution pathways, we need to realise that solution pathways often depart from different underlying ecological principles and socio-cultural values. Breeding is not only a technical act, but also a socio-economic activity embedded in culture. Hence, most problems related with breeding have technical, ecological, socio-economic and cultural aspects. And as different groups in society have different opinions on what exactly is the problem and what knowledge is available or not, and what norms and values to meet, many problems are so-called 'messy' problems (see Hisschemöller and Hoppe 2001). In order to better understand possible solution pathways, and to provide potential bridges between initiatives and to see how they complement each other, we need to disentangle messy problems associated with organic breeding developments.

### Conceptual frameworks

Often, solution pathways are embedded in particular types of culture. Culture can be understood as a rather fixed or solidified set of norms, values and principles, which is the result of social dynamics within communities. Over time culture may change based on processes within communities and through outside influences. To an extent culture determines the glasses we use to view the world around us and to look for solutions. Our cultural glasses shape our view of nature, the agricultural landscape (the ecological aspects), and also our perception of risk and risk management (socio-economic aspects). Cultural theory identifies four basic forms of social organisation, or solidarity: hierarchism, individualism, egalitarianism and fatalism / isolationism (Maat 2001, Thompson et al. 1999). Fatalism is more commonly used in cultural theory studies, but isolationism may be more informative in our study. These four basic forms are based on a combination of two basic forces: the measure of regulation (grid) and the measure of social involvement (group). With each basic form of social organisation goes a different thought style, a different morality and a different way of perceiving risks and ecology (Maat, 2001). In terms of risk management, solutions typical for hierarchism are insurances and alike, while solutions typical for egalitarianism are often diversification and alike. For example, breeding solutions that aim for diversification (in crops, in varieties, through populations, typically can be considered to have an egalitarian element, breeding approaches that aim to improve particular traits can be considered to have an hierarchical element, while high-tech high-cost approaches could have an individualistic element. Cultural theory is also useful to better understand why certain technology pathways are part of the so-called dominant socio-technical regimes or belong to niche innovations (Geels and Schot 2007). With this information, we can better decide whether it is possible to link certain initiatives, how to stimulate particular initiatives, and why certain initiatives are more worthwhile supporting than others.

### Common underlying principles for new chain based breeding models

These different styles of thought shape solution pathways in breeding. Worldwide, within the so-called dominant (socio-technical regime, more and more emphasis is put in (single) trait breeding (with molecular tools etc), while for organic and low input agriculture more holistic breeding approaches are needed. An example of trait breeding is that conventional breeders often work with monogenic disease resistance, Another example is that breeding research
projects, although departing from a holistic context such as need for nutrient use efficient (NUE) varieties, focus on single relationships such as root architecture and its relation to NUE. These are examples of a view in which plants can be subdivided into traits, and that particular traits can be improved

and that with an improved plant a farming system can be improved. If a particular crop cannot be improved, it may be replaced with another crop. In an extreme case, a particular farming system may be considered obsolete, as it no longer economically viable. This is not considered a problem as the forces of a free market are at work. A farming system can be considered a set of building blocks in which blocks can be easily replaced with other blocks. However, a perspective typical for organic agriculture is that a crop can have multiple functions, and that relationships in a farming system are very complex. For example, organic agriculture requires not only varieties that are adapted to low-input farming systems but also requires varieties that allow such systems them to work. This means that varieties should be able to contribute to resilience, e.g. in such a way that grass varieties not only have enough roots to exploit larger soil volumes for higher and more stable yields but that such varieties also contribute with more roots to the long-term building up of soil fertility and water holding capacity by delivering organic matter with their root biomass to increase soil organic matter. Another example is the straw length of cereal crops which modern breeding has eliminated to enhance harvest index. However, organic farming systems need long straw for compost making and needs straw length for soil shading to supress weeds. In other words: crops have multiple functions to support farming systems, and a systems approach is needed to breed different varieties adapted to specific farming systems.

The underlying principles of trait breeding are also visible in the way conventional breeding companies invest in breeding: to breed in particular crops enough return of investment is needed. As the costs of breeding have increased rapidly, and continue to increase, more crops become uneconomical to breed in, and at a certain stage become, or already have become uninteresting, for farmers for cultivation. However, for organic agriculture, crops have multiple functions, and hence crops cannot be so easily discarded, e.g. small crops like endive, spring wheat, oats or leguminous crops. To maintain breeding for such crops alternative organizational and/or financial models are needed. As each crop has different ecological, socio-economic and cultural roles in a farming system, different models are needed. When following a chain based breeding model the following key-elements need to be addressed: ownership of the problem, complexity of the market chain, crop specific traits and the level of policy support needed (Nuijten et al. 2012). For example, club varieties of apple and tomato are examples of chain based breeding, in which various chain partners contribute to the breeding, financially and/or through information. The extent of openness may vary between cases. A different approach is the organizational model of Kultuursaat, where a group of farmers are breeders of new varieties. Such approach can be considered community based breeding. Such approach may also be feasible for community supported agriculture, where also consumers are actively involved. It is important to realize that for each crop, the key-elements are interrelated in different ways. The possibility of using particular technical breeding approaches (OP varieties, populations, F1-hybrids) and organizational models depends on the interests of the various players in a food chain or community.

**Future development or research steps**

A better balance is needed in technical breeding approaches and organisational breeding models. Pluriformity is important for a viable agriculture, and hence pluriformity is needed in breeding. More attention is needed for community oriented and chain-based breeding models. We propose a conceptual framework as a first step to understand how and which technical breeding approaches can be combined with which organisational models. In this model the breeding approaches can be put along an x-axis describing the level of diversity in the breeding products (from clones and pure lines to composite cross populations) and the organisational models along the y-axis describing the level of ownership (from patents to open source) of the new breeding products. The potential use of various breeding approaches (OP varieties, population breeding) in combination with different models can be better understood by describing various key-elements as outlined by Nuijten et al. (2012). These key-elements may also be useful to understand what new alternatives, e.g. farmer based breeding initiatives are viable for which crops. A further understanding and description of thought styles of different initiatives helps us to identify barriers and bridges to better integrate different breeding approaches.

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# Cereal breeding : a more appropriate direction ?

MARTIN STUART WOLFE[1], THOMAS DŐRING[1]

[1]The Organic Research Centre, Wakelyns Agroforestry, Metfield Lane, Fressingfield, Eye, Suffolk IP21 5SD, UK, wolfe@wakelyns.co.uk

**Key words: cereals**, wheat, populations, mixtures, breeding, evolutionary

**Summary:** Massive growth in the human population means growth in demand for cereals. Continuing use of only monocultures causes difficulties in meeting the demand because of increasing cost of the resources needed to maintain monocultures, climate change and its unpredictability, and competitive evolution of diseases, pests and weeds. To reduce all of these problems simultaneously needs much more within-crop diversity, particularly through the use of variety mixtures and composite cross populations. The positive effects of these approaches have been demonstrated widely and the EU has agreed to allow an EU-wide experiment to see if a proposed protocol for marketing population seed could provide effective help.

**Background**

As a major cereal example, domestication of wheat and its large-scale use as a human staple, has led to a massive increase in crop area and production over the whole planet. Recently, however, this has been accompanied by a major decrease in crop diversity. This has two major consequences, the first of which is an increase in the vulnerability of the crop to climate change, pests, diseases, weeds and other environmental variables. The second is that the cost of maintaining production while attempting to protect against vulnerability, is increasing as essential resources decline, fossil energy becomes more expensive and damaging, and the need for better maintenance of ecosystem services becomes increasingly apparent. Based on growing understanding of natural ecosystems, it is becoming increasingly clear that a major solution to such problems is to increase crop diversity massively, over large areas. One simple, cheap, but currently illegal way of so doing, is to develop and promote the use of composite cross populations and their many variants. Through the development and impact of SOLIBAM, the EU has now made possible an opportunity to test the practicality of using composite cross populations in current farming systems.

**Main chapter**

The need for crop diversity
The domestication of wheat occurred in the 'fertile crescent' and surrounding countries over a long period and involved repeated exchanges between wild and cultivated stands, and among farmers. This meant that there was little reduction in diversity in the cultivated relative to the wild crop stands. In addition, hexaploid bread wheat emerged during domestication which, because of its three genomes, is able to support considerable internal variation for all characters. This may have been one of the major reasons for the development of wheat into one of the world's major crops.

However, over the last two hundred years, the success of wheat in terms of area grown and grain produced, has been accompanied by a large-scale reduction in genetic diversity (Pautasso 2012). In other words, at a time when the need for the availability of more genetic diversity was increasing rapidly because of the exposure of the crop to new environments and challenges, that diversity was decreasing. The potential negative effects were alleviated partially by plant breeders together with chemists and engineers who supplied a wide range of supporting inputs, not all of which have been benign. However, the challenges to wheat production are now escalating and accelerating because of human population growth, instability and unpredictability in the environment, caused by climate change, the costs, financial and biological, of supporting inputs, and the negative biological impacts of mass monoculture on diseases, pests and weeds.

Ecology, experience and experiment tell us that increasing diversity within and among crops should be effective in helping to deal with all of these problems simultaneously. Within the crop, three alternatives have shown potential importance, the simplest being the use of variety mixtures, followed by evolutionary breeding (Suneson, 1956) and decentralised plant breeding (Ceccarelli & Grando, 2007). Exploiting and integrating these developments could provide a comprehensive, long-term solution for cereal production in agriculture. All have received close attention within SOLIBAM; here we concentrate on some aspects of evolutionary breeding.

Experimental and agricultural development
Evolutionary breeding is based on the development of composite cross populations (CCPs). This means inter-crossing a number of appropriate parent lines in all combinations to generate segregating F2 populations. The seed populations produced are grown in the field, harvested without human selection and then re-sown. The selection that does occur is essentially natural selection for the environment in which the population is grown, which includes effects of the management system. Heterozygosity is more or less lost after 8-10 generations so that the population beyond this stage is effectively a highly complex mixture. Potentially, however, the number of genotypes is extremely high and many orders of magnitude greater than in any variety mixture. For this reason, it is useful to retain the different terms, mixture and population.

Experimental approaches have involved multi-site testing and observation of populations in wheat, barley, maize and other crops including variety mixture and monoculture controls, among the partner countries. Quality and other observations have also been carried out within SOLIBAM, with a key focus on seed health because of the importance of generating population seed for use close to where crops are to be grown. The central conclusion from these and other trials is as expected, that populations are able to adapt rapidly to the environment and, most important, that they show stability in space and time to a greater extent than most pure line varieties. Stable pure line varieties do occur, but, unlike populations, the characteristic of stability is not predictable.

These approaches also show that there are many ways of using the available diversity. For example, pure line varieties can be mixed into populations. This can have the advantage of allowing exploitation of a special characteristic of a variety, for example high yield or quality, while protecting the variety to some degree by the presence of other genotypes which diversify resistance to diseases, pests and weeds (Döring et al., 2013). Another approach being developed is to select desirable individual lines from a successful population, multiply the seed and then form a new mixture from those lines. This may, for example, improve the yield relative to the population at the cost of a possible reduction in protection of the crop against environmental variables.

Extending the available genetic diversity

The approaches outlined are dependent on the base range of genetic diversity currently available in the breeding stock of wheat or other cereals. In the case of bread wheat, one way of extending this range is by combining different forms of the three genomes. This approach is being used increasingly widely and some examples are being developed within the SOLIBAM project. Over the long term, however, there is a need to make much more intensive use of the large stocks of genetic diversity held in gene banks. This is the main aim, for wheat and barley, of the new FP7 project, WHEALBI, started in 2014.

The legal challenge

Despite the positive results, progress has been hindered by the international legal seed system which has been based on the distinctness, uniformity and stability (D.U.S.) criteria designed for separation and administration only of true breeding pure lines. This system has been in effect in an increasingly strict format for, more or less, a century, and prevents full development of the use of diversity. Mixtures of pure line varieties are allowed, but only if the mixture contains new seed of the varieties in question. The seed produced from the mixture cannot be traded, even though it might be undergoing useful adaptation to local conditions.

The legislation currently prevents development of the evolutionary breeding approach and the potential developments outlined above. This represents 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.

**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

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# Organic Seeds and Plant Breeding: Stakeholders' Uses and Expectations
## French Inputs on Vegetables.

FRÉDÉRIC REY[1], NICOLAS SINOIR[1], CATHERINE MAZOLLIER[2]

[1]ITAB, French Research Institute of Organic Farming, France, www.itab.asso.fr, frederic.rey@itab.asso.fr
[2]GRAB , Groupe de Recherche en Agriculture Biologique, Avignon, France, www.grab.fr

**Key words:** organic seed, horticulture, limiting factors, farmers' practices, Tomato

**Summary:** All organic agricultural systems suffer from a lack of plant cultivars adapted to organic production. Within the framework of the European project SOLIBAM a study was undertaken to determine which cultivars farmers grow, why they grow them, and the expectations in plant breeding of organic stakeholders. A comprehensive range of investigations carried out between 2010 and 2012 provided information on the state of organic seed in France. Results fit with the hypothesis that the market is a significant factor influencing the choice of seeds and cultivars (local cultivars, landraces, modern cultivars). Expectations and practices of producers selling on a local market (i.e., direct sale) differ radically from those of producers selling to long food supply chains. This study shows that the availability and use of organic seeds have significantly improved over the last three years. A vast majority of organic producers willingly use organic seeds, with, on average, 45-70% (cereals) and 75%-100% (vegetables) of organic seeds being planted on farms. However, the total number of derogations remains quite high: there is still space for improvement in organic seed use and supply. Several limiting factors and levers were identified during the study, as well as farmers' expectations for the future on horticultural crops.

### Background

Organic agriculture (OA) is characterised by a great diversity of cropping systems based on the agroclimatic conditions and the social and technical contexts in which they are cultivated. Farmers are faced with many limiting factors and seek cultivars that are both adapted and adaptable to their different systems and environments. In order to develop OA and improve the quality of organic products, special breeding techniques based on specific criteria and methods that are consistent with the principles of this mode of production are required (Lammerts et al., 2008). The ultimate goal is to ensure that all systems evolve towards quality, performance and autonomy (restricting the use of external inputs, and therefore of fossil fuels) based on the principles of sustainable development. Moreover, the cultivars selected for OA may interest any farmer, organic or not, who is operating within this framework.
The different types of seeds used by organic producers, therefore, are: i) Commercially traded organic seeds, whose supply tends to grow; ii) Commercially traded conventional seeds, which are untreated post-harvest and are authorised by exemption; iii) Farm-seeds (farm saved seeds and/or "peasants' seeds": seeds originating from in situ dynamic management of cultivated biodiversity) that are produced by farmers for their own use.

### Main chapter

A Comprehensive Range of Investigations
Within the framework of the European SOLIBAM project a first (qualitative) telephone survey was conducted by ITAB in 2010 with a wide range of participants (farm advisors, researchers, producers' organisations, seedling producers) from the organic sector pertaining to arable and horticultural crops. The qualitative data obtained was used to identify the main challenges and to build a second, more targeted questionnaire. In the framework of a national project, online quantitative surveys were launched targeting all certified OA operators in France. With a response rate close to 20% for each type of crop (more than 650 respondents for arable crops, 700 for forage crops and 720 for horticultural crops), the results can be considered representative. The survey data were supplemented by information from various statistical sources (e.g., Agence bio, 2013) as well as some bibliographical resources, which are relatively limited on this subject, with the notable exception of the report on the situation of organic seeds in the USA (Dillon, 2011).

*Types of Cultivars / Seeds Used for Organic Vegetable Production*

The majority French organic vegetable producers operate in short food supply chains (79% of respondents). They are mainly market gardeners, who are growing different vegetables on about 2 ha and are working with close to 70 different cultivars. The 12% of producers supplying mainly long distribution chains are more specialised vegetable producers working on larger areas (about 11 ha) with fewer species and cultivars. The distribution channel dictates the production system, and has a significant impact on both the acrearage and number of species and cultivars of vegetables grown. Importantly, the majority of producers resort to the services of a seedling producer for at least a part of their vegetable transplants (53% of respondents). It appears that producers' reasoning differs according to the distribution channel they use. In short food supply chains, the producers aim to offer a wide range of cultivars to meet consumer expectations. They will use old cultivars as a loss leader product (exoticism / originality), and also produce modern cultivars for their productivity and because they correspond to a well identified standard by the consumer. Stakeholders interviewed during the telephone survey indicated that they grew an average proportion of one-third old cultivars to two-thirds modern cultivars. Long food supply chains, on the other hand, work according to well-identified and highly standardised niches, so they use modern cultivars which guarantee high productivity and compliance with the requirements of their buyers (e.g., appearance of vegetable). Old cultivars, which are less uniform, are not adapted to their systems, with a few exceptions.

In general, producers of organic vegetables claim to be intensive users of organic seeds: nine out of ten producers are convinced of the benefits of using organic seeds to ensure the coherence of the organic sector. This is also reflected in practice, as between 2009 and 2011, the use of organic seeds increased to 43% among them; 44% of respondents have used only organic seeds, which is significant given the number of cultivars they grow; 82% of respondents say they use more than 75% of organic seeds.

*Case Study: Producers' Expectations on Tomato*

The organoleptic quality is clearly the most important factor for producers operating in short food supply chains, but the producers put great emphasis on the importance of compromise with yield, and to a lesser extent, the various disease resistances. The need for compromise in order to meet consumer expectations, some of which are incompatible with each other, is also reflected in the varietal range and it raises an important point: producers choose cultivars that represent different trade-offs on the scale of taste / performance when deciding on the cultivars they will grow. This kind of producer is growing tomatoes both in greenhouses and in open fields.

Producers in long food supply chains are growing tomatoes in greenhouses and have more simple needs: the cultivars used must be productive, adapted to greenhouse production and meet the requirements of long food supply chains (presentation and conservation). Resistances are also frequently mentioned. All actors agree that they would like their tomatoes to have a better taste!

*Limiting Factors Regarding Organic Seed Use and Supply*

Several factors limiting organic seed use and supply were identified during the study:

i) A lack of knowledge of organic farmers' needs and expectations by seed companies.

ii) A low investment in plant breeding for organic agriculture and organic seed production at the public and private levels.

iii) The negative attitudes both among some producers (e.g., 10% of organic vegetable producers remain unconvinced of the value of organic seeds), and some seed companies with plant breeding activities that are less keen on producing organic seeds.

iv) Constricting regulatory requirements: organic seeds must comply with double regulation: an obligation of means (the specifications of OA) and an obligation connected to results (seed quality, accreditation of lots). In addition, there is a lack of specific and appropriate rules for the registration of varieties for OA.

v) A new business model is needed: 1) to finance a specific breeding, evaluation and registration process so that organic seeds of newly available cultivars may be included in the official catalogue, 2) to reduce production cost of organic seeds, which is higher than that of conventional seeds due to lower yields in OA and to a fragmented market,

## Conclusions

This comprehensive study conducted between 2010 and 2012 provides an overview of the state of "organic seeds in France". Results fit with the hypothesis that the market is a significant factor influencing the choice of seeds and cultivars (local cultivars, landraces, modern cultivars). Expectations and practices of producers selling on a local market (i.e., direct sale) differ radically from those of producers selling to long food supply chains. This study shows that the availability and use of organic seeds have improved significantly over the last three years. A vast majority of organic producers willingly use organic seeds, with on average 75-100% of horticultural crops grown by them coming from organic seeds.

However, the total number of derogations remains very high in France (45,000 in 2013). There is room for improvement, in terms of enhancing the provision and use of organic seeds. Cultivar breeding programs are needed, especially for broccoli, cantaloupe, cauliflower, onion and radishes to produce cultivars that are more adapted to organic growing conditions and better suited to the expectations of customers (suppliers and / or consumers), particularly where the organoleptic quality is concerned.

Several limiting factors were identified, including a lack of investment in organic plant breeding, a lack of profitability (a new business model must be developed) and negative attitudes amongst some farmers, seed companies and transplant/seedling producers. This comprehensive study led us to develop a national action plan to improve organic seed use and supply in 2012. The entire OA sector depends on the development of a wide and adapted offer of organic seeds.

## Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

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# SOLIBAM Farm Day

## An innovative tool for multi-actor projects' dissemination

FREDERIC REY[1] , RICCARDO BOCCI[2]

[1] ITAB, French Research Institute of Organic Farming, France, www.itab.asso.fr, frederic.rey@itab.asso.fr
[2] AIAB, Associazione Italiana Agricoltura Biologica, Italy, r.bocci@aiab.it

**Key words:** dissemination, multi-actor, skills, knowledge, exchange, communication

**Summary:** Farm days are designed to be an innovative tool for the dissemination of the project outcomes amongst farmer's communities in each country. They are held each year, to enable breeders, farmers, extension services and researchers involved in SOLIBAM to share their skills, information, and knowledge also with non-participating farmers. Farm days are also a way to communicate on the Solibam project, to distribute booklets and other dissemination tools to farmers and other stakeholders. In addition, Farm days stand as a space for discussion of the project results and related topics with farmers. Between 2010 and 2013, 84 Farms days were organized in the framework of SOLIBAM.

### Background

Multi-actor projects like SOLIBAM need specific and innovative dissemination tools. The Farm days concept stands for one of them.

### Main chapter

Farm days are designed to be an innovative tool for the dissemination of the project outcomes amongst farmer's communities and other stakeholders in each country. They are held each year, to enable breeders, farmers, extension services and researchers involved in SOLIBAM to share their skills, information, and knowledge also with non-participating farmers. Farm days are also a way to communicate on the Solibam project, to distribute booklets and other dissemination tools to farmers and other stakeholders. In addition, Farm days stand as a space for discussion of the project results and related topics with farmers.

ITAB was responsible for the overall co-ordination of Farm days but SOLIBAM National partners were in charge of the organisation and implementation of Farm days in their country. Between 2010 and 2013, 84 Farms days were organized in the framework of Solibam in 7 countries: France, Austria, the United Kingdom, Spain, Portugal, Switzerland and in Italy. This yearly appointment became an important moment of scientific and technical discussions at National level. They mainly enabled to present discuss around the objectives of the project through practical and tangible demonstrations of farms and field trials. They have also allowed connecting various kinds of stakeholders by bringing together scientists, farmers, advisors, students, policymakers, etc… By this multi-actor involvement, Farm days led in 2013 to policy discussions, to research track definition, to further experimentation design and to future project. In some cases, during Farm days, spike selection (e.g. barley in Italy) or organoleptic quality assessments (e.g. on bread and on Tomatoes) were carried out with participants. Their feedbacks are very positive: several new farmers wish to join future participatory projects and to implement trials on their farms. They also wish to have Farm days organized even after the end of the SOLIBAM project. Farmers and experimental sites were very proactive in organising these visits and therefore they need to be implemented in the future to carry on the work started by SOLIBAM.

This tool seems to be very promising for supporting innovation in rural areas and at local level. This approach can be thoroughly implemented in the new Common Agricultural Policy within the framework of the European Partnership for Innovation.

### Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM


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Figure 1. The SOLIBAM Farm days concept

# Session A

# Managing diversity for robustness, resilience and yield stability

# Breeding for Diversity:
## A review of 10 years of evolutionary participatory breeding, and a look ahead.

KEVIN MURPHY[1], ADAM PETERSON, ARRON CARTER, STEPHEN JONES

[1] Department of Crop and Soil Sciences, Washington State University, kmurphy2@wsu.edu, Northwest Research and Extension Center, Washington State University

**Key words:** evolutionary participatory breeding, wheat, quinoa, buckwheat, spelt

**Abstract:** Evolutionary participatory breeding (EPB) utilizes the methodological framework of evolutionary breeding to promote resilience and yield stability, in combination with the practice of participatory breeding, in order to address the needs of farmers across a wide range of agroecological niches in Washington State, USA. Here, EPB projects have resulted in diverse and stable wheat and buckwheat farmer populations as well as homogeneous and high-yielding open-source spelt varieties. Currently, EPB is being utilized as our primary method of selection for quinoa in order to optimize adaptation across diverse farming systems and challenging and dissimilar environments that require unique genetic blends of heat, drought, salinity and pre-harvest sprouting tolerance.

### Background

The genetic uniformity within, and typified by, most monocultural cereal-based systems has been shown to limit the crops' capacity to evolve in response to adverse environmental conditions, thereby leading to a possible decrease in the yield stability of the cropping system. Deployment of significantly increased crop diversity across the global landscape has the potential to reduce the progress of crop epidemics, optimize yield stability, and positively enhance crop resilience in the ever-changing visage of climate-induced stress. One method of increasing genetic diversity within cereal crop populations is through evolutionary breeding (EB). In EB populations of self-pollinating cereals, natural selection acts upon the heterogeneous mixture of genotypes over generations and across environments and traits positively correlated to reproductive capacity increase over time. Crop populations with enhanced genetic diversity mimic natural ecological communities, which are better equipped to adapt to future unpredictable temporal climate shifts than are monocultures. Evolutionary participatory breeding merges the EB method with farmer selection to develop high-yielding, disease-resistant cultivars while maintaining a high degree of genetic variation to allow for adaptability to fluctuations in environmental conditions. The EB method can contribute to the development of cropping systems with greater resilience and yield stability in the climate change era.

### Main chapter

There is much reported unpredictability in future global agriculture due to the considerable variability within and between countries, with some areas potentially benefiting, and others suffering from, climate change (Jones and Thornton 2003; Gregory et al. 2009). Crops that are grown in regions that reach their maximum temperature tolerance, particularly in low-latitude dryland farming systems, are expected to experience yield decreases with even minimal changes in climate (Parry et al. 2005). The distribution of the effects of climate change will almost certainly be uneven, with the livelihoods of subsistence farmers likely being the most negatively affected and the risk of hunger increasing predominantly in the most marginalized economies (Rosenzweig and Parry 1994; Parry et al. 2005).
Many complex crop × climate interactions are influenced by crop pathogens and insect pests. Each year, plant diseases account for global harvest losses of approximately 10 to 16% (Oerke 2006), and disease resistance in cultivars of wheat, oats, rice, tobacco and sunflower have been shown to be differentially affected by temperature (Gregory et al. 2009). For example, differential resistance expression has been shown at 10˚C and 25˚C against isolates of *Pucciniarecondita*among cultivars of wheat, and similar temperature sensitivities have also been reported to *P. striiformis*in wheat, *P. tritici* in oats and to *Xanthomonasoryzae*pv. *oryzae* in rice (Martens et al. 1967; Dyck and Johnson 1983; Gerecheter-Amitai et al. 1984; Jones 2003; Garrett et al. 2006). The effectiveness of currently deployed resistance genes have been shown to be compromized, over- or underexpressed when faced with more extreme and variable climatic conditions (Gregory et al. 2009). Resistance genes in barley have been shown to lose gene expression due to drought stress and salt stress as well as to drought stress relief and cold stress relief (Newton and Young 1996; Barker 1998; Stewart 2002; Goodman and Newton 2005). Aphids, one of the most important pests in agriculture throughout the globe, may be able to exploit the changing conditions particularly well due to their short generation time, low developmental threshold temperature and significant dispersal abilities (Sutherst et al. 2007).

It is impossible to predict annual fluctuations in rainfall and temperature in any given location, much less across locations, thereby making proper varietal selection somewhat of a guessing game. This could become progressively more problematic in the face of increasingly unpredictable environmental fluctuations of a potentially larger magnitude due to climate change. One way to combat this issue is to deploy inter- and intra-specific crop diversity across the landscape, thereby reducing the progress of crop epidemics and optimizing yield stability (Gregory et al. 2009). Increased crop diversity should positively enhance crop resilience in the ever-changing face of climate-induced stress, resulting in improved crop performance (Newton et al. 2009) and enhanced food security.

### Evolutionary Breeding

Many decades before warnings of climate change emerged in the scientific literature, Harry Harlan, a plant explorer and cereal geneticist of the USDA, constructed his first barley composite cross populations (Harlan et al. 1940). For example, Barley Composite Cross II (CC II), one of the most widely studied of the Harlan's composite cross populations, was created in 1929 through the hybridization of 30 diverse barley cultivars from around the world in all possible cross combinations (Harlan and Martini 1929). CC II and other composite cross populations were grown annually, first at the University of California at Davis and later in other environments, under the typical agronomic conditions of the time period, and harvested at maturity without any targeted selection by the researchers (Suneson 1956; Ramage 1987; Murphy et al. 2005). Results have been promising, with reproductive capacity over 50 generations of evolutionary breeding of CC II consistently kept yield performance within 95% of the most current highest yielding varieties (Allard 1990).These populations were subjected to natural selection through temporal and spatial fluctuations in rainfall and temperature, similar to, though perhaps of less magnitude than, the climatic fluctuations of the present day.

**Natural Selection and Fitness in Heterogeneous Populations**

Coefficients of variability are an indicator of yield stability across years and locations. In comparison with the high-yielding cultivar Atlas, Suneson (1956) reported a coefficient of variability across environments almost twice as low in CCII over an 18 year time period (1937-1955). CCII progressed from $F_{11}$ to $F_{29}$ during this time period. Newer composite crosses in the same study, including CCV ($F_{15}$), CCXII ($F_{14}$), and CCXIV ($F_{12}$) had yields similar to Atlas in 1955. Similarly, in a study comparing seed yields of lima bean composite cross populations, pure lines and seed mixture over four years in California, the CC populations outproduced both the mixtures and the pure lines (Allard 1961). To minimize the effects of genotypic variation, both the mixtures and populations were developed using the pure lima bean lines in this study as parents. Suneson (1956) estimated that 15 generations of natural selection in barley was sufficient time for the composite crosses to have improved fitness traits compared to the parent genotypes.

Natural selection must favor genotypes with superior agronomic performance, otherwise the composite populations will not reach optimal fitness levels (Phillips and Wolfe 2005). Jain and Qualset (1975) suggested that stabilizing natural selection was the driving force for many traits, including seed size, spike length, days to heading and spike density, whereas directional selection was the primary selective force influencing seed number per plant. Evolutionary breeding is clearly most effective in increasing grain yield when selection pressures are constant and directional (Degago and Caviness 1987), although disruptional selection can also be effective in increasing yield. For example, even under conditions that fluctuated significantly in rainfall, temperature and day length, segregating bean populations showed a mean yield gain of 2.5% over a 17-year time period when compared to the mean of the parents (Corte et al. 2002). In fact, the utilization of different sites with contrasting, disruptional selection pressures has been recommended as an effective method to maintain genetic diversity of disease resistant genes within a population, thereby increasing the overall fitness of the population (Paillard et al. 2000; Phillips and Wolfe 2005).

**Evolutionary Participatory Breeding**

Based on the limitations inherent in reliance solely upon natural selection within heterogeneous populations, researchers have suggested the utilization of artificial selection within composite cross populations to drive each population in the desired direction for non-fitness related traits of interest (Mak and Harvey 1982; Patel et al. 1987). This artificial selection may be done by breeders on research stations and farmers' fields, as well as by farmers in their own fields.

In regard to the latter option, farmer participatory breeding has been shown to be effective in selecting varieties of major cereal crops, including barley, maize, wheat and rice (Sthapit et al. 1996; Bänziger and Cooper 2001; Ceccarelli et al. 2001; Witcombe et al. 2003; Thapa et al. 2009; Bachmann 2010). In fact, farmers have been shown to be as capable as plant breeders in selecting high yielding varieties on research stations, and when selection occurred on the farmers individual fields, more proficient than plant breeders in selecting high yielding varieties (Ceccarelli et al. 2000). Evolutionary participatory breeding (EPB) merges the evolutionary breeding method described above with farmer participatory breeding to develop high-yielding, disease-resistant cultivars of desired quality while maintaining a high degree of genetic variation to allow for adaptability to fluctuations in environmental conditions (Murphy et al. 2005). For a complete review of the EPB process, please refer to Murphy et al. (2005). Below is a case study that will illustrate EPB in wheat.

**Case Study of EPB in Wheat**

In 2002, Lexi Roach, an 8th grader at Kahlotus, WA middle school, drove two hours from her family farm in Kahlotus, WA to Pullman, WA, with her grandfather Jim Moore. Jim and his family grow winter wheat on approximately 10,000 acres of farmland in a low rainfall, rain-fed environment (~200-250mm precip/yr) in South-Central Washington State. In this environment, it typically takes two years of moisture to raise one crop of winter wheat. The only non-irrigated rotation in the area is winter wheat in Year 1 followed by fallow (tillage or chemical) in Year 2.

Lexi and Jim were traveling to Pullman to make crosses between varieties of wheat that did well on their farm, and took the initial step in the EPB process. Working with Kerry Balow in the winter wheat program, three crosses were successfully completed. $F_1$ seed was obtained and advanced to the $F_2$ in the greenhouses at WSU in Pullman. This seed was then planted on their farm using small, plot-scale breeding equipment. In the $F_3$ to $F_8$, seed from each population was planted each year in the late summer, subjected to natural selection and to farmer selection by Lexi and Jim, and then harvested in bulk, subsampled and replanted.

The seed was typically planted 5 to 7" deep in order to reach available moisture, thereby selecting for genotypes with strong emergence qualities, including longer coleoptiles and perhaps faster germination and shoot initiation. Each summer, individual plants that were susceptible to yellow rust were pulled out of the population by Lexi and Jim and the farm crew.

By 2009, one of the populations, now called Lexi II, proved to be the highest yielding and was included as 'WA 8094' in the WSU Statewide Variety Testing program and grown in yield trials along with 59 of the most promising varieties from 11 regional breeding programs at over 16 locations in high, medium and low rainfall regions across the state. In the low rainfall zone, six locations including Connell, Harrington, Horse Heaven, Lind, Ritzville and St. Andrews, were represented. When compared to the top five varieties (by acreage) grown in Washington State in 2009-2010, WA8094 yielded significantly lower than 'Xerpha', the highest yielding of the dominant varieties (Table 1). However, WA8094 yielded the same as the most widely grown variety statewide in dry areas, 'Eltan', and yielded significantly higher than 'ORCF-102', 'WB-528' and 'Madsen' (ranked 2,4 and 5 respectively in Washington acreage) when averaged across the six low-rainfall locations (Table 1). In this same year, at the St. Andrews location, WA8094 was the top yielder surpassing all of the 59 other varieties.

In 2010-2011, WA8094 yielded lower than Xerpha and ORCF-102, and was statistically equal to Eltan, WB-528 and AP 700 CL (which had replaced Madsen as the 5th most widely grown soft white winter wheat variety in Washington State, when averaged across all six locations (Table 2).

Although WA8094 has a very high yield potential under this selection criteria, there are other disease factors that need to be taken into account. New shifts in pathogen races warrant the need for selection each year. During the F3 to F8 stages when WA8094 was selected on farm, it was resistant to local races of yellow rust. Two years after commercial production on the farm, a new race entered the area which is virulent on WA8094. Currently, fungicide applications are needed to protect the yield potential of this line. Similarly, a long, cool growing season in 2011 caused aphid populations to increase, and resulted in a severe case of the aphid transmitted barley yellow dwarf virus (BYDV). Since this growing region seldom sees aphid problems, WA8094 was highly susceptible to BYDV, a problem attributed mainly to changing climate variables. As climate change will not only change the agronomic growing conditions but also pest populations, concurrent production and selection fields are needed to maintain identification of high yielding adapted lines with excellent resistance to changing pest populations.

The fact that a bulk population with recurrent, farmer imposed, natural and intentional selection could rank high in an elite yield nursery demonstrates with some clarity the potential for this method. Continued annual selection under changing environmental and disease pressures will maintain populations of adapted and resistant material. As our climate becomes less predictable we will be well served to not only increase the diversity in our fields but also in the approaches that we take towards crop improvement. f

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# Diversity for robustness, resilience and yield stability

## SOLIBAM approaches to promote strong crop performance in heterogeneous conditions

SALLY HOWLETT[1], MARTIN WOLFE[1]

**Key words:** robustness, resilience; stability; organic; low-input; diversity

**Summary:** A SOLIBAM hypothesis is that diversity both within and between species and varieties will increase *robustness* (i.e. ability of a plant to maintain performance in face of perturbation) and *resilience* (i.e. capacity of an ecosystem to respond to a perturbation), thereby helping to *stabilise* yield in different environments. We focus on research carried out within SOLIBAM aimed at testing this hypothesis, highlighting diverse traits, management practices and breeding methods which can improve such performance characteristics.

**Introduction**

Decreasing availability and rising costs of fossil fuel along with decreasing availability of energy resources, rapid climate change and destabilization mean that continued increasing environmental variability is unavoidable. We need crops and cropping systems with the flexibility to be able to cope in such unpredictable conditions. This fundamentally requires a capacity for buffering which can be achieved only by higher levels of genetic diversity.

Commercially available crop varieties have largely been bred for high-input agriculture; they are genetically uniform and reliant on external inputs to create the optimal growing environment necessary for yielding to their full potential. By definition, this makes them unsuitable for organic and low-input systems, and poorly adapted to respond to increasingly frequent weather extremes. Regardless of the production system, however, there is a need for yield stability, and clearly this stability should be at a high level. Robustness and resilience are both important components of high yield stability. These refer respectively to the ability of a crop to withstand damage, and to quickly recover from any damage that is incurred. It can, however, be difficult to separate these concepts in practice as they are strongly interlinked.

There is a need to re-evaluate the characteristics that confer robustness and resilience on crop plants, allowing them to perform well in heterogeneous conditions, with more stable yields and greater long-term food security. The SOLIBAM project has investigated a number of different approaches exploiting diversity in genetics, crop management and breeding strategies. Collectively, they are all aimed at supporting the ability of plants and their growing environments to behave in a stable manner in the face of various perturbations, whether these arise from biotic or abiotic causes. Whilst differing in their detail, the main objective of all crop trials was to compare the performance of different breeding and management strategies in terms of yield, quality and key traits identified as specific goals important for organic and low-input production.

**Main Chapter**

Breeding approaches considered within the context of SOLIBAM include the use of landraces, variety mixtures and composite cross populations (CCPs). Variety mixtures consist of physical mixtures of pure lines that are grown together; in contrast, populations are more diverse as they are made by intercrossing large numbers of parents. The progeny of the crosses are then pooled and sown together in the field. Here, natural selection ‘refines’ the population as those individuals most suited to the growing environment thrive, and those least suited do not. Each approach has advantages and disadvantages, and the challenge for SOLIBAM was to try and maximise the exploitation of the most useful features of each in a flexible way appropriate to particular crops and cropping systems.

In tandem with the diverse breeding approaches under consideration, SOLIBAM also took a fresh view on what crop traits should be targeted as the most appropriate for organic and low-input agriculture. In this regard, it is not enough only to look at specific traits as it is the full plant phenotype that is the end result of interest in heterogeneous settings such as these, and therefore, the concept of ideotype was an important factor.

Ten ‘key concepts’ necessary for cultivating diversity have been developed within SOLIBAM, taking into account the multi-disciplinary expertise represented within the project consortium. These are described in a booklet which is freely available from the project website (www.solibam.eu/) and is referred to throughout the congress and they are interlinked as shown in Figure 1. In this paper we focus on three of the concepts (robustness, resilience and yield stability) and give examples of how they have been addressed within the SOLIBAM activities.

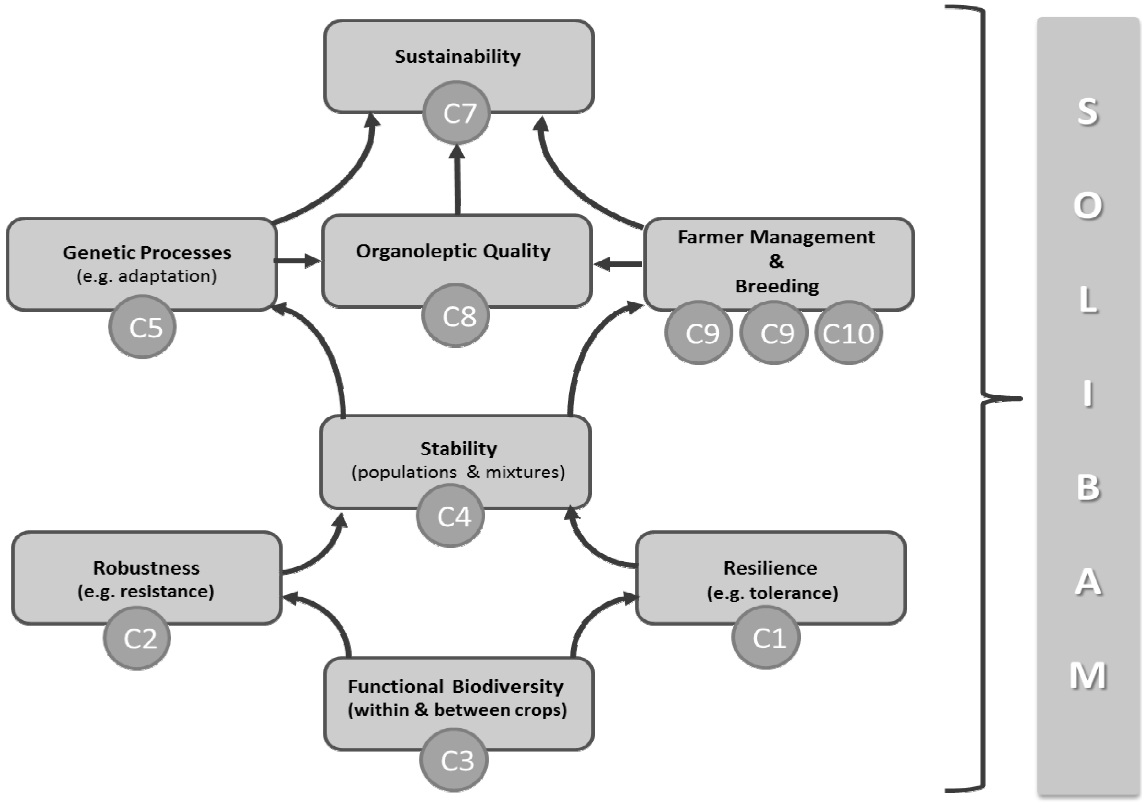


Figure 1: Interactions between the 10 SOLIBAM Key Concepts for Cultivating Biodiversity.
C1…C10 refer to detailed concept descriptions referred to in the SOLIBAM booklet downloadable from
http://www.solibam.eu/ modules /wfdownloads /singlefile.php?cid=5&lid=45

**Robustness**

Robustness is defined as the persistence of a certain trait or characteristic in a system undergoing perturbations and uncertainty. Examples of robust crop characteristics include high levels of resistance and tolerance to pests and diseases, strong competitive ability against weeds and deep root systems for high nutrient use efficiency. The robustness of populations has been dramatically illustrated on a number of occasions where they have withstood adverse conditions that caused the failure of pure lines. In Germany, for example, prolonged severe frosts in the winter of 2011 destroyed monoculture sowings of the pure line parent varieties, but the CCPs in the same field survived and yielded in 2012 (Brumlop, 2013). Similar effects had been previously observed in Hungary. In 2012-13, many autumn sown crops in the UK failed due to a number of factors including poor weather conditions, forcing late drilling. Two sets of plots comprising the pure line variety Alchemy and a population (YQCCP) were drilled nine days apart. The early plots of both (drilled 16.10.12) established well; however in the later plots (drilled 25.10.12) Alchemy struggled to establish and only partially recovered by harvest. In contrast there were no discernible differences between the early and late population plots.

**Resilience**

The concept of resilience was first applied to ecological situations by Holling (1973). It is the capacity of a system to cope with adverse events by both resisting damage (robustness) and recovering quickly (resilience). Farms can handle adverse events better if the soil is healthy, crops are robust and water/nutrient supplies are sufficient (www.far.org.nz). When this is not the case, they are at higher risk in difficult environmental circumstances. A resilient system will reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks. As such, resilience is related to the adaptive capacity of a system. For example, a SOLIBAM trial which addresses robustness in relation to genetic diversity focuses on a sprouting broccoli landrace. Progeny from 17 parent plant half-sib crosses were compared with synthetic populations comprised of 4 or 8 parents respectively and a commercially available F1 hybrid control, in agronomic trials in Italy and the UK. In both countries the synthetic varieties showed far less variation between years. In the UK, under favorable conditions for broccoli, the F1 hybrids produced a higher overall yield than the more diverse populations; however in poor conditions, it was the populations that had better productivity. In this sense they were more robust and represented a better 'insurance' for the grower in adverse conditions.

**Yield Stability**

Yield stability is the ability of a variety (pure line, mixture or population) to yield consistently at high levels in different environments. This is a function of the robustness and resilience of the crop in question. As explained in the key concepts booklet, there are different types of stability according to whether the yield is consistent across environments, within location or if it follows the yield potential in different environments. A SOLIBAM winter wheat trial looking at yield stability exemplifies the idea of combining the most useful aspects of different diverse breeding methods in what can be described as 'flexible diversity'. The trial compared yields from plots of populations mixed with pure line varieties in two different ratios, with sole-crop plots and was carried out over three seasons in Hungary and the UK. Analyses compared the actual mixed plot yields with the predicted values based on the yields of their individual components in the sole-crop plots. Linear models showed a high degree of correlation between the actual and predicted yields of the mixtures in both locations ($p<0.001$), which suggests that it is feasible to gain benefit from the stability of populations, but boost overall yield performance in a predictable way by adding in a suitable pureline.

### Conclusion

The increasing need for high yield stability in an environment of reduced inputs and increasing climate destabilization is dependent on robustness and resilience which are, in turn, provided by the concept of functional biodiversity within cropping systems. The 10 key SOLIBAM concepts for cultivating diversity together act as 'tools' to provide the flexibility for crops to withstand or respond to changes in their growing conditions, thereby providing a dynamic basis for sustainability, reliable food production and strengthening future food security.

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# Responses of bread wheat varieties to different environments

## Differences among wheat traits in sensitivity to organic and low input growing conditions

Péter Mikó[1], Franziska Löschenberger[2], Mária Megyeri[1], Gyula Vida[1], Marianna Rakszegi[1], Márta Molnár-Láng[1]

[1]Agricultural Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Hungary, www.agrar.mta.hu, miko.peter@agrar.mta.hu
[2] Saatzucht Donau GmbH & Co KG, Austria, www.saatzucht-donau.at, franziska.loeschenberger@saatzucht-donau.at

**Key words:** wheat, organic breeding, low input

**Summary:** 37 winter bread wheat varieties were compared in organic and low input conventional management systems of Austria and Hungary through 3 years to identify traits sensitive to management systems, which could be later separated according to their suggested selecting environments. Based on the results, 7 traits showed significant management × genotype interaction. Heading date, sensitivity to leaf rust and powdery mildew had high repeatabilities making it reasonable to select them for organic agriculture also in conventional field. However, it is suggested to select for the other four traits (yield, test weight, leaf-inclination and vigorous growth) later under organic growing conditions.

### Background

According to the regulations (Council Regulation [EC] 2007, No. 834/2007) of the rapidly developing organic agriculture movements organic farmers have to endeavour to use organic seeds, but this demand is satisfied in 95 % with organically grown varieties that were bred for conventional agriculture. However, it is important to increase the adaptability of the new breeding lines in order to cope with abiotic and biotic stresses which are the main characteristics of organic agriculture usually carried out under diverse agro-ecological conditions. A rational solution is to keep the breeding process in the target environment in order to develop the most adaptable varieties, but traits that can indicate difference between the conventional and organic sites have to be identified first.

### Introduction

In recent years needs have increased to develop organic bread wheat varieties for organic agriculture, which mostly represents diverse growing conditions. Conventional plant breeding is usually resulted in limited environmental variability, because the selection environment is continuously stabilised using artificial fertilizers, herbicides and other chemicals against pests and diseases. Therefore, the performance of conventionally bred varieties is often different in other environments with lower inputs due to genotype × environment (G × E) interactions. Although, organic breeding seems to be a favourable solution to develop well adapted, resilient and robust varieties for organic farmers, for economic reasons there is a need to use a combined strategy for breeding for organic agriculture (BFOA). The aim of this breeding strategy is to select the material for highly heritable traits in the early generations in (mainly low input) conventional fields, and further selections should be carried out under organic growing conditions for the less heritable traits (Löschenberger et al. 2008). Therefore, before starting the selection process in certified organic fields, it is important to evaluate characteristics of varieties both under conventional and organic management conditions in order to identify the sensitivity of traits to the different growing conditions and to select those that can be assessed more efficiently in low input field.

### Material & Methods

In the present study 37 winter bread wheat (*Triticum aestivum* L.) varieties and advanced lines were examined in Austria and Hungary for three years (2011-2013) representing altogether 6 sites (year × country). Varieties were chosen to represent different breeding origin (20 conventional, 9 organic and 8 BFOA varieties), countries of origin (Austria, France, Germany, Hungary and Switzerland), years of release (from 1989 till advanced lines that are not released yet) and quality groups (excellent and good). On each site similar randomised small plot (Hungary – 6 $m^2$/plot, Austria – 9 $m^2$/plot) trials were established with 3 replicated blocks under certified organic (O) and low input conventional (LI) growing conditions, which fields were close to each other to ensure the same soil parameters for O and LI in both countries.
Fifteen of the main agronomic and quality characteristics were assessed on each site. Beside traits shown in Table 1, winter hardiness, number of tillers, soil coverage at tillering and booting, lodging, plant height, thousand kernel weight and grain protein content were also assessed on each variety. Statistical evaluation of the assessment data was carried out using the Linear Mixed Model analysis module of SPSS 16.0 software (SPSS Inc., Chicago, IL, USA).

### Results and Discussion

Large significant environmental (E) and genotypic (G) effects were observed in the case of all traits, however, the effect of management (M) was less emphasised. All the 15 traits showed strong G × E interaction, except soil coverage, which was affected mainly by the different environmental conditions rather than the genotypes itself. Although, present study failed to give evidence for the different effects of genotype on soil coverage, it could give in the case of leaf-inclination, which is very important trait for competing against weeds through its shading effect. The large G × E interaction under variable farming conditions will still have great impact on variety performance, which can be decreased by the decentralisation of breeding and/or by increasing the buffering capacity through the increased genetic diversity of the wheat crop using variety-mixtures or composite cross populations.

Based on the significant M × G interactions, seven traits were found to be an efficient indicator for examining the differences between the performance of bread wheat varieties grown under O and LI growing conditions. Mean values of these traits and the corresponding variance components split by management systems are demonstrated in Table 1. In average of the 37 trial entries of all the 6 sites the organic management resulted in 5 % less yield (4.38 t/ha in O field, and 4.61 t/ha in LI field) and in 3% lower test weight (80.13 kg/0.1 $m^3$ in O field, and 82.37 kg/0.1 $m^3$ in LI field), but powdery mildew infection was scored 22 % higher in LI field, which could be the consequence of the more dense stand. Average values of the other traits were almost the same in both management systems, but the organic site had slightly higher deviations, which could be derived from the more extreme growing conditions.

Genotypic variance and variance of G × E were significant for all the traits in the low input system, except the G × E interaction of LR (see Table 1 for abbreviations). However, in the case of the organic management system, significant genotypic variance was not found for INC and TW. Repeatability ($h^2$, ratio of genotypic to phenotypic variance) values of the traits were relatively high (except INC and TW in organic field) ranging from 0.66 to 0.98 in LI field and from 0.76 to 0.98 in O field. The repeatability for HD, PM and LR in the average of the two management systems were 0.98, 0.91 and 0.91, respectively. Therefore, early stage selection for organic agriculture should be based on them even if it occurs in LI field, as it is recommended by Löschenberger et al. (2008) regarding the highly heritable traits. According to the results, the less heritable traits (INC, TW, VIG and GY) should be among the secondary selection targets that should be done under organic growing conditions.

### Conclusion

Based on the fifteen traits examined in the present study, it can be concluded that promising winter bread wheat varieties for organic agriculture (having good shading ability, high test weight, vigorous growth and high yield) should be selected in the later generations in organic systems with direct selection and not in conventional fields using indirect selection. In contrary, selection should be done in the early stage generations for early heading and disease resistance in conventional field. Thus the application of this combined breeding strategy (BFOA) might be economically more favourable for the organic wheat breeders.

Table 1: Mean values with standard deviations (SD), variance components estimates and their standard errors (± SE) for genotype (G), genotype × environment (G × E) interaction and error, and repeatability of 7 traits assessed on 37 winter bread wheat varieties in organic and low input conventional fields of Austria and Hungary between 2011 and 2013

| Trait (unit) | | | INC (1-9; 1=upright) | VIG (1-9; 1=vigorous) | HD (1=1st May) | PM (1=resistant; 9=susceptible) | LR (1=resistant; 9=susceptible) | GY (t/ha) | TW (kg/0.1$m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| Organic management | mean | | 3.59 | 2.97 | 22.34 | 2.30 | 3.61 | 4.38 | 80.13 |
| | SD | | 2.22 | 1.70 | 4.90 | 1.35 | 1.87 | 1.71 | 7.82 |
| | G | $\sigma^2_G$ | 0.31 | 0.57** | 9.13*** | 0.90** | 1.60*** | 0.07** | 3.51 |
| | | ±SE | 0.25 | 0.20 | 2.22 | 0.31 | 0.44 | 0.02 | 3.85 |
| | G×E | $\sigma^2_{G\times E}$ | 2.48*** | 1.05*** | 1.19*** | 0.56** | 0.44** | 0.07*** | 43.89*** |
| | | ±SE | 0.38 | 0.16 | 0.17 | 0.21 | 0.15 | 0.02 | 6.20 |
| | Error | $\sigma^2_e$ | 1.19 | 0.38 | 0.71 | 0.41 | 1.03 | 0.25 | 4.62 |
| | | ±SE | 0.15 | 0.05 | 0.07 | 0.07 | 0.12 | 0.02 | 0.41 |
| | $h^2$ | | 0.41 | 0.76 | 0.98 | 0.89 | 0.94 | 0.85 | 0.32 |
| Low input conventional management | mean | | 3.59 | 2.82 | 22.51 | 2.96 | 3.76 | 4.61 | 82.37 |
| | SD | | 2.07 | 1.60 | 4.32 | 1.22 | 1.51 | 2.08 | 2.93 |
| | G | $\sigma^2_G$ | 1.26** | 0.33** | 8.10*** | 0.47*** | 0.68** | 0.08* | 3.40*** |
| | | ±SE | 0.40 | 0.12 | 1.96 | 0.13 | 0.24 | 0.03 | 0.85 |
| | G×E | $\sigma^2_{G\times E}$ | 1.24*** | 0.98*** | 0.77*** | 0.17** | 0.44 | 0.17*** | 0.88*** |
| | | ±SE | 0.22 | 0.12 | 0.14 | 0.06 | 0.23 | 0.03 | 0.12 |
| | Error | $\sigma^2_e$ | 0.56 | 0.27 | 0.74 | 0.59 | 0.72 | 0.41 | 0.57 |
| | | ±SE | 0.08 | 0.03 | 0.07 | 0.06 | 0.14 | 0.03 | 0.05 |
| | $h^2$ | | 0.85 | 0.66 | 0.98 | 0.93 | 0.87 | 0.70 | 0.96 |

$\sigma^2_G$, $\sigma^2_{G\times E}$, $\sigma^2_e$ = genotypic, genotype × environment interaction and residual variance components, respectively; $h^2$ refers to the repeatability for the inclination of leaves at booting (INC), vigorousness of growth during booting (VIG), heading date (HD), susceptibility to powdery mildew (PM) and leaf rust (LR), grain yield (GY) and test weight (TW); *, **, *** significant at the 0.05, 0.01, 0.001 probability level, respectively

### Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM (supplementary Hungarian project EU_BONUS_12-1-2012-0032).

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# Exploitation of diversity in grain Maize

## Effects of increased genetic and species diversity on weed suppression, yield and yield stability

NEVENA NOL*, GIONATA BOCCI*, ANNA-CAMILLA MOONEN*, PAOLO BÀRBERI*

*Land Lab, Institute of Life Sciences, Scuola Superiore Sant'Anna, Pisa, Italy, www.sssup.it, nevena.nol@sssup.it

Key words: organic systems, cover crops, CCPs, *Zea mays*, weed suppression, yield stability

Summary : During both cover crop and maize growing cycles, we studied the effects of increased species diversity of cover crops and genetic diversity of maize populations on crop performance in terms of weed reduction, grain yield and yield stability observed over four consecutive growing seasons (2011-2014) in a Mediterranean region. Our results suggest that planned agrobiodiversity at the species level, but not always at the genetic level, can contribute to increase in grain maize yield and yield stability, while crop performance and weed suppression also greatly depend on many other factors, among which climate, environment and crop management are the main determinants.

### Background

Cover crop mixtures (Teasdale et al. 2008) and composite cross populations (Wolfe et al. 2008) offer a great opportunity for testing the utilization potential of higher crop heterogeneity in rainfed maize low-input and organic systems, especially under conditions of severe (a)biotic stress and climate change (Phillips and Wolfe 2005). The actual value of "evolutionary plant breeding" approach although still limited in its broader acceptance, could be revealed by significant research efforts related to the identification of an adaptation potential of maize cultivars and improvements of crops' traits for sustainable agroecosystems. Furthermore, increasing species agrobiodiversity through the introduction of winter cover crops (green manures) is one of the most useful pro-active component to enhance the production sustainability and environmental suitability of field management while gaining independence from external inputs (Malézieux 2012).

### Introduction

Cover crop species can contribute to better use of alternative weed management tactics, soil fertility and cash crop performance (e.g. Teasdale and Daughtry 1993). Although facing an argument that organic systems may offer decreased yields (Connor 2013) and could therefore undermine already identified benefits of organic technologies, there is a growing realization that future organic farming should be based on tactics that mimic natural ecosystems (Doré et al. 2011) and rely on functional agrobiodiversity principles (Moonen and Bàrberi 2008) that promote system resilience and sustainability. Giving the fact that improved crop cultivars are the key element in agricultural sustainability, here we tested the hypothesis that cropping system based on higher diversification of system components (genetic, species and management), will promote overall improvement of the crop agronomic performance.

### Material & Methods

Field experiments were carried out in four consecutive growing seasons (2010-2014) at the Interdepartmental Center for Agri-Environmental Research "Enrico Avanzi" of the University of Pisa, at San Piero a Grado (Pisa) in Italy. In the first two years of study, experimental playgrounds were placed in the fields (latitude 43°40'N, longitude 10°18'E) belonging to the long-term experimental system MASCOT (Mediterranean Arable Systems Comparison Trial), while in the last two seasons experiment was transferred to the field of the same research center (latitude 43°40'N, longitude 10°20'E), with a previous short agronomic history. The climatic conditions of the trial sites are typical of Mediterranean areas, with a mean total rainfall ranging from 550 to 1180 mm year$^{-1}$. The soil was a silty-loam (Typic Xerofluvent) with a low content of organic matter. Before cultivation of maize, four winter soil cover types were grown: *Brassica juncea* L. Czern., *Vicia villosa* Roth, a commercial mixture of seven cover crop species (Mix 7) and natural vegetation (control). After spring termination of the cover crops, the introduction of the cash crop was laid out in the same organic field as a split-plot design. The experimental trial comprised 12 main plots, each measuring 3 x 50 m, and 60 subplots, each measuring 3 x 10 m. The main plots consisted of four green manure treatments and subplots included five maize cultivars, three composite cross populations (CCPs), namely Complete Composite, PC Composite, Composite 1 Gyula, and two maize hybrids, conventional Pioneer® PR64Y03 and organic MvTc TO341.

### Results & Discussion

The most productive cover species in our study was *V. villosa* when observed in monoculture, with highest average dry shoot biomass production of 343.8 g m$^{-2}$. The pure stand of *B. juncea* showed the lowest production capacity and yield stability, with average dry shoot biomass production of 175.9 g m$^{-2}$ and highest coefficient of variation (64.6 %). In contrast, increased species diversity in cover crop mixture (Mix 7) resulted in higher stability of dry biomass production (CV= 34.4%) compared to other cover types. Weed reduction by living winter cover crops significantly varied over the seasons. Compared to the control, the most effective treatments for weed suppression were pure stand of *V. villosa* (45.2%) in 2013, *V. villosa* and *B. juncea* (both > 60%) in 2012, while significant reduction of weed shoot biomass production was not observed in 2011 and 2014. Unexpectedly, significant levels of weed reduction were not observed in Mix 7, due to moderate levels of cover crop plant establishment and biomass production. Maize dry shoot production was increased by 21% after *V. villosa*, with the highest biomass stability observed in the organic hybrid (CV= 24.3%) and the lowest in

Complete Composite (35.4%), while highest grain yield was recorded in plots with conventional hybrid after *V. villosa* (2.5 t $ha^{-1}$) and Mix 7 (2.3 t $ha^{-1}$). Furthermore, our findings indicated clear differentiation between two categories of maize cultivars differing in genetic diversity: CCPs, constantly with lower dry grain yield (≤ 1.2 t $ha^{-1}$), and hybrids, with significantly higher dry grain production (≥ 1.9 t $ha^{-1}$). The most stable maize genotype in terms of dry grain yield performance was the conventional hybrid (CV = 27.5%), while the Complete Composite showed the highest variability (CV = 63.2%) across years. Dry grain production over the years of study was significantly influenced by maize genotype, year of production and their interaction, but increase of agrobiodiversity at the genetic level did not contribute to improvement of the grain yield nor yield stability, mostly due to the low adaptability of CCPs in the Mediterranean environment. Our results suggest that increased agrobiodiversity at the species and especially at the genetic level, have major effect on maize grain yield and yield stability, while agronomic performance and weed suppression ability of crops are also influenced by many other factors, among which climate, environment and crop management are the main determinants.

**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

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# Breeding for improved nitrogen fixation
## Improving Soybean x Bradyrhizobium Symbiosis for Cool Growing Regions

MONIKA M. MESSMER[1], FLORIAN HERTENSTEIN[1], ESTELLE BERSET[1], CHRISTIANE BALKO[2],WERNER VOGT-KAUTE[3], KLAUS-PETER WILBOIS[4]

[1] Research Institute of Organic Agriculture (FiBL), Switzerland, www.fibl.org, monika.messmer@fibl.org
[2] Julius Kühn Institute (JKI) Groß Lüsewitz, Germany, www.jki.bund.de, christiane.balko@jki.bund.de
[3] Naturland e.V., Germany, Germany, www.naturland.de, w.vogt-kaute@naturland.de
[4] FiBL Deutschland e.V., Germany, www.fibl.org, klaus.wilbois@fibl.org

**Key words:** soybean, Bradyrhizobium, cold tolerance, N fixation, symbiosis

**Summary:** Protein yield of soybean depends heavily on successful symbiosis with *Bradyrhizobium* bacteria able to fix atmospheric nitrogen. Low temperature limits the growth of soybeans but also the efficiency of biological nitrogen fixation (BNF). Cold tolerant *Bradyrhizobium* strains could be identified, and significant differences in BNF were found for *Bradyrhizobium* and for soybean genotypes allowing selection for improved BNF. Significant soybean x *Bradyrhizobium* interactions were found in mesocosm and field trials, as well as complex temperature dependent interactions with mycorrhiza strains. More studies are needed to elucidate the important plant – rhizosphere interactions.

### Background

Soybean (*Glycine max* (L.) Merr.) is the most important protein source for human food and animal feed worldwide, however Europe is largely dependent on imports from Americas and Asia. Soybean production in Central Europe is limited by short season and low temperature as a single night of 8°C is sufficient to inhibit pod formation (Strauss et al. 2006). Very early (maturity group 000 to 00) and cold tolerant soybean genotypes are required for cultivation in Germany and Switzerland (Gass et al. 1996). In order to produce high protein content, soybean plants depend on their symbiotic bacteria *Bradyrhizobium japonicum* which allow the fixation of atmospheric nitrogen ($N_2$). As *Bradyrhizobia* are not endemic to European soils the soybean seeds need to be inoculated before sowing. Low root zone temperature (RZT), is also a major limiting factor for biological nitrogen fixation (BNF) in short season production areas (Zhang et al., 2003). Therefore, research efforts to improve BNF need to be applied to both soybean and *Bradyrhizobia* (Keyser and Li, 1992). While several breeding programs focus on selecting for cold tolerant soybean genotypes, little attention has been given so far to the selection of *Bradyrhizobium* strains adapted to European cool growing conditions. This study aims at improving the BNF of soybeans by optimizing plant – microbe interaction under low temperature and its implementation for plant breeding.

### Main Chapter

Yield stability and protein content of soybean production under cool growing conditions of Europe shall be improved by increasing BNF through optimizing soybean – *Bradyrhizobium* symbiosis. The objectives of the study are (i) to select *Bradyrhizobium* strains adapted to cool growing conditions, (ii) to identify optimal soybean x *Bradyrhizobium* combinations and (iii) to quantify the impact of triplex interactions with mycorrhiza and plant growth promoting rhizobacteria (PGPR).

In microcosm trials twelve different *Bradyrhizobium* inoculants and one inactivated control were tested on three early soybean varieties (maturity group 000) at three different temperature regimes (14/10°C; 16/12°C; 22/20°C). The number of nodules, root, and shoot biomass as well as chlorophyll content were assessed after six weeks. The five most promising *Bradyrhizobium* strains from the microcosm trial were multiplied and were tested on 20 different soybean varieties (maturity group 0000/000 to 00) under 16/12°C temperature regime for 6 weeks. The same traits were assessed. In addition, nitrogen content and $\delta^{15}N_{air}$ of shoots and seeds were determined by the $^{15}N$ natural abundance method. The percentage of BNF was calculated according to Unkovich et al. (2008). In parallel we tested the effect of co-inoculation of two different mycorrhiza strains and two *Bradyrhizobium* strains on one soybean cultivar under two different temperature regimes (16/12°C; 20/20°C). In addition, four *Bradyrhizobium* strains were tested on two soybean varieties in mesocosm trials to assess their impact on chilling tolerance during flowering. The number of nodules, chlorophyll content, number of pods and seeds on main and side branches were assessed. To verify the results of the mesocosm trials, on-farm field trials at two sites were conducted in 2012 and 2013 under organic growing conditions in the middle and North of Germany. The number of nodules was assessed six weeks after sowing and at beginning of flowering. Yield, thousand kernel weight and protein content were assessed at soybean harvest.

In mesocosm trials we found significant *Bradyrhizobium* x soybean variety interactions at 14/10°C and at 16/12°C. At 14/10°C the highest number of nodules was obtained with the strain USDA 30 and the variety Protina (8.5 nodules per plant), whereas at 16/12°C one commercial product HiStick yielded highest number of nodules with the variety Bohemians (21.2 nodules per plant). The 20 soybean varieties showed significant variation for number of nodules, total N uptake and N derived from BNF when tested with the selected *Bradyrhizobium* strains under cool conditions (16/12°C) (Fig. 1).

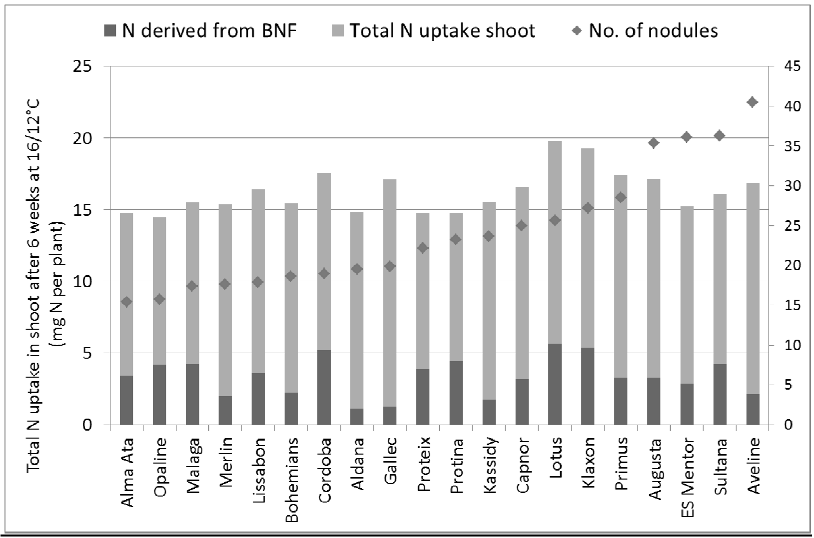


Figure 1. Total nitrogen (N) uptake, N derived from biological nitrogen fixation (BNF) and number of nodules of the 20 soybean varieties tested against five Bradyrhizobia strains at 16/12°C

Significant differences were also found for the different *Bradyrhizobium* strains, but no *Bradyrhizobium x variety* interaction was detected at this early stage development. Co-inoculation with mycorrhiza resulted either in a significant increase or decrease of nodules depending on the used mycorrhiza strain, the *Bradyrhizobium* strain and the tested temperature, demonstrating the complex interaction in the rhizosphere. The impact of *Bradyrhizobium* strains on chilling tolerance during flowering was of minor importance. However, significant *Bradyrhizobium* x temperature interaction occurred. The cold tolerant USDA 30 strain resulted in higher number of pods per side branch as compensation to the chilling stress, whereas without cold stress the commercial product HiStick showed the best performance.

Under organically managed field conditions the *Bradyrhizobium* strains had a significant effect on all assessed traits. Significant soybean variety x *Bradyrhizobium* interactions were found for protein content at both sites. Best combination was Protina x Legumefix and Merlin x Biodoz at site 1 and Protina x Legumefix and Merlin x Celltech at site 2. Across varieties, Biodoz revealed highest number of nodules per plant, followed by USDA 30, whereas HiStick consistently showed lowest number of nodules at these two stress environments.

This study shows that the early development of soybeans depends to a great extent on the soybean variety, the *Bradyrhizobium* inoculation and the temperature. Interactions between soybean variety and *Bradyrhizobium* strains are of main importance under cool growing conditions in mesocosm and field trials. The natural abundance method is a powerful tool to assess the BNF under different growing conditions and can be applied to select both soybean genotypes as well as *Bradyrhizobium* strains with improve BNF. Further studies are needed to elucidate the complex rhizosphere interactions in order to identify optimal co-inoculations with mycorrhiza and plant growth promoting rhizobacteria to support sustainable soybean production in Europe.

**Acknowledgement**

This research project was funded by the German Federal Ministry of Food, Agriculture and Consumer Protection under the program for organic and other sustainable agricultural systems (BÖLN) „Expansion of soybean cultivation in Germany through adaptation by breeding as well as optimization of crop production and processing technology“ (www.sojainfo.de), the Mahle Stiftung GmbH in Stuttgart, Germany, and the Swiss Agency for Development and Cooperation, Government of Switzerland under the Indo-Swiss Collaboration in Biotechnology (ISCB). We thank all farmers,advisers, technicians and researchers who contributed to this project.

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

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# Breeding winter peas in diversity for diversity

ULRICH QUENDT[1], THORSTEN HAASE[2], JÜRGEN HEß[3]

[1]Cereal Breeding Research Darzau, Darzau Hof 1, D-29490 Neu Darchau, Germany. www.darzau.de, u.quendt@darzau.de

[2]Landesbetrieb Landwirtschaft Hessen, Kölnische Straße 48-50, 34117 Kassel, Germany

[3]Department of Organic Farming & Cropping Systems, Nordbahnhofstrasse 1A, D-37213 Witzenhausen, Germany

**Key words:** winter pea, organic plant breeding, inter cropping, mixed cropping

**Summary:** Since 2004 Cereal Breeding Research Darzau is breeding winter peas adapted to organic conditions, resistance to frost under continental influence, low precipitation and sandy soils. Selection of winter pea takes place in intercropping with cereals. Until now there were no practical experiences how the progeny lines and its morphological traits will perform in mixed cropping with different mixture partners in yield testing. A three year project was set up to test progeny lines, varieties and genetic resources with 5 mixture partners at two locations. The genotypes were evaluated for field emergence, frost resistance, soil cover, lodging, disease resistance, protein content and yield.Background

Grain legumes are one of the limited sources for nitrogen input in organically managed cropping systems. Grain legumes can be a source of home-grown feed resources. But due to disease susceptibility, yield instability and a low market value the grain legumes growing area also in the organic sector extremely decreased in the last decades. To turn around the situation new strategies for grain legumes were searched for. Urbatzka et al. (2012) showed that winter peas are more favourable to organic farming compared with spring peas. Pre-tests of winter peas at Darzau also showed favourable traits in adaptation on sandy soils and early spring droughts due to the developed root system over winter. Up to now real winter hardiness could be found predominantly in old fashioned fodder peas like Austrian winter pea types, which mean tall plants, indeterminate growth habit, normal leaf type, coloured flowers and low TKM. Coloured flower are linked to dark pigmented seed coat with high content of tannins which interferes the digestion process of monogastric animals. At the moment there are no winter peas for use as grain protein livestock feed with corresponding traits for organic cropping available. To increase the suitability of winter peas for organic farming mixed cropping may be favourable. Mixed cropping increases the diversity of plants at field scale. Further advantages of mixed cropping are yield stability through compensation, reduced weed pressure and reduced pathogen pressure. Disadvantages can be competition between plants in mixture. Especially for mixed cropping of peas and cereals there has been observed strong competition of cereals against peas (Rauber et al. 2001). Little is known about the interaction of winter peas with diverse morphological traits in mixed cropping with cereals or oil crops.

## Introduction

After 10 years organic breeding of winter peas at Cereal Breeding Research Darzau there are many different progeny lines of winter peas available with different morphological traits in leaf type – semi-leafless and normal leaf, flower colour – coloured and white flowering and plant height – short 50 up to 180cm. The selected progeny lines are adapted to the conditions at Darzau (continental influence, predominantly dry and sandy soils). The organic breeding of winter pea takes place in inter resp. mixed cropping. In the nursery we tested some cereals in different densities in intercropping with peas. But we did not know how the peas which are selected in intercropping in the nursery will perform in mixed cropping at field scale. In a three year experiment we tested the progeny lines of winter pea crosses at two locations with 5 mixing partner. The questions of the experiment were: (1) Show the progeny lines different performance with different mixing partners (2) if yes, which partner will be the best for which progeny line (3) are there differences in adaptation to the locations and (4) can the results related to the morphological traits for further selection decisions?

## Method and Material

*Table 1: Genotypes and morphological traits*

| genotype | source | leaf type and flower color | Plant height [cm] |
|---|---|---|---|
| 44F1 | line | sc | 160 |
| A1 | line | sw | 120 |
| A4 | line | sw | 130 |
| C1 | line | sw | 130 |
| C3 | line | sw | 120 |
| D6 | line | sw | 130 |
| D7 | line | sw | 125 |
| EFB33 | variety | nc | 150 |
| Griechische | gen. res | nc | 140 |
| L1 | line | nc | 135 |
| Nischkes | gen. res | nc | 150 |
| P1 | line | nc | 60 |
| Würtemberg | gen. res | nc | 135 |
| I1 | line | nw | 125 |
| I3 | line | nw | 125 |
| Q2 | line | nw | 130 |

s = semileafless; n = normal leaf; c = coloured flower; w = white flower

The experiment was set up from 2011 to 2013 at two locations Darzau (DAR) (53.2; 10.8, 680 mm; 8°C – Haplic Luvisol – texture: loam sand) and Hessische Staatsdomäne Frankenhausen (DFH) (51.4 N; 9.4 E; 698 mm; 8.5°C mean, Haplic Luvisol – texture: silt loam) – organically managed research farm of the university of Kassel. At the end of the project we had a collection of 16 winter pea genotypes – progeny lines, genetic resources and the reference variety EFB33 – differentiating in leaf type, flower colour and plant height (*Table 1*). Due to different preconditions of soil and nutrient level at the two locations we chose different mixture partners for the locations. The partners at Darzau were rye (*Secale Sereale*, cv. Lichtkornroggen), wheat (*Triticum aestivum*, cv. Govelino) and triticale (*Triticosecale* Wittmack, cv. Benetto) and at Frankenhausen rape (*Brassica napus,* cv. Visby), turnip (*Brassica rapa,* cv. Largo) and triticale. Only the mixture partner triticale was the same at two locations. We applied substitute mixtures - half of the normal seed density of every mixed cropping partner. For comparison reasons all partners were also grown in sole crop. The experiment design were complete randomized at Darzau and two-factorial split-plot at Frankenhausen. The sowing time was mid September. To differentiate the adaptation on mixed cropping resp. sole cropping we assessed crop emergence, over wintering rate (%), phenological development (BBCH system), crop and weed cover (%), disease resistance, lodging, thousand-kernel mass (g), yield of the mixture partner(dt/ha), relative yields (deWit 1960) and grain protein concentration (%DM).

### Outcomes and discussion

The results were strongly influenced by weather and soil condition of the different locations. The overwintering rate of the genotypes over all three years was higher at Frankenhausen (40 to 100%) than at Darzau (0 to 90 %). In the winter 2012 nearly all genotypes disappeared at Darzau due to three week bare frost where as at Frankenhausen under the same weather conditions only a few genotypes completely disappeared. The differences of the genotypes in the overwintering rate influenced plant cover, lodging and yield. To normalize the differences for yield we calculated relative yields (deWit 1960). The relative yields for pea are presented in *Table 2*. An entry with relative yield of 0.5 performed in relation to its seed density in sole crop as good as in mixed crop. An entry with greater than 0.5 achieved in mixed cropping more than in sole crop. And a relative yield greater than 1 indicates that an entry achieved double as much as in sole crop.

*Table 2: Relative Yields - Yield of genotypes grown in mixture to the yield in sole crop - two locations (DAR and DFH), two years (2011 and 2013), 5 mixture partners*

| genotype | leaf type and flower color* | DAR 11 | | | DFH 11 | | | DAR 13 | | | DFH 13 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | rye | triticale | wheat | rape | triticale | turnip | rye | triticale | wheat | rape | triticale | turnip |
| 44F1 | sc | 0.3 | 0.3 | 0.3 | | 0.5 | | 0.6 | 1.0 | 0.8 | 1.0 | 0.7 | 0.9 |
| A1 | sw | 0.4 | 1.0 | 1.1 | 1.3 | 0.4 | 0.9 | 0.5 | 0.8 | 0.6 | | | |
| A4 | sw | 0.2 | 0.4 | 0.6 | 1.4 | 0.4 | 0.9 | 0.7 | 1.0 | 0.8 | 1.1 | 0.8 | 1.0 |
| C1 | sw | 0.3 | 0.5 | 0.4 | 1.5 | 0.5 | 1.4 | 0.6 | 0.8 | 0.7 | | | |
| C3 | sw | 0.3 | 0.4 | 0.6 | 1.7 | 0.6 | 1.3 | 0.6 | 0.8 | 0.7 | 1.0 | 0.8 | 0.9 |
| D6 | sw | 0.2 | 0.4 | 0.5 | 1.8 | 0.6 | 1.0 | 0.7 | 0.9 | 0.7 | 1.2 | 0.9 | 1.0 |
| D7 | sw | 0.3 | 0.3 | 0.7 | 1.3 | 0.4 | | 0.6 | 0.8 | 0.6 | | | |
| EFB33 | nc | 0.4 | 0.6 | 0.6 | 1.7 | 1.1 | 2.2 | 0.7 | 1.2 | 1.0 | 1.1 | 0.9 | 1.2 |
| Griech | nc | 0.6 | 0.8 | 0.8 | | 1.2 | | 0.4 | 0.7 | 0.4 | | | |
| L1 | nc | 0.4 | 0.6 | 0.7 | 1.2 | 0.6 | 1.3 | 0.6 | 0.8 | 0.7 | 1.3 | 0.9 | 1.1 |
| Nischkes | nc | 1.1 | 1.6 | 1.3 | 1.9 | | | 0.8 | 1.1 | 0.9 | | | |
| P1 | nc | 0.5 | 0.9 | 1.0 | 2.4 | 0.5 | 0.8 | 0.6 | 0.9 | 0.7 | 0.8 | 0.6 | 0.6 |
| Würt. | nc | 0.6 | 0.8 | 0.9 | 1.8 | 1.1 | 2.2 | 0.4 | 0.8 | 0.5 | | | |
| I1 | nw | 0.3 | 0.3 | 0.4 | 1.1 | 0.4 | 0.9 | 0.8 | 1.0 | 0.8 | 0.9 | 0.6 | 0.8 |
| I3 | nw | 0.2 | 0.4 | 0.4 | 0.9 | 0.4 | 0.8 | 0.4 | 0.7 | 0.5 | 0.8 | 0.5 | 0.8 |
| Q2 | nw | 0.2 | 0.4 | 0.4 | 1.6 | 0.5 | 1.3 | 0.5 | 0.9 | 0.6 | | | |
| mean RY pea in mixture | | 0.4 | 0.6 | 0.7 | 1.5 | 0.6 | 1.3 | 0.6 | 0.9 | 0.7 | 1.0 | 0.8 | 0.9 |

*s=semileafless; n=normal leaf; c=color flower; w=white flower; light grey: (=>0.5) Genotypes achieved more than the half of the sole crop; dark grey: (=>1) Genotypes achieved the same or more than the sole crop and (=>2) Genotypes achieved more as double as the sole crop

The performance of the genotypes showed differences for the mixture partners, the location and the morphological traits. The highest relative yields of the peas were found in mixtures with oil crops followed by the mixtures with triticale particularly at Darzau. The lowest relative yield was found in mixture with rye and wheat at Darzau. Rye was very competitive due to strong tillering and very broad leafs in the first development stages. In the later stages plant height of rye (160 cm) became another reason for suppression. Wheat also developed broad leafs in the first developing stages but the plant height was shorter (85 cm), so that suppression was not as strong as from rye. Triticale had the same plant height (90 cm) than wheat but leafs are not as broad as from rye or wheat so that competition was relative low in the beginning. Due to high nutrient levels at Frankenhausen triticale showed more tillering and was more competitive against peas. Even a lower seed density of triticale did not reduce the competition of triticale. At Frankenhausen rape and turnip showed the best relative yields for pea. The sowing date mid of September was too late for oil crops and the development was delayed so that the competition against peas was low. But the ripening time was 2 weeks earlier than of the pea. In contrast the cereals showed more accordance in ripening time to the peas. That makes cereals despite the higher competition more favourable for mixtures with peas than oil crops. In 2011 the genotypes of the morphological combination normal leaf type and colour flowering showed relative yields greater than 0.5 with all mixture partners. In 2013 the difference between the normal leaf, colour flowering and the semi-leafless, white flowering was not as distinctive as in 2011 but still there. Across all mixture partners the genotypes with normal leaf type and white flowers (I1 and I3) was not as competitive as the other genotypes and performed better in sole crop (*Table 2*).

### Outlook

We found that most of the selected progeny lines were adapted to the climate of mid and north Germany. Depending on the location some of the progeny lines even the white flowering ones performed better or equal in frost resistance and yield than the standard variety EFB33. But the competitiveness in mixture with cereals of the semi-leafless and normal leaf, white flowering genotypes should be further increased especially at locations with low nutrient level like Darzau. Furthermore mixture cropping of peas and cereals can compensate yield even if peas failed completely never a zero yield occurred. Cultivating winter peas without mixed cropping is not suitable due to less weed resistance and lodging in sole crop. The optimal seed density of the cereal mixture partners for smallest competition and highest standing ability should be further evaluated. Also the crop management of winter peas with winter oil crops should be enhanced. Much more elaborated explanation of organic breeding of winter peas and results of the project will be presented at the conference.


### Acknowledgements

The financial support of the project by the Federal Office for Agriculture and Food is gratefully acknowledged


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# Hill Placement of Manure and Mineral Fertilizer for Improved Millet Yield and Water Use on Acid Sandy Soil of Niger, West Africa

IBRAHIM ALI[1,2], CLEMENT ABAIDOO ROBERT[1,3], DOUGBEDJI FATONDJI[2], ANDREWS OPOKU[1]

[1]Department of crop and soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
[3]International Institute of Tropical Agriculture, Ibadan, Nigeria

**Keywords:** Pearl millet, fertilizer micro-dosing, manure, placement, water use

**Summary :** The aim of this study was to determine the optimal combination of fertilizer micro-dosing and manure application rate that should improve millet yield and enhance water use efficiency on an acid sandy soil of Niger. To achieve this objective an experiment was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) research station in Niger using a randomized complete block design replicated three times. The treatments used consisted of the factorial combination of three factors: (i) fertilizer micro-dosing options with 2 levels (2ghill$^{-1}$ of DAP and 6ghill$^{-1}$ of compound fertilizer NPK), (ii) cattle manure with 4 levels (0 kgha$^{-1}$ 1000 kgha$^{-1}$, 2000 kgha$^{-1}$, 3000 kgha$^{-1}$) and (iii) method of manure application with two levels (broadcasting and hill placement). Millet grain yield under fertilizer micro-dosing combined with manure was increased by 62%, 115% and 160% resulting to an increase in grain water use efficiency by 88%, 200% and 225% respectively for 1 Tha$^{-1}$, 2 Tha$^{-1}$ and 3 Tha$^{-1}$ as compared to fertilizer micro-dosing alone. Hill placement of manure improved total dry matter by 23% as compared to manure broadcasting. These results indicated that the application of 2ghill$^{-1}$ of DAP combined with 2 Tha$^{-1}$ of manure hill placing appears to be a viable option for improving millet yield and water use efficiency in low input smallholder millet-based system.

## I. Introduction

Pearl millet is the major food cereal cultivated in Niger on the coarse textured soils using up to 90% of the cropped area . Even though this crop has a potential to adapt to harsh conditions its yield is still very low with an average of 400 kg ha$^{-1}$ in low input smallholder millet farming system. The reasons for this low millet yield are multi-folds. However, the inherent low soil fertility is the main cause explaining the low millet productivity in the Sahelian zone of Niger. The use of mineral fertilizers by farmers in Niger remains very low because of their high cost . To increase the rate of on-farm application of these sources of nutrients, the so-called fertilizer micro-dosing technology that consists of the application of a tiny quantity of mineral fertilizer with the target crop seeds in the planting hill at the sowing event or few weeks after planting has been developed by ICRISAT and partners. This technology has shown very promising results in improving millet yields in the Sahel . In the recent works on millet response to fertilizer micro-dosing technology, the authors indicated that low soil organic matter characterizing the Sahelian sandy soils leads to low millet response to fertilizer micro-dosing technology . Therefore, for this technology to be more promising and maintaining the soil organic matter in the low fertility soils, there is a need to sustain it with organic amendment. However the main sources of organic amendments such as crop residues to be applied to the soil surface as mulch or incorporated into the soil are used for other purposes which limits their availability for agricultural purpose. Manure is the most important nutrient resource for smallholder farmers in Niger but its availability in sufficient quantity is also a major challenge. One of the options to address this problem could be through hill placement of manure which if combined with fertilizer micro-dose would be an optimal way for more sustainable millet production in Niger. Therefore the objective of this study was to determine the optimal combination of fertilizer micro-dosing and organic amendment application that would favor the expression of optimal millet yield and enhance water use efficiency on an acid sandy soil.

## II. Material and Methods

The experiment was carried at Sadore research station of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Niger (13˚ 15’ N and 2˚ 18’ E). The trial was laid out in a randomized complete block design replicated 3 times with 3 factors: (i) fertilizer micro-dosing options with 2 levels (20 kg ha$^{-1}$ of DAP and 60 kg ha$^{-1}$ of compound fertilizer NPK which are equivalent of 2g hill$^{-1}$ of DAP and 6g hill$^{-1}$ respectively), (ii) cattle manure with 4 levels (0 kgha$^{-1}$, 1000 kgha$^{-1}$, 2000 kgha$^{-1}$, 3000 kgha$^{-1}$) and (iii) mode application of manure( broadcasting and hill placement). In the plots with manure broadcasting treatments, the corresponding quantity was broadcasted and incorporated in the soil. For manure hill placement plots, each quantity was divided and applied according to the number of hill per hectare. Individual 5 m x 6 m plots were separated by a 1 m alley and pearl millet seeds of improved variety ISC 89305 were sown at 1 m x 1 m spacing to get a planting density of 10, 000 hillsha$^{-1}$ . The millet was thinned to three plants per hill at 3 weeks after planting. There were three weeding events during the growing period. Access tubes were installed in all the plots to monitor weekly soil moisture during the growing period with a calibrated neutron probe (Didcot) from 0.15 to 2 m depth at 0.15 m intervals. Evapo-transpiration was calculated from the formula used by . Data collected were subjected to analysis of variance using GENSTAT v.9 . Means separation were done using least significant difference (LSD) at 5%. Only the results where significant difference was observed are presented in this paper.

## III. Results and Discussion

*Grain yield, straw yield and total dry matter as affected by the treatments*

Grains yield was much lower in the un-fertilizer treatments as compared to that receiving amendment( Table 1). There was an increase in millet grain yield when manure was added to fertilizer micro-dosing. Adding manure significantly increased millet grain yields by 62%, 115% and 160% respectively for 1 $Tha^{-1}$, 2 $Tha^{-1}$ and 3 $Tha^{-1}$ .These results were in accordance with the earlier findings reported by who showed that application of small mineral fertilizer with manure frequently increased significantly grain yields in the Sahelian condition. The grain yield was not significantly affected by fertiliser micro-dosing option and manure placement method. However, manure and its method of placement were significantly affected straw yields. The highest straw yield was recorded with hill placement of manure compared to broadcasting the same rate of manure. Hill placement of manure increased millet straw yields by 26% as compared to manure broadcasting. The total dry matter recorded showed the same tendency as straw yield. Manure application improved millet total dry matter from 30 to 100% regardless to fertilizer micro-dosing options as compared to no-manuring treatment. This can be explained by the low level of organic matter content of the soil in the experimental field (data no showed). These results show once more the need of improving soil organic carbon in order to improve productivity in low input millet-based rainfed systems. The method of manure application did significantly affect millet dry matter production. Hill placement of manure performed better in improving millet production than broadcast regardless to the fertilizer micro-dosing options. Spot application of manure led to a significant increase in total dry matter compared to broadcast (Table 1). The probable explanation of this effect was that the concentration of manure in the vicinity of crop led to the creation of a micro-climate around plant rooting system resulting to the rapid root growth leading to better use of nutrients and rainwater. No significant interactions were recorded among the different factors studies in this experiment with regard to total dry matter production.

*Water use and water use efficiency as affected by the treatments*

Water use (WU), Grain yield and total dry matter water use efficiencies as affected by the treatments are showed in Table 1. The water use (ET) did not significantly change with fertilizer micro-dosing option. However there was a significant increase in water use with manure rate applied. This can be probably attributed to the increase of soil water holding capacity of the experimental sandy soil leading to a decrease in drainage. On other hand, the obtained results can be explained by the reduction of evaporation due to the increase in leaf area index observed in this experiment even though it was not reported here. The method of manure application did not show any significant change in water use. The grain water use efficiency was very low with fertilizer micro-dosing alone which recorded 0.9 $kgmm^{-1}$ and 0.6 $kgmm^{-1}$ respectively for 2$ghill^{-1}$ of DAP and 6$ghill^{-1}$ of NPK. The grain WUE was significantly increased by 88%, 200% and 225% respectively for 1 $Tha^{-1}$, 2 $Tha^{-1}$ and 3 $Tha^{-1}$ respectively as compared to non-manure treatment (Table 1). The grain water use efficiency increased with manure rate regardless to the fertilizer micro-dosing option. Many studies have reported an improvement of millet water use efficiency in response to soil fertility management options in the Sahelian zone due to increase in biomass production. These results are in line with observation's who found a significant increase in water use efficiency with manure application rate in maize. The highest grain water use efficiency was recorded with 6$ghill^{-1}$ of NPK combined with 3 $T.ha^{-1}$ of manure hill placing (3.2 $kgmm^{-1}$). The water use efficiency in total dry matter was significantly improved among the treatments with manure and its application method. The dry matter water use efficiency was greater with hill application of manure as compared to broadcasting (Table 1). There was no significant increase in total dry matter WUE with fertilizer micro-dosing option. However the combination of manure with fertilizer micro-dosing has significantly affected the total dry matter water use efficiency. Our results indicated that the application of 2$ghill^{-1}$ of DAP combined with 2 $Tha^{-1}$ of manure hill placing appears to be a viable option for improving millet yield and water use efficiency in low input smallholder millet-based system.

Table 1: Means separation on Yields, water use and water use efficiency(WUE)

| | Manure | Grain yield | Straw yield | Total dry matter | Water use | Grain WUE | Total dry matter WUE |
|---|---|---|---|---|---|---|---|
| Treatments | Rate($Tha^{-1}$) | | ($kgha^{-1}$) | | mm | | ($kgmm^{-1}$) |
| means for manure | 0 | $296^{bc}$ | $875^{c}$ | $1355^{c}$ | $292^{b}$ | $0.8^{b}$ | $4.5^{c}$ |
| | 1 | $480^{b}$ | $1241^{b}$ | $1992^{b}$ | $322^{a}$ | $1.5^{ab}$ | $6.1^{b}$ |
| | 2 | $637^{ab}$ | $1341^{b}$ | $2254^{b}$ | $288^{b}$ | $2.4^{a}$ | $8.5^{b}$ |
| | 3 | $771^{a}$ | $1750^{a}$ | $2728^{a}$ | $290^{b}$ | $2.6^{a}$ | $9.8^{a}$ |
| mean for manure placement | | | | | | | |
| | Broadcasting | 527 | $1153^{b}$ | $1864^{b}$ | 294 | 1.8 | $9.1^{b}$ |
| | Hill | 564 | $1451^{a}$ | $2300^{a}$ | 302 | 1.9 | $13.3^{a}$ |
| Lsd ( 0.05) for: | | | | | | | |
| Manure rate | | $211^{*}$ | $332^{*}$ | $575^{*}$ | $13^{*}$ | $1.1^{*}$ | $2.8^{*}$ |
| Manure placement | | $149^{ns}$ | $235^{*}$ | $407^{*}$ | $9^{ns}$ | $0.78^{ns}$ | $1.3^{*}$ |

*Means affected by the same lettre in the same colum are not significantly different. $^{*}$ significant at 0.05, $^{ns}$ =non significant*

# Comparison of different spring barley variety types in various farming systems

## Populations, mixtures and pure lines under organic and conventional farming

INDRA BEINAROVIČA[1], LINDA LEGZDIŅA[1]

[1] State Priekuli Plant Breeding Institute, Latvia, www.priekuliselekcija.lv, Linda.Legzdina@priekuliselekcija.lv

**Key words:** populations, mixtures, yield stability, grain quality, disease incidence, weed suppression

**Summary:** Most of breeding programs are aimed at fast production of new varieties. This approach has reduced genetic diversity and adaptability. Solutions for increase of diversity in varieties are genotype mixtures and populations. Trials in order to compare performance of barley populations, genotype mixtures and pure lines were carried out in two organic and two conventional sites during three years. The results did not show clear advantages of populations and mixtures; the purposefully selected lines were more efficient under organic and conventional conditions. No significant effect of multiplication environment was found, however, similar trends for populations from two crosses were observed.

### Background

Uniformity and stability has become a requirement for registration of crop varieties during the last century and has led to fully homogeneous crops grown by intensive technologies and using chemical inputs. Development of integrated and organic farming systems promotes increase of genetic diversity within crop varieties. Solutions for increasing diversity within a variety of self-pollinating species are variety mixtures and populations. It was suggested that composite cross populations may be an efficient way of providing heterogeneous crops and of selecting superior pure lines for low input systems characterized by unpredictable stress conditions (Phillips and Wolfe 2005). A more practical way of diversifying crop fields may be the increase of diversity by planting cultivar mixtures; it can be done with minimal financial investment or changes in production practices (Tooker and Frank 2012). Possible advantages of diverse material including buffering capacity against various stress factors, adaptation to specific environments, reduced disease distribution, improved competitive ability with weeds and nutrient uptake efficiency can be caused by complex interactions between the diverse plants including compensation and supplementary mechanisms. For instance, winter wheat mixtures showed greater stability than pure cultivars (Cowger and Weisz 2008, Löschenberger and Müllner 2013) and spring wheat mixtures were found to provide greater competitive ability in addition to stability (Kaut et al. 2009). Similarly spring barley variety mixtures provided slightly better adaptability and were less sensitive to environmental stress than their component varieties (Kiær et al. 2012).

The aim of our research was to assess the advantages of spring barley (*Hordeum vulgare* L.) populations and genotype mixtures in comparison to pure lines and parental varieties.

### Main chapter

Preliminary experiment with spring barley populations, genotype mixtures, pure lines and parental varieties was carried out during 2010-2012 in two organic and two conventional sites. Highly distinctive varieties in respect to time of release, morphological and phonological traits 'Idumeja' (Latvia), 'Primus' (Sweden), 'Anni' (Estonia) and 'Dziugiai' (Lithuania) were used as parents for five pure lines selected as superior from the respective cross combinations with a target for organic production and two simple cross populations ($F_7$-$F_9$), multiplied under the respective environment starting from $F_4$). Components for four investigated mixtures were the four varieties and pure lines mentioned before. $F_9$ populations multiplicated for 5 years in the four sites were compared in all the sites in 2012. Yield and its stability, infection with leaf diseases, grain quality traits and weed suppression were assessed.

Grain yield of populations, mixtures and pure lines (Figure 1) did not differ significantly from the range between parents or mixture components grown in pure stand except for two cases when breeding lines significantly surpassed the higher yielding parent in organic sites. No consistent trends in respect to surpassing of parent range in organic and conventional conditions were observed.

To compare the yield of populations, mixtures and lines originating from the two parent/component combinations the general tendency was that the yield increases following: parent mixture < population < line mixture < breeding lines. Populations yielded slightly more than the respective parent mixtures in most of the cases (the effect was more explicit for Anni/Dziugiai combination). Mixture made of all four parents usually yielded less than mixture of two lines each from cross between two different parents (difference was significant in only one case). The most successful mixture was composed of two lines originating from the same cross with distinctive plant growth types (erectophile with excellent early vigor and planophyle with low early vigor) and adaptability; however, it outyielded both component lines in only one case and under conventional conditions.

No significant differences from the parent/component range were found for crude protein and starch content in grain and weed ground cover; grain volume weight was significantly below and thousand grain weight significantly above the parent range for some breeding lines. Significantly higher infection level with leaf diseases than for parents was recognized frequently and mostly under conventional environments but significantly lower infection was observed in a few cases under both organic and conventional sites.

In respect to yield stability and adaptability one of the two breeding lines with the highest average yield over all environments (3.64 t/ha) showed adaptability to unfavorable environments (b=0.82, significantly different from 1) and the other one had broad adaptability (b=0.93, no significant difference from 1). The most superior mixture composed of two breeding lines provided adaptability to favorable environments (b=1.13, significantly above 1). Both populations had broad adaptability; however, the yield level was above the overall average for population derived from cross Anni/Dziugiai only.

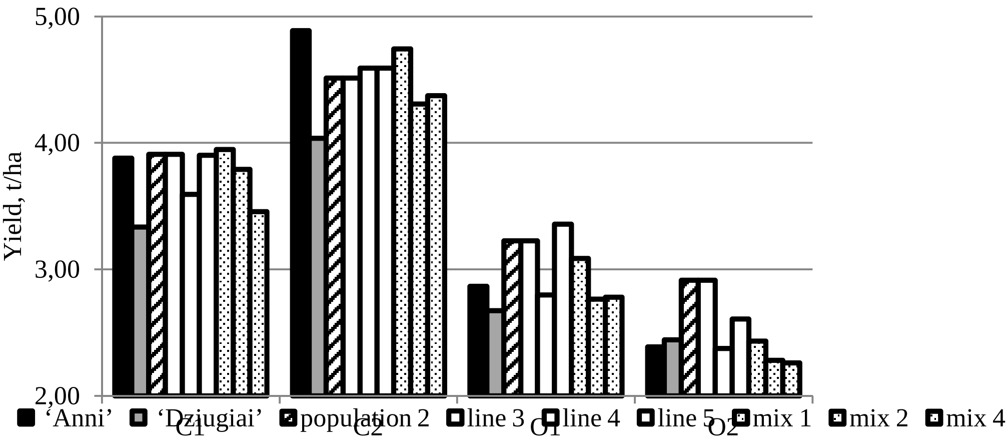


Figure 1. Average grain yield (2010-2012) of population, pure lines and mixtures originating from parent/component varieties 'Anni' and 'Dziugiai' in two conventional (C1, C2) and two organic (O1, O2) sites

The comparisons of populations from the two crosses multiplied in the four distinctive environments did not prove a significant effect of multiplication environment and interaction between testing and multiplication environments for grain yield and grain quality traits. However, similar trends for populations from both crosses were observed which were especially visible under both organic environments; it could be considered as effect of natural selection specific for the different multiplication sites. Populations multiplied under organic farm with unstable yield level between the years had higher yield if compared to populations from other multiplication sites in the respective organic farm environment and also in other environments. It might be caused by better ability of population multiplied in such conditions to adapt to diverse environments. A tendency to comparatively lower yield was found for populations multiplied in organic trial field; differences were larger while testing in the respective organic trial field.

The results did not show clear advantages of populations and mixtures. With the initial material used we can conclude that the purposefully selected lines were more efficient than populations and mixtures under both organic and conventional conditions.

Currently the investigations are continued in more detailed study with populations containing higher diversity level and mixtures composed of genotypes with diverse traits related to weed competitiveness and resistance to leaf diseases and adaptability.

This research was supported by European Social Fund co-financed project 2009/0218/1DP/1.1.1.2.0/09/APIA/VIAA/099 and project financed by Latvian Council of Science "Genetically diverse varieties for environmentally friendly agriculture - study on advantages and breeding strategies".

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# Intercrops can increase the profitability of low-input rotational cropping systems

JOHN A BADDELEY, VALENTINI A PAPPA, ROBIN L WALKER, CHRISTINE A WATSON, ROBERT M REE

SRUC, UK, www.sruc.ac.uk, john.baddeley@sruc.ac.uk

**Key words:** barley, oats, peas, clover, protein crop, gross margin

**Summary:** Cereal/legume intercrops are often proposed as an alternative to monocropping, particularly in temperate low-input farming systems. Here we present results of an investigation into the potential economic benefits of cereal/legume intercrops in both the year of intercropping and on the subsequent year of cropping. The two-year gross margins for the intercrops followed by oats were much greater than for barley-oat, pea-oat and clover-oat systems. This study highlights the importance both of taking a multi-year approach to assessing the value of intercropping, and also shows that intercrops offer a potential route to improving profitability in rotational farming systems.

### Background

The replacement of industrially-produced fertiliser nitrogen (N) by improved use of symbiotically fixed N is frequently proposed as a route to creating more sustainable and less environmentally harmful agricultural systems. While there is some progress in addressing this approach through the use of forage legumes, the greater integration of grain legumes into cropping systems has been relatively neglected. Increased use of grain legumes would also help to address current policy issues relating to both the reduction of plant protein imported into Europe, and to the diversification of cropping systems.

Intercropping (the simultaneous cultivation of two or more crops on the same area of land) of legumes with cereals has been proposed as a system to increase the amount of legumes in a rotation. This has the advantage of not sacrificing a year of potential grain yield, and if a grain legume is grown then total grain yields may actually increase. Despite this high level of interest in intercrops, to date most studies have based their conclusions on measurements of final yield and data from only one growing season. The aim of this study was to assess the contribution of intercrops and monocrops to the profitability of a rotational cropping system using gross margins.

### Materials and Methods

The experiment was carried out at the Craibstone Estate (57°12' N, 2°13' W) near Aberdeen, UK. The treatment plots in 2006 consisted of a monocrop of spring barley (*Hordeum vulgare* cv. Westminster), or cereal-legume intercrops (50:50 replacement design) of barley with either spring pea (*Pisum sativum* cv. Zero 4) or clover (*Trifolium repens* cv. Alice). Monocrops of pea and clover were also grown. In 2007 spring oats (*Avena sativa* cv. Firth) were grown on all plots. No fertilisers, herbicides or pesticides were used throughout the experiment. Grain yields were calculated from samples taken at crop maturity. Full details are given in Pappa et al (2011).

Gross margins were calculated using economic data (Lampkin et al. 2007) combined with the experimental yield data. For comparative purposes, gross margins were also calculated for conventionally-grown spring barley for 2006 and spring oats for 2007 from the Farm Management Handbook (FMH, Beaton et al. 2007). Gross margins at the time of the experiment were compared with those that would be realised currently by recalculation using 2014 economic data (Craig & Logan, 2013; Lampkin et al. 2014).

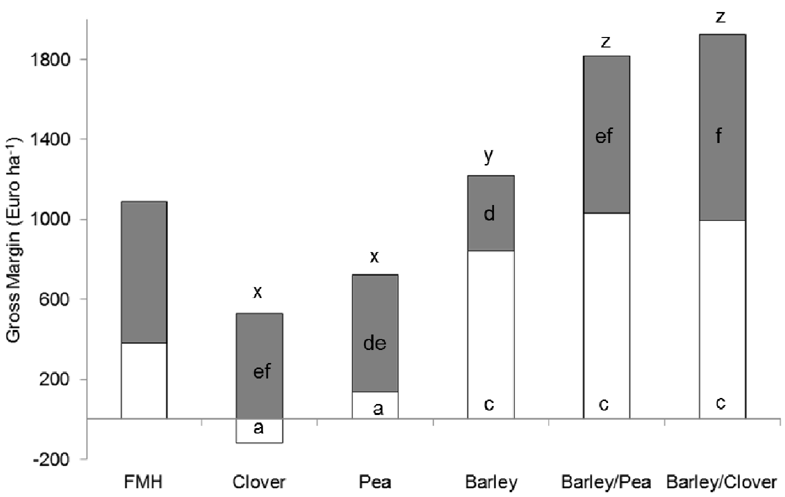


Figure 1. Gross margins (€ ha$^{-1}$) for mono/intercropping in 2006 (open) and the following monocrop of oats in 2007 (shaded). All values are means (n=3). Within each year similar letters are not significantly different. Similar letters over the bars indicate treatments that are not significantly different for the total gross margin over two years. Treatments are labelled according to the treatments in 2006. FMH

is conventionally cropped barley and oats.

**Results**

In the season of intercropping the gross margins for the two barley/legume intercrop treatments were similar to each other and were not significantly greater than the monocropped barley. Over the two seasons however, the intercrop treatments followed by oats had significantly greater gross margins than the monocropped barley/oats by about €600. Gross margins for clover or peas followed by oats were similar to each other and about one third of the intercropped treatments. This difference was driven by the lack of a cereal in 2006, and that the oats grown in 2007 only gave similar income to the oats after the intercrops. The gross margins for the highest intercrop was greater than for FMH by about €800.

Recalculation of the gross margins using 2014 economic data showed substantial increases for all treatments (Table 1). All but one treatment showed a greater increase in output than the FMH reference value and this reflects the greater difference between organic and conventional grain prices in 2014 than in 2006/07. Variable costs in the FMH reference have increased much more than in any of the experimental treatments and this is largely due to large increases in the cost of manufactured fertilisers. The overall effect of these changes is that at 2014 prices the gross margin for the best-performing treatment barley/clover intercrop nearly doubled, while that for the FMH reference increased by only 40%.

| | FMH | Clover | Pea | Barley | Barley/Pea | Barley/Clover |
|---|---|---|---|---|---|---|
| Increase in Output (€) | 864 | 751 | 924 | 1 932 | 1 870 | 2 001 |
| Increase in Variable Costs (€) | 410 | 11 | 123 | 26 | 74 | 18 |
| Gross margin 2014 (€) | 1 543 | 1 271 | 1 523 | 3 125 | 3 615 | 3 906 |

Table 1: Increases in output and variable costs, and the revised gross margins, when experimental data are recalculated using 2014 economic data. All figures are Euro $ha^{-1}$ for 2 years. Treatments are labelled according to the treatments in 2006.

**Discussion**

While the gross margin approach is not a comparison of fully-functional farming systems it does allow comparison of an important cash cropping phase of a rotational system. Despite generally being considered as a good second cereal, oats gave a lower gross margin after the barley monocrop than after barley/legume intercrops. Thus it seems that the intercrops have at least as large an effect on the performance of the system in the year after they are grown than when they are in the ground. These two-year gross margins show that intercrops offer a potential route to improving profitability in low-input rotational farming systems. As a result of having a cereal in the ground for both of the potential cropping years the barley/legume intercrops realised much higher gross margins than barley-oat or legume-oat sequences. Currently the gross margins are largely driven by yields as the grain price for peas is only slightly higher than for cereals. If the relative price for peas were to increase significantly in the future as demand for protein crops increases this would increase the gross margins of the cereal/pea intercrops considerably.

In the time since this trial was completed the costs of many inputs and value of outputs have changed considerably. This provided a timely opportunity to investigate how the economics of these intercropping systems respond to such changes. To aid this comparison, gross margins were also calculated for a 2-year sequence of conventionally produced spring barley-spring oats (FMH), to act as a reproducible reference rather than as a comparison of different farming systems. the gross margins of the intercropping treatments, which had been similar to FMH, are now much higher. This difference was driven partly by the higher prices for organic grain than conventional, and also by the reduced reliance on increasingly expensive inputs such as manufactured fertilisers.

**Acknowledgements**

The authors would like to thank Colin Crawford, Amy Milne, John Parker and Derek Simpson for technical assistance. SAC receives financial support from the Scottish Government RESAS.

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# Adaptability and yield stability of barley genotypes across various growing conditions

MARA BLEIDERE [1], ZINTA GAILE [2] , LINDA LEGZDINA [3]

[1]State Stende Cereals Breeding Institute, Latvia, www.stendeselekcija.lv, maara.bleidere@stendeselekcija.lv
[2]Latvia University of Agriculture, Latvia, www.llu.lv, zinta.gaile@llu.lv
[3]State Priekuli Plant Breeding Institute, Latvia, www.priekuliselekcija.lv, linda.legzdina@priekuliselekcija.lv

**Key words:** spring barley, grain yield, adaptability, stability, organic and conventional environments.

**Summary:** The objective of this research was to determine adaptability and stability of spring barley genotypes grain yield under different organic and conventional growing conditions (in total 12 different environments). Heightened mean grain yield across environments (3.95 t ha$^{-1}$) with adaptability for relatively lower yielding environments ($b_1$=0.89) showed line PR-4814. The most productive variety 'Vienna' was in the top of ranking in 10 out of 12 environments showing a great deal of adaptability to more favorable environments ($b_1$=1.30). Line PR-4181 provided a good combination of yield (3.77 t ha$^{-1}$) and stability as had b-value close to one ($b_1$=0.96) and a small deviations from regression ($s^2d$=0.10).

## Background

In organic production system the environmental conditions are also known to have significant influence on yield of spring barley therefore an understanding of environmental and genotypic causes of G x E interaction is important at all stages of organic plant breeding, including ideotype design, parent selection based on traits, and selection based on yield. A major challenge is to breed new varieties that are able to cope also with increasing environmental variability. These varieties could be appropriate for low input cultivation systems showing high degree of adaptation to different stress factors and high quality characteristics.

## Main chapter

The popularity of barley is due to its broad ecological adaptation, utility as a feed and food grain. As the majority of requirements for varieties in organic production system are distinctive from those in conventional farming the release of new varieties developed under organic growing conditions and suitable for organic agriculture is of arising interest in Latvia.

The differences of yield in relation to environmental changes are studied in the context of the dynamic yield stability and adaptability concepts. Adaptability can be described as the reaction of the genotype to environmental factors, often defined in terms of linear or quadratic functions but stability is often described as the variability of the genotype's performance around its environmental mean performance. There are two major approaches for studying G x E interaction to determine the adaptability of genotypes such as parametric and non-parametric (Mohammadi and Amri 2008). The most widely used parametric method developed to assess the adaptability and stability of varieties is the joint regression including regression coefficient ($b_1$) and variance of deviations from regression ($S^2d$) (Eberhart and Russell 1966). Non-parametric procedures are based on the ranks of genotypes in each environment, and the genotypes with similar ranking across environments are classified as stable (Fox et al. 1990). The objective of this research was to assess G x E interaction and determine adaptability and stability of spring barley genotypes for grain yield under different (organic and conventional) growing conditions. The effects of genotype and growing environment on variation of canopy height, coefficient of productive tillering, crude protein, 1000 kernel weight (TKW) and test weight (TW) were determined as well.

The field trials were conducted during three years (2010-2012) in the organic farming system in three locations –Stende (northwest part of Latvia), Priekuli (northeast part) and Vecauce (southern part) and in the conventional farming system in one location (Priekuli) (in total 12 different environments). The experimental design was a randomized complete block with plot size 5.0-6.5 m$^2$, and 3 replicates. Twenty one spring barley genotypes (10 varieties and 11 breeding lines) were chosen for this experiment. Genotypes with various origins, types of intensity and time of release were selected according to previous results on the basis of variability in traits that are important for organic agriculture such as growth habit, early vigor, plant morphology, and resistance to diseases.

ANOVA procedures were used for statistical data analysis. Three stability parameters were applied, including a linear regression coefficient ($b_1$) and the deviation from regression ($s^2d$) (Eberhart and Russell 1966) and ranking method (Fox et al. 1990) consisting of scoring the number of environments in which each genotype ranked in the top (TOP), middle (MID), and bottom (LOW) part of trial entries. A genotype that occurred mostly in the top third (high TOP-value) was considered a most widely adapted one. The coefficient of variation (CV) for traits except yield were determined for each genotype across growing locations in order to evaluate the relative environmental stability.

According to the results obtained, the mean yield across environments was ranging from 2.18 to 4.13 t ha$^{-1}$ ($LSD_{0.05}$=0.36). The analysis of variance for grain yield in all environments showed that the effect of environment and genotype, as well as the interaction between these two factors was significant ($p$ <0.001). Partitioning of sum of squares of environment variance component was 56%, while genotype effect was 16% and interaction 11%.

Coefficients of regression which varied from 0.42 to 1.30 gave the information about response of genotypes to favorable and unfavorable growing conditions. Out of all the tested genotypes, 13 genotypes produced greater yield than overall mean (3.41 t ha$^{-1}$) showing their above average mean performance. Regression coefficient of four genotypes ('Vienna', PR-4812, 'Rubiola' and 'Anni') was significantly greater than 1 ($b_1$=1.21-1.30) indicating adaptability to favorable environments.

Table 1: Mean yield (t ha$^{-1}$) and stability measures for barley genotypes across 12 environments (in rank order according to grand mean yield)

| Genotype | Origin | Mean | min-max | $b_1$ | $s^2d$ | TOP[1] | MID | LOW |
|---|---|---|---|---|---|---|---|---|
| Vienna | Austria | 4.13 | 1.98-5.80 | 1.30**> | 0.23 | 10 | 2 | 0 |
| PR-4814 | Priekuli/Latvia | 3.95 | 3.93-5.30 | 0.89** | 0.21 | 7 | 5 | 0 |
| PR-3605 | Priekuli/Latvia | 3.89 | 3.86-5.30 | 1.02** | 0.26 | 8 | 3 | 1 |
| PR-4812 | Priekuli/Latvia | 3.84 | 3.81-5.30 | 1.21**> | 0.08 | 9 | 3 | 0 |
| PR-4181 | Priekuli/Latvia | 3.77 | 3.77-5.00 | 0.96** | 0.10 | 9 | 3 | 0 |
| BZ14-12 | Priekuli/Latvia | 3.71 | 3.71-5.10 | 0.87** | 0.10 | 7 | 4 | 1 |
| Rubiola | Latvia | 3.67 | 3.66-5.20 | 1.20**> | 0.09 | 3 | 9 | 0 |
| Inari | Finland | 3.64 | 3.66-5.20 | 1.04** | 0.09 | 6 | 3 | 3 |
| Abava | Latvia | 3.60 | 3.62-5.10 | 0.84** | 0.08 | 5 | 6 | 1 |
| Rasa | Latvia | 3.50 | 3.59-4.80 | 1.05** | 0.13 | 5 | 4 | 3 |
| Anni | Estonia | 3.48 | 3.47-5.40 | 1.30**> | 0.07 | 3 | 7 | 2 |
| PR-4121 | Priekuli/Latvia | 3.46 | 3.44-4.70 | 1.02** | 0.16 | 3 | 5 | 4 |
| BZ14-99 | Priekuli/Latvia | 3.43 | 3.42-4.90 | 1.14** | 0.07 | 4 | 3 | 5 |
| PR-5145 | Priekuli/Latvia | 3.23 | 3.23-4.80 | 1.26** | 0.19 | 1 | 6 | 5 |
| Idumeja | Latvia | 3.13 | 3.12-4.50 | 0.82** | 0.21 | 1 | 5 | 6 |
| BZ12-83 | Priekuli/Latvia | 3.12 | 3.10-4.70 | 1.29**> | 0.07 | 0 | 5 | 7 |
| PR-4407 | Priekuli/Latvia | 3.10 | 3.09-4.70 | 0.98** | 0.21 | 1 | 4 | 7 |
| Dziugiai | Lithuania | 3.08 | 3.08-4.50 | 0.85** | 0.15 | 0 | 5 | 7 |
| Primus | Sweden | 2.99 | 2.98-4.60 | 1.03** | 0.10 | 0 | 1 | 11 |
| Annabell | Germany | 2.67 | 2.65-3.70 | 0.42 | 0.27 | 1 | 1 | 10 |
| PR-4825 | Priekuli/Latvia | 2.18 | 2.18-3.40 | 0.51* | 0.42 | 1 | 0 | 11 |
| Average | | 3.41 | | | | | | |
| $LSD_{0.05}$ | | 0.36 | | | | | | |

*significant at P<0.05 and **significant at P<0.01; > the slope of the regression is significantly greater than 1. [1] the number of environments in which each genotype ranked in the top (TOP), middle (MID), and bottom (LOW) part of trial entries

By the ranking method there was a possibility to obtain additional information about peculiarities of adaptability for a particular genotype in relation to specific environments. The most productive variety 'Vienna' (short straw, planophyle growth habit, comparatively low early vigour) was in the top of ranking in 10 out of 12 environments showing a great deal of adaptability. According to regression analysis genotypes with wide adaptability were PR-3605, PR-4181, 'Inari', 'Rasa' and 'PR-4121' ($b_1$=0.96-1.05). However, line PR-3605 with heightened mean grain yield had a relatively large deviation from the regression ($s^2d$=0.26) indicating less stability.

More suitable to relatively lower yielding environments were genotypes PR-4814, BZ14-12 and 'Abava' ($b_1$=0.84-0.89).

From these genotypes the highest grain yield across environments provided breeding line PR-4814. This line around 40% of cases was in the middle of the ranking, and was characterized by good early vigour and soil shading capabilities. This line had one of the largest canopy heights at early stem elongation stage (Zadoks GS 31-32) in combination with slightly planophyle growth habit and comparatively large coefficient of productive tillering. Line PR-4181 had a good combination of yield (3.77 t ha$^{-1}$) and stability as it had b-value close to one ($b_1$=0.96) and a small deviation from regression ($s^2di$=0.10).

Canopy height at early stem elongation stage was affected significantly by genotype and environmental conditions (p<0.01, partitioning of sum of squares 42 and 49 %, respectively). The average environmental mean value ranged from 18.1 cm to 34.6 cm. The highest mean values of canopy height had the variety 'Dziugiai' (32.8 cm) and breeding lines BZ14-12, PR-3605, PR-4812, PR-4814 (30.4-31.9 cm). The results showed a significant environment (47%) and genotype effect (22%) on productive tillering capacity. Maximum value of tillering coefficient had short straw varieties with planophyle growth habit 'Anni' and 'Vienna' with overall variation of this trait between genotypes from 1.2 to 1.7. Highly significant effect (p<0.0001) on variation of crude protein, TKW and TW was due to different growing conditions (54-75 %) and genotype (15-37 %). Overall the highest crude protein content accumulated varieties 'Dziugiai' (136.0 g kg$^{-1}$) and 'Primus' (132.2 g kg$^{-1}$).


**Acknowlegement**

This study was carried out in project co-financed by EU Social Fund „Development, improvement and implementation of environmentally friendly and sustainable crop breeding technologies", No 2009/0218/1DP/1.1.1.2.0/09/APIA/VIAA/099.


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# Performance and stability of new broccoli syntheric varieties in organic and low-input conditions

SIMONA CIANCALEONI S[1], LUOISA WINKLER[2], RENZO TORRICELLI[1] AND VALERIA NEGRI[1]

[1]Dip. Scienze Agrarie, Alimetari e Ambientali, Università degli Studi di Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy, simona.ciancaleoni@gmail.com, renzo.torricelli@unipg.it, valeria.negri@unipg.it
[2]Organic Research Centre, UK, Wakelyns Agroforestry, Fressingfield, IP21 5SD, UK, research@organicresearchcentre.com

**Key words:** Synthetic varieties, landrace, GxE interaction, stability

**Summary:** Organic (OA) and low-input (LI) farming rely on genotypes with high adaptability that maintain good performance over a broad range of agronomic and environmental conditions. Two synthetic varieties of *Brassica oleracea* var. *italica* Plenck. (broccoli) were developed from a landrace. Their performance and stability under LI and OA farming conditions were then assessed and compared to a F1 hybrid variety. Identical experiments were carried out over a period of three years in three locations in Italy and one in UK having different management and pedo-climatic conditions. Initially, an analysis of variance, carried out using a linear mixed model (LMM), with "Genotype" ("G") and "Location" ("L") as fixed factors and "Year" ("Y") as a random factor, showed that the "Genotype" effect was significant for, head number (HN), plant diameter (PD), plant vigour (PV) and plant height (PH). The "L" effect was significant for PD and PV. "GxL" interaction was significant for HN, PV and for yield (YLD). To obtain a better understanding of entry performances across years and locations, each location - year combination was considered as "Environment" and the Additive Main Effects and Multiplicative Interaction (AMMI) analysis was used to dissect the "GxE" interaction. Synthetic varieties had good performances and always had a higher stability than the F1 hybrid. The data discussed in this study suggest that heterogeneous varieties developed from adapted materials are suitable for OA and LI because of their stability.

## Introduction

Organic (OA) and low-input (LI) farming should rely on genotypes with high adaptability that are able to maintain good performances in a broad range of agronomic and environmental conditions. In allogamous species, synthetic varieties are populations characterised by heterogeneity which should give them greater plasticity, that, in turn, would allow them to better adapt to biotic and abiotic stress and to the non-homogeneous management conditions where OA and LI are practiced. Two synthetic varieties of *Brassica oleracea* L. var. *italica* Plenck (broccoli) (Syn_4C and Syn_8C), that are based on a different number of components, were developed from a landrace and then they were assessed under LI and OA farming conditions in order to evaluate their performances and stability, in comparison to a hybrid variety.

## Materials and Methods

*Field trials and characterisation*

The experimentation was carried out in two organic site: Perugia (Umbria region) (PG-OA) and United Kingdom (UK-OA) and in two low input site: Perugia and Grosseto (Tuscany) (PG-LI and GR-LI). The same identical plan, a randomized block design with four replications comprising 10 plants per entry per replication, was used in each trial. The entries under study were: Syn1_4C, Syn1_8C, the original landrace (LR) and the hybrid variety Santee (Figure 1). Sixteen morpho-physiological traits were recorded for each plant on all entries.

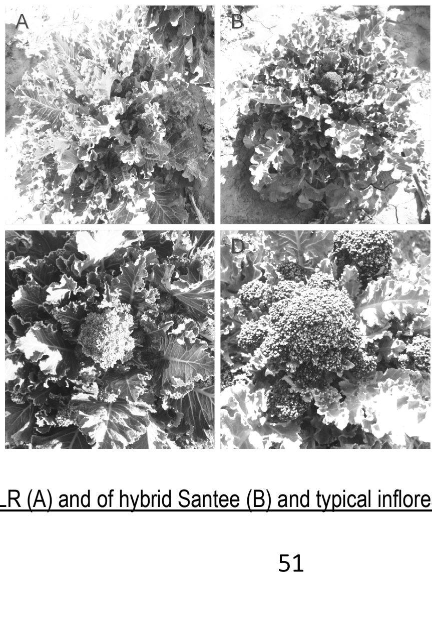


Figure 1. Typical plant of LR (A) and of hybrid Santee (B) and typical inflorescence of LR (C) and of hybrid Santee (D)

*Data analysis*

To determine the significance of the sources of variation, the recorded data were processed by analysis of variance (ANOVA) using a linear mixed model (LMM), where an individual trait value $T_{ijzk}$ of the levels i of the fixed effect “Genotype” (G), *j* of the fixed effect “Location” (L), *z* of the random effect “Year” (Y) and *k* of the random effect “block” (B), is:

$$T_{ijzk}=m + G_{ijzk} + L_{ijzk} + Y_{ijzk}+ B(LY)_{ijzk} +(LY)_{ijzk} + (GL)_{ijzk} + (GY)_{ijzk} + (GLY))_{ijzk} + e_{ijzk}$$

where m is the grand mean and $e_{ijkz}$ is the experimental error.

For traits with significant GxL interaction, the AMMI (Additive Main effects and Multiplicative Interaction) analysis was used. To obtain a better understanding of performance of genotypes $(G)_i$ across years and locations, each location - year combination was considered as “Environment” $(E)_j$, using the following ANOVA model:

$$T_{ijzk}=m + G_{ijzk} + E_{ijzk} + B(E)_{ijzk} +(E)_{ijzk}+ (GE)_{ijzk} + e_{ijzk}.$$

The “GxE” effect was then partitioned according to the AMMI analysis.

**Results**

The ANOVA (Table 2) showed that the effect of genotype was significant for HNRadQ (i.e.the transformation into square root of HN), AHW, PD, PH and PV. The environment effect was significant for PD and PV. GxE interaction was significant for HNRadQ, HW, AHW, PV and for YLD. The AMMI biplot for YLD (Figure 2) showed that the genetically heterogeneous varieties (synthetic varieties and LR) were more stable than the genetically uniform hybrid and they are the best performing in OA. This can be due to their adaptation to the pedo-climatic conditions of Central Italy, their intrinsic diversity or a combination of these factors.

Table 2. “Linear mixed model analysis of variance for one landrace, two synthetic varieties and one hybrid variety grown in 2010/2011, 2011/2012 and 2012/2013 in four different locations (PG-OA, PG-LI, GR-LI and UK-LI). $^{**}P\leq0.01$, $^{*}P\leq0.05$

| Effects | | HNRadQ | HW | AHW | YLD | PH | PD | PV |
|---|---|---|---|---|---|---|---|---|
| Means Squares for fixed effetcs | | | | | | | | |
| | Df | | | | | | | |
| Genotype (G) | 3 | 33.4** | 21227 | 217.6* | 37238 | 1162.5** | 4109.3** | 86.2** |
| Location (L) | 3 | 3.2 | 38185 | 66.7 | 52776 | 146 | 1722.9** | 8.6* |
| GxL | 9 | 43.9* | 91964** | 124.7** | 112472** | 84.3 | 95.4 | 12.7** |
| Variance components for random effects | | | | | | | | |
| Year (Y) | | 0.55 | 0.00 | 0.00 | 0.00 | 65.94 | 6.14 | 0.16 |
| GxY | | 0.01 | 203.85 | 0.54 | 187.17 | 0.98 | 1.88 | 0.01 |
| LxY | | 0.60 | 14409.35 | 5.15 | 23271.30 | 108.18 | 87.36 | 1.14 |
| Block (LxY) | | 0.01 | 142.06 | 0.23 | 25.69 | 0.38 | 58.72 | 0.83 |
| GxLxY | | 0.00 | 442.18 | 1.02 | 866.79 | 3.25 | 0.17 | 0.08 |
| Residuals | | 1.61 | 14019.96 | 5.39 | 132.22 | 67.19 | 114.43 | 1.61 |

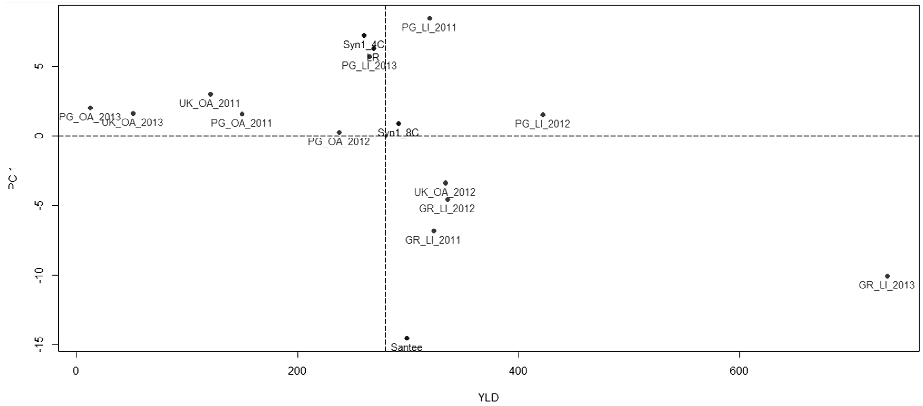


Figure 2. AMMI1 biplots showing the first principal axis of interaction (PC1) versus mean yield for YLD

**Conclusion**

To the best of our knowledge this is the first reported evaluation of the performance and stability of different types of broccoli varieties under different agronomic systems. Sustainable agriculture requires stabile genotypes over time in order to overcome biotic and abiotic stresses and, eventually, sub-optimal agronomic conditions. The data presented in this study suggest that heterogeneous varieties such as synthetics, due to their stability, are the best materials for OA and LI. They also can only support the general opinion that in order to breed for OA and LI, it is necessary to start from adapted materials.

Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

# A crowdsourcing approach to detect farmers' preferences

## A case study from Ethiopia for adapting to climate change

CARLO FADDA[4], CHIARA MANCINI[1,4] DEJENE KASSAHUN MENGISTU[1,2], YOSEF G. KIDANE[1,3], M. ENRICO PÈ[1]

[1] Scuola Superiore Sant'Anna, Pisa, Italy, dejenekmh@gmail.com; marioenrico.pe@sssup.it
[2] Mekelle University, Makalè, Ethiopia
[3] Sirinka Agricultural Research Center, Sirinka, Ethiopia, yosefgk@yahoo.com
[4] Bioversity International, Nairobi, Kenya, www.bioversityinternational.org, cfadda@cgiar.org, c.mancini@cgiar.org

**Key words:** durum wheat, farmers' participatory selection, climate change, Ethiopia, crowdsourcing

**Summary:** Durum wheat is a strategic crop for food security and livelihood improvement of smallholder farmers in Ethiopia, yet is productivity is declining largely due to climate change. It is critical to identify accessions with adaptive traits to the changing climatic conditions. We identified 400 accessions of durum wheat and farmers identified the one that match their needs. We subsequently distributed a small amount of seeds of the most preferred ones using a crowdsourcing approach. From feedback received from farmers on performance under their growing conditions we were able to identify the ones with highest potential. This form the basis of enhanced local seed systems.

### Background

Climate change is severely affecting production systems in the whole of Africa (IPCC, 2014), with a predicted yield loss in all major cereals crops across the continent. Ethiopia will also be affected, in particular there will be an increase in temperature in all four seasons and changes in rainfall patterns . In Ethiopia, however, direction of changes in rainfall patterns is very difficult to predict . One solution for long term adaptation, management of climate related risks (including increased unpredictability and uncertainties in the models) is to enhance the level of genetic diversity available to farmers, by introducing new traits into the production system. It is clear that business as usual is not enough. Unfortunately, despite the fact that this diversity often represents one of the few options available to smallholder farmers in marginal areas to adapt , significant parts of the original diversity have been eroded and cannot be found anymore in production. Durum wheat in Ethiopia is not an exception , despite the fact that durum wheat is one of the officially announced strategic crops for contributing to food security and livelihood improvement of smallholder farmers in Ethiopia. The IPCC (2014) recognizes that one of the key adaptive strategy for farmers in several parts of Africa is to shift to crops varieties that better suit the current climatic conditions , yet these better adapted varieties have to be identified and delivered quickly to the farmers. Here we present an approach to quickly deliver to farmers a selected number of preferred accessions of durum wheat using a crowdsourcing approach.

### Main chapter

In order to achieve the results of understanding the performances of accessions in different climatic conditions and to address farmers' needs, we followed a three-pronged approach: i) phenotypic and genotypic characterization of Ethiopian durum wheat landraces; ii) farmers' participatory selection; iii): distribution of selected seeds to a large number of farmers using a crowdsourcing approach. In addition, and in order to monitor performance based on The first two steps will be described very shortly as they are presented in Mengistu et al (2014). We will therefore focus here in the crowdsourcing methodology and preliminary results (Fig. 1 shows the process and the potential implication of the approach).

***1. Germplasm Characterization***. In 2012 we sowed 373 accessions of durum wheat obtained from the Ethiopian Biodiversity Institute (EBI) and collected from various regions in Ethiopia and 27 released varieties. Those 400 genotypes were grown in two consecutive years in two differently characterized agro-ecological zones of Northern Ethiopia: Hagereselam (2,590 meters above sea level), in the western part of the Tigray Region, and Geregera (2,890 masl), in the eastern part of the Amhara Region. Several landraces outperformed improved varieties, indicating that under changing conditions the improved varieties were not the best choice for farmers and that landraces could be used for immediate distribution to farmers and for breeding purposes. There was a clear incentive to test the material with farmers.

***2. Farmers' participatory selection.*** All the 400 varieties were evaluated in the two locations) by 30 local farmers (15 males and 15 females) for each location before harvest. Through focus group discussion with the farmers traits the farmers use to evaluate wheat varieties were identified and ranked. Earliness, tillering capacity, ear morphology and overall plot characteristics were evaluated, giving a score from 1 to 5. More than 200,000 data points were collected and allowed to relate farmers' preference with agromorphological traits. Forty landraces were selected on the basis of metric measurements and farmers' scoring, amplified and distributed to the farmers for further analysis.

***3. Crowdsourcing of selected varieties.*** In 2013 season we distributed 20 varieties among the best and one check, an improved variety, *Assasa,* very common in both areas to 200 farmers in 12 villages per site, covering an area of roughly 350 km$^2$. Farmers were given 3 varieties and the check, each farmer receiving a different combination of accessions and each variety being equally represented in the sample. In addition, in each village we included 2 i-buttons, measuring temperature and humidity every 3 hours throughout the growing season. This allowed to analyse the data at the light of some critical climatic parameters. At each village 12 enumerators are recruited for data collection and a mobile phone is provided for all to facilitate communication. Farmers are unaware of which varieties they are given and were trained on how to conduct the experiment and to provide information. In one of the site, farmers from each village formed groups with defined by-laws to better monitor and discuss the experiment.

Results show clear indication on farmers preferences, there is a confirmation that landraces were preferred to improved varieties for their multiple uses, we can customize preferences over a broad geographic area, we shift from a scientist based approach where farmers are asked to evaluate a plot in one location to a decentralised approach where farmers are providing scientific information to the scientists and are therefore part of the research, we have a better understanding of the criteria farmers use to select their preferred varieties: normally, a combination of traits are important to farmers, including straw and grain yield, drought tolerance, uniformity, long and dense spike.

**In conclusion:**

- this process has been very effective in disseminate seeds that match farmers needs in a very short amount of time as after 2 years already several hundred farmers have the potential to use better adapted material, with a large snowball effect potential.
- It shows the potential of landraces to provide immediate option for managing climate related risks and call for broader use of material conserved in gene banks.
- It indicates the need to strengthen local seed systems in order to manage these resources in a sustainable manner.
- It indicates how farmers can provide very valuable scientific information that can be translated into research as well as development outcome also in other areas of research.

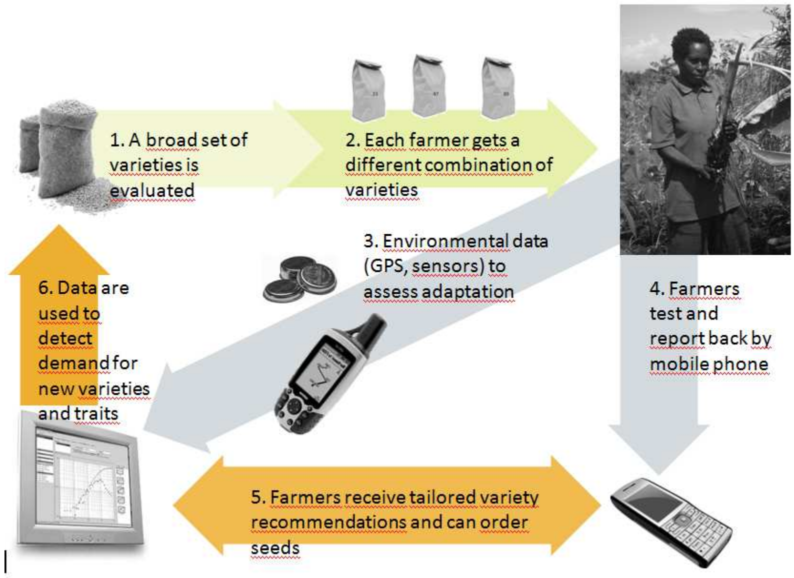


Figure 1 – Process of the crowdsourcing, potential development, and implication for seed system

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# Applications of crop competitive ability in winter oats (Avena sativa L.)

## Weed tolerance and suppressive ability in organic and low input systems.

NICHOLAS STANLEY FRADGLEY NICHOLAS FRADGLEY[1], HENRY CREISSEN[1], SALLY HOWLLET[1], HELEN PEARCE[1] & ROBBIRE GIRLING[1]

[1]The Organic Research Centre, UK, www.organicresearchcentre.com, nick.f@organicresearchcentre.com

**Key words:** Oats, weed suppression, weed tolerance, yield trade-offs.

**Summary:** Crop competition is a key component of an integrated approach to weed management. Variation in competitive ability and competitive traits have been identified in many other crop species, however little work has been done on oats. Trials were carried out over four years at one organic site with five husked and three naked oat varieties. Mid-season Leaf Area Index (LAI) and tillering ability were identified as weed suppressive traits using path analysis. Differences in weed tolerance were found among varieties. Trade-offs may exist between competitive traits and yield potential which could be optimised by limiting competitive traits later in the season. Selection of competitive traits with high heritability, whilst minimising yield penalties, could be applied in breeding programs to develop varieties with greater weed competitive ability.

Dependence on unsustainable herbicide inputs as well as degradation of soil and high energy consumption of mechanical weed control means that crop competitive ability is a key component of an integrated, ecological approach to weed management. Variation in competitive ability among crop cultivars and their associated weed suppressive traits have been identified in many crop species. However, there have been few studies examining this in the oat crop even though oats are widely considered to have superior competitive ability over other cereal crops. This poster outlines the key weed suppressive traits of oats as well as how these relate to weed tolerance and trade off against yield potential.

In the framework of the DEFRA funded project QUOATS (LK09124) a four year trial studied the performance of five husked and three naked oat varieties under organic conditions. Crop assessments were made throughout each season and weed populations were assessed in the spring and after harvest.

Weed levels had the greatest influence on crop yield over the four years. Results from path analysis suggest that traits involved in rapid early growth rates, such as establishment rates, tillering ability and Leaf Area Index (LAI) before panicle emergence, are most important for effective weed suppression. Significant differences in weed tolerance were found among varieties indicated by a differing rate of yield loss with increasing weed cover. Results suggest that in oats weed tolerance can be conferred by some suppressive traits. For example, varieties such as Brochan with a combination a high LAI and sufficient height suffer less of a yield loss when under high weed competition than varieties such as Gerald which has low LAI or Balado which is particularly short. Because of the counterproductive effects of later season competitive traits limiting the crop potential yield through intra-crop competition and resource allocation, characteristics such as LAI and vegetative growth should be enhanced early in the season during the critical weed control period but limited later in the season during the reproductive phase. The beneficial effect of weed suppression on crop yields would only be realised under significant weed levels. The heritability and consistency of expression of suppressive traits, as well as potential trade-offs with grain yield, would need to be considered to develop varieties with appropriate enhanced competitive ability in oat breeding programs aiming to maximise productivity and sustainability.

# The older the stronger

## Competition in Variety Mixtures of Spring Wheat

Samuel Knapp

Agroscope, Institute for Plant Production Sciences IPS, Reckenholzstrasse 191, 8046 Zürich, Switzerland, www.agroscope.admin.ch, samuel.knapp@agroscope.admin.ch

**Key words:** *Triticum aestivium*, variety mixture, competitive ability, intergenotypic competition

**Summary:** One way to deal with unpredictable growing conditions and pest pressure is to employ within crop diversity to achieve greater stability. One major question is how to design this diversity. In this study the yield performance of a historic set of spring wheat varieties in monoculture and mixtures has been assessed. It was found that competitive ability is often reversed to monoculture yield. Plant height was identified as a major mechanism for competitive strength. Progress in plant breeding for high monoculture yield has produced varieties that are smaller and of less competitive ability. The implications of this reverse relationship for plant breeding and the identification of varieties for mixtures are discussed.

### Background

Mixtures of varieties are expected to be more resistant towards plant diseases and produce more stable yields across environments and years than monoculture stands. However, yields of mixtures often deviate from the expected yield calculated from the monoculture yields of the components. Besides the competition against weeds, crop plants in a monoculture stand are only exposed to intragenotypic competition; whereas plants in a mixture of varieties are also exposed to the competition of other varieties – intergenotypic competition. This additional type of competition leads to a different performance of a variety in a mixture and thus to deviation of the mixture yield from the expected yield.
Modern varieties are selected for good performance under monoculture conditions and the choice of varieties for mixtures will rely on such varieties. Thus, the objective of this study was to assess the relation of monoculture performance and the competitive abiltiy in variety mixtures.

### Material and Methods

Eight Swiss spring wheat varieties from the last 30 years have been grown in monoculture and in 50:50 mixtures with either the oldest or the youngest variety. In the mixture treatments varieties were separated in alternating rows (**Erreur ! Source du renvoi introuvable.**). Plant density was 600 plants / m$^2$ and plots consisted of 6 rows with a distance of 17 cm and length of 2 m long. The trial was conducted at one site with 2 replicates. In the monoculture treatments final plant height was measured and grain yield of the components was assessed by harvesting each row separately. Competitive ability (CA) of a variety was calculated as the yield of a variety in the mixture divided by half of the yield in monoculture as it is assumed that without any interaction or competition effects the expected yield in the mixture would be half of the monoculture yield. ). A CA below 1 means that a variety has a lower yield in mixture than in monoculture and is thus a bad competitor.

Figure 1: Mixture plot where two varieties where grown in separate rows. Variety A in row 1, 3 and 5; variety B in row 2, 4 and 6

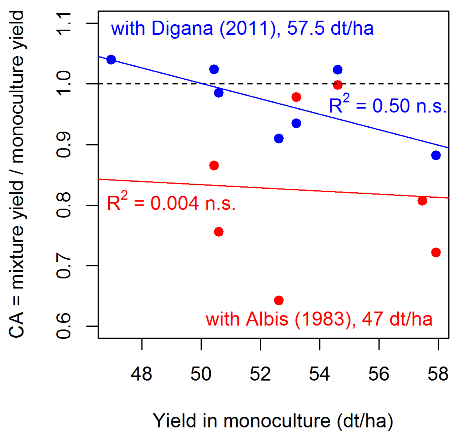


Figure 2: CA (CA) of seven varieties competing with the oldest variety, Albis, (red) and competing with the youngest variety, Digana, (blue) against the yield in monoculture stand

### Results

The yields of the varieties in mixture showed a CA below 1, except in three cases (**Erreur ! Source du renvoi introuvable.**There is a pronounced difference in CA between competing against variety Albis, which was released in 1983 and competing against variety Digana, which was released in 2011: the varieties could much better compete against Digana than against Albis (**Erreur ! Source du renvoi introuvable.**). When competing against Digana there is a negative - although not significant – relationship between the monoculture yield and the CA of a variety, whereas this relationship can not be discovered when competing against Albis.

Plant height of a variety showed to have an impact on the CA: taller plants were better competitors against both Albis and Digana (**Erreur ! Source du renvoi introuvable.**). The year of registration showed a negative relation to the CA when competing against Digana but not when grown with Albis (**Erreur ! Source du renvoi introuvable.**). Younger varieties were worse in competitive strength in mixture.
To summarize, in competition with the variety Digana, the following three parameters are related to greater CA: (1) lower monoculture yield, (2) greater plant height and (3) earlier year of registration.

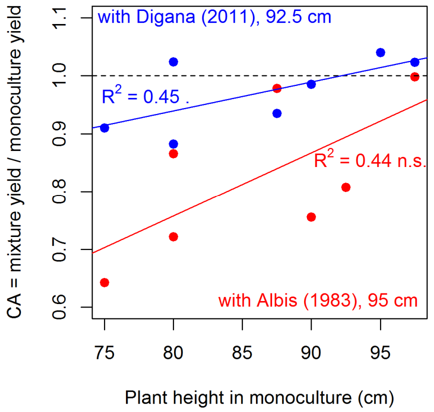


Figure 3: CA (CA) of seven varieties competing with the oldest variety, Albis, (red) and competing with the youngest variety, Digana, (blue) against plant height in monoculture stand ( . = sign. at p<0.01)

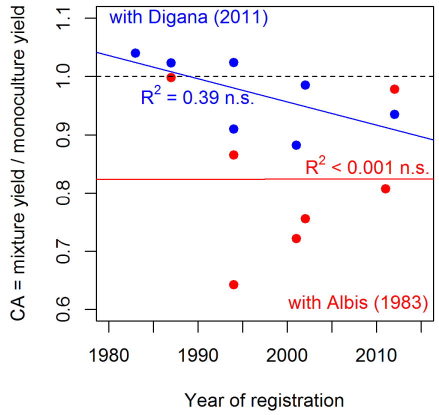


Figure 4: CA (CA) of seven varieties competing with the oldest variety, Albis, (red) and competing with the youngest variety, Digana, (blue) against the year of registration

## Discussion

With a perspective on breeding history, it can be concluded that progress in breeding for better monoculture yield has led to a decrease in intergenotypic CA. This could be due to the decrease in plant height, which has been shown here to have a strong impact on CA. Decrease in plant height is related to higher harvest index and thus less investment in vegetative growth. This can lead to greater yield in monoculture as more resources are left for generative growth and thus grain filling, which was proposed as a crop ideotype by Donald (1968). One implication of this negative relationship between monoculture and mixture performance is that in early screening steps in a breeding program the performance of lines in mixed stands (e.g. adjacent rows of different genotypes) can be reversed to their actual performance in a monoculture field (Goldringer et al., 1994).
However, in a competitive setting, which could be a mixture with other varieties or other species, or under strong weed pressure, this relationship can be reversed and investment in vegetative growth (great plant height or low harvest index) could pay off. The crucial trade-off will then be between the advantage of competitive strength versus the loss of resources through investment in vegetative growth. The threshold will depend on the amount of competition the crop will be exposed to.
One major obstacle in the design of variety mixture is the choice of the components. The fact that varieties with a higher CA yield better in a mixture than in monoculture does not necessarily justify that they are the best choice for well yielding mixtures as their increase in yield is often on the cost of the neighbouring variety. The reverse relationship of monoculture and mixture yield rather complicates the identification of components as the performance in a mixture is difficult to predict from merely monoculture performance. It could be suggested that for the design of variety mixtures varieties with similar height and thus similar CA should be selected in order to avoid suppression of weaker varieties. However, if superior performance - and particularly stability - of mixtures is due to compensation it could be of advantage that mixtures are composed of varieties of different height or CA (Creissen et al., 2013).
Evolution is based on natural selection and selects for strong competitors (Darwin, 1859). In sight of the reverse relationship of CA and monoculture yield, domestication and selection for harvestable population yield is thus detrimental to natural selection. Although natural selection for local adaptation, as it is the idea in “evolutionary plant breeding” (Döring et al., 2011), can produce a crop population which is adapted to local conditions but probably consists of strong competitors that invest too much resources in vegetative growth and competitive behaviour that are not available for grain filling and thus final yield (Denison, 2012).

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# Yield of cereals after legume crops in organic conditions

REINE KOPPEL, ANNE INGVER, ILMAR TAMM, ÜLLE TAMM, ILME TUPITS, ANTS BENDER, SIRJE TAMM, LEA NARITS

Estonian Crop Research Institute, Estonia; reine.koppel@etki.ee

**Key words:** leguminous pre-crop, cereal, grain yield, organic management

**Summary.** The aim of the trial was to diversify the selection of green manure leguminous crops. A yield trial was carried out in ECRI in 2013. There were clear differences in grain yield between spring and winter crops after annual and perennial legume species. All the leguminous pre-crops exceeded timothy in yield. The yields of spring cereals were lower after annual compared to perennial legumes. The best pre-crops for spring cereals were red and alsike clover (especially for barley and spring wheat) followed by lupine. The best pre-crop for winter cereals was sweet clover followed by annual clover species. The less favourable, opposite to the spring cereals, were red and alsike clover.

## Introduction

The area of organic cereals cultivation was ca 21,5 thousand ha (ca 7 % of total cultivation area) in 2013 in Estonia. About 33 % of oat, 32 % of rye, 3,5 % of spring wheat, 2,1% of barley and 1,7 % of winter wheat is cultivated as organic.
In organic cultivation lack of nitrogen may be problem to obtain high yield and quality of grain. Therefore selection of suitable pre-crop is of importance. Symbiotic nitrogen fixation by legumes is one of the primary sources of N in organic farming (Berry et al., 2002, Mäder et al., 2002). The most widespread pre-crop in organic cultivation in Estonia has traditionally been red clover. The aim of the trial was to diversify the selection of green manure leguminous crops and determine their influence to grain yield. A trial was carried out in Estonian Crop Research Institute in 2011–2013.

## Materials and Methods

Two varieties of each cereal crop were tested: barley (Grace, Maali), spring wheat (Manu, Uffo), oat (Ivory, Kalle), winter rye (Sangaste, Elvi), winter wheat (Ada, Skagen). The 5m² plots were sown in three replications after six different leguminous pre-crops in organic conditions. Pre-crops were lupine, red clover, alsike clover, sweet clover, Alexandria clover, crimson clover and timothy as standard.

For winter crops the overwintering conditions (2012/2013) were quite unfavourable due to long winter and deep snow cover. The weather conditions in 2013 were quite favourable for yield. The most important characteristic – grain yield was analysed in this paper. ANOVA was used for statistical data management.

## Results

The average yield level of cereals was quite high after leguminous pre-crops in the trial in 2013. All the leguminous pre-crops exceeded timothy (control variant) in yield (Figure 1).

Surplus compared to timothy was 1030–3940 kg/ha. Effect of pre-crop to winter rye was the highest as average yield of timothy pre-crop plots were the lowest. Clear negative effect of timothy to rye was not determined after one-year results.

Barley showed best yield after red clover (5850 kg/ha), alsike clover (5790 kg/ha) and lupine (5710 kg/ha) (Table 1). The lowest yields of barley were obtained after annual clovers.
Red and alsike clover turned out to be the best pre-crops also for spring wheat, yielding respectively 5530 and 5630 kg/ha. The lowest yields of spring wheat were obtained after annual clovers and sweet clover.
Oat showed somewhat lower average yield among spring cereals as it suffered the most by the comparatively dry weather conditions. Different from barley and spring wheat the yields of oat after annual pre-crops were not considerably lower to compare the yields after perennial clovers.

Winter rye showed the highest yields after Alexandria clover (4865 kg/ha) and sweet clover (4380 kg/ha). The yield was good also after crimson clover (4117 kg/ha). Opposite from the spring cereals, winter rye had the lowest effect of legume pre-crop to the yield after red and alsike clover. Overwintering of rye was the lowest after red clover.

Winter wheat showed good results after sweet clover (6140 kg/ha) and annual clovers similarly to winter rye. The lowest yield levels of winter wheat were after red and alsike clover as it was in winter rye.

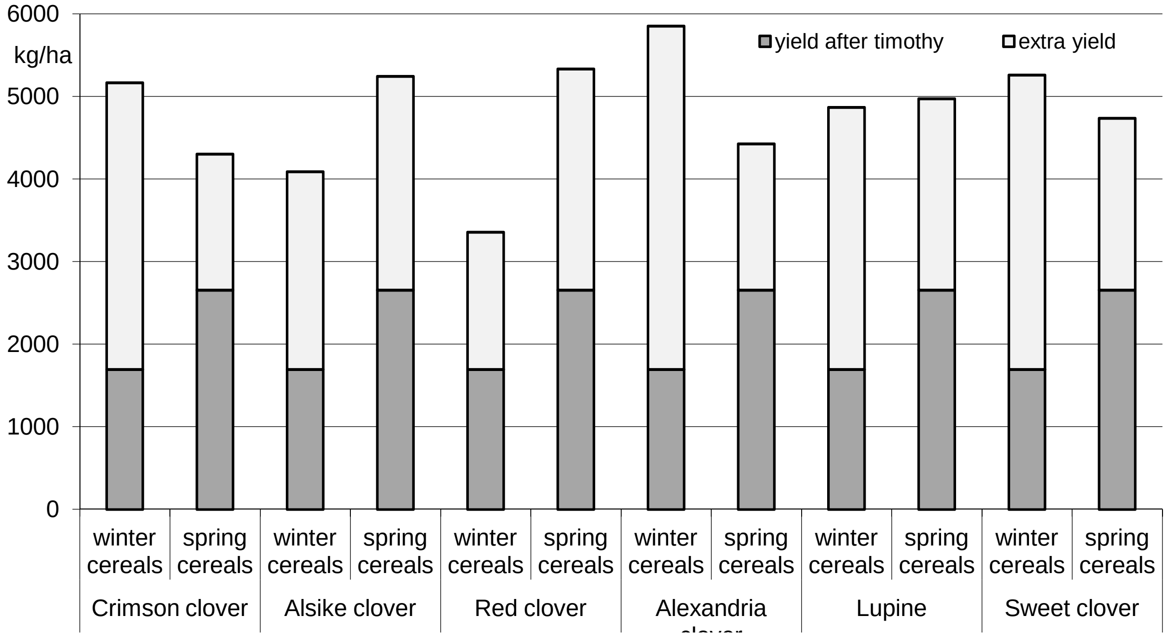


FIGURE 1. AVERAGE YIELD OF SPRING AND WINTER CEREALS AFTER TIMOTHY AND EXTRA YIELD AFTER LEGUME CROPS.

Table 1. Yield of cereals after leguminous pre-crops at Estonian Crop Research Institute in 2013

| | Barley | | Spring wheat | | Oat | | Winter rye | | Winter wheat | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kg/ha | +/- timothy | kg/ha | +/- timothy | kg/ha | +/- timothy | kg/ha | +/- timothy | kg/ha | +/- timothy |
| Crimson clover | 4130 | 1610 | 4430 | 1865 | 4270 | 1380 | 4117 | 3193 | 6216 | 3751 |
| Alsike clover | 5790 | 3270 | 5630 | 3065 | 4320 | 1430 | 3817 | 2893 | 4362 | 1897 |
| Red clover | 5850 | 3330 | 5530 | 2965 | 4580 | 1690 | 3601 | 2677 | 3494 | 1029 |
| Alexandria clover | 4900 | 2380 | 4120 | 1555 | 4210 | 1320 | 4865 | 3941 | 5701 | 3236 |
| Lupine | 5710 | 3190 | 4750 | 2185 | 4450 | 1560 | 4023 | 3099 | 5712 | 3247 |
| Sweet clover | 5430 | 2910 | 4420 | 1855 | 4360 | 1470 | 4380 | 3456 | 6140 | 3675 |
| Timothy | 2520 | | 2565 | | 2890 | | 924 | | 2465 | |
| PD95% | 180 | | 350 | | 220 | | 497 | | 339 | |

**Conclusions**

The highest grain yields were obtained after red and alsike clover for spring cereals and after sweet clover and annual clovers for winter cereals.

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# Perennial legumes in cereal rich rotations increase productivity in low input systems

## The effect of legume cropping strategy on subsequent winter wheat yields

PETRA LACHOUANI[1], PER AMBUS[1], RENE GISLUM[2], HENRIK HAUGGAARD-NIELSEN[1]*

[1] Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU), Kgs. Lyngby, Denmark, www.eco.kt.dtu.dk, *hnie@kt.dtu.dk

[2] Department of Agroecology, Aarhus University, 4200 Slagelse, Denmark, www.dca.au.dk

**Key words:** biological nitrogen (N) fixation (BNF), N cycle, N management, sustainable agriculture

**Summary:** Due to the ability to fix atmospheric $N_2$ biologically perennial legumes can be very valuable for low-input agricultural systems requiring reduced N inputs and N for subsequent crops. The highest cumulative aboveground $N_2$ fixation was observed for the legume sole crops with up to 300 kg N ha$^{-1}$ in aboveground red clover biomass. In addition, an additional soil N pool was reached primarily in intercropping systems without N application. Subsequent winter wheat yields showed no significant differences between high and low fertilized plots. It was concluded that legumes can optimize cereal rich rotations lowering external N input needs without compromising yield levels safeguarding farmers earnings and mitigate climate change.

### Background

Legumes have been used in agriculture for hundreds of years to overcome N limitations to crop growth, either directly (grain legumes, forage legumes) and/or by providing N for subsequent non-fixing crops (green manure). However, with the discovery of the Haber-Bosch process, artificial N fertilizers became available and revolutionized agriculture radically declining the use of legumes. The available amount of fossil hydrocarbons is not infinite though and climate change is creating a critical necessity of reducing their use. Various strategies have been proposed to re-introduce legumes into modern agriculture such as (i) intercropping legumes with cereals, (ii) including perennials in legume-based pastures, (iii) establishing catch crops including legumes, among several others. Intercropping integrates leguminous $N_2$ fixation capacity together with niche differentiation and complementary interspecific competitive interactions between the species often leading to increased yields compared to sole cropping (Hauggaard-Nielsen et al., 2009). Another advantage is the in-field diversification regarded as a “farmer insurance”, with one crop possibly doing better under certain biotic or abiotic stresses in specific growing seasons (like drier years) and vice versa for the other (e.g. more competitive in wetter years) and therefor optimizing yield independent on yearly variations. Catch crops have the advantage of taking up residual soil N left in the soil together with other functions like weed management or decreased soil erosion while transferring N to subsequent crops. In addition, perennial systems can produce high annual yields of green biomass for feed and bioenergy purposes while increasing the soil organic carbon pools (Müller-Stöver et al., 2012).
The aim of the present study was to investigate the effects of different perennial cropping strategies and fertilizer levels on N use and subsequent winter wheat yields.

### Material and methods

A perennial experiment was conducted in two subsequent cropping sequences at the Aarhus University Research Center in Flakkebjerg (55°19'N, 11°24'E), Denmark, respectively. Barley (*Hordeum vulgare* L. cv. Quencha) was undersown with different perennial grass-clover mixtures including ryegrass (*Lolium perenne* L.), cock’s foot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* L.) and the legumes white clover (*Trifolium repens* L.), red clover (*Trifolium pretense* L.) and alfalfa (*Medicago sativa* L.). The experimental design was a fully randomized four replicate block design. In the subsequent season (sward season) the perennials received 3 fertilizer dressings after each cut corresponding either to the conventionally recommended amounts for grass in Denmark (high) or a third of this (low).

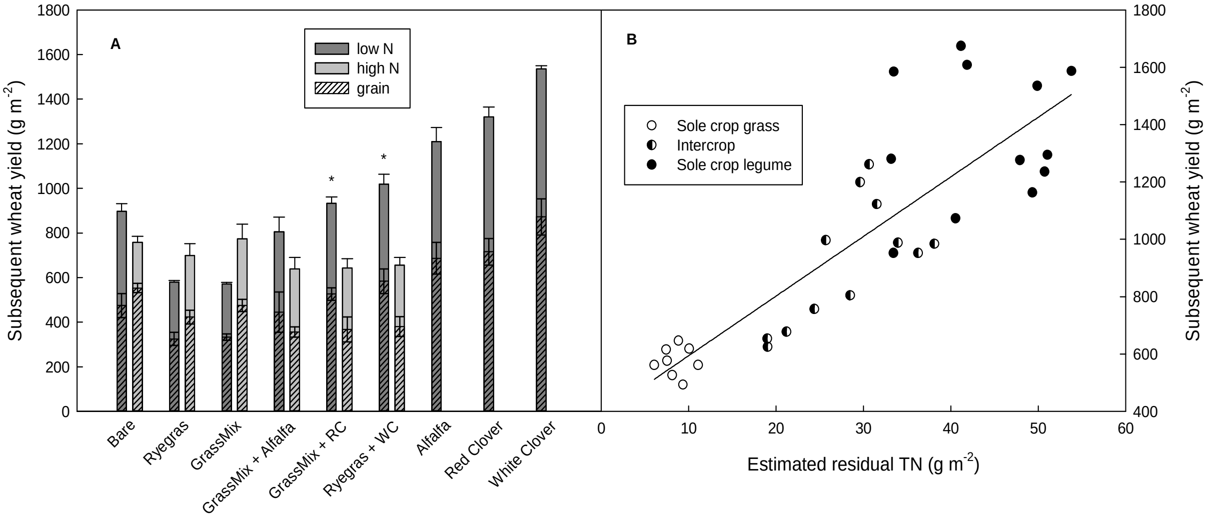
**Table 1: Fertilizer amounts (g m$^{-2}$) applied after each cut**

| NPK | Treatment | High | | | | Low | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | April | June | July | Total | April | June | July | Total |
| N | Sole grass | 163 | 9.8 | 6.5 | 32.6 | 4.5 | 2.7 | 1.8 | 9.0 |
| | Intercrop | 11.8 | 7.1 | 4.7 | 23.6 | 4.5 | 2.7 | 1.8 | 9.0 |
| | Sole legume | - | - | - | - | - | - | - | - |
| P/K | Sole grass | 3.4/21.7 | - | - | 3.4/21.7 | 3.6/28.1 | - | - | 3.6/28.1 |
| | Intercrop | 3.2/19.2 | - | - | 3.2/19.2 | 3.6/28.1 | - | - | 3.6/28.1 |
| | Sole legume | - | - | - | - | - | - | - | - |

## Results

The perennial treatments in the high fertilizer section showed a total aboveground N content equivalent to the amount of N fertilizer applied (Table 1). However, in the low fertilizer section, the perennials were able to acquire significantly more N than supplied by N fertilization; intercrops significantly more than the sole crop grasses. The sole crop legumes did not only exhibit the highest fixed N values, but were also capable at mobilizing significant amounts of soil N. The uptake took place mainly in the grass fraction of the intercrop, while legume soil N uptake remained low, except for the legume sole crops (data not shown). Fixation rates in the low fertilizer sections were highest and significantly different from the sole crop situation (data not shown). Cumulative $N_2$-fixation was highest in the sole crop legumes with significant less fixation, when intercropped with grass. In the intercrops the legumes showed a low N contribution to the total aboveground accumulation (<20%); with red (~40%) and white clover (~30%) as exemptions in the low fertilizer section.

Figure 1. Subsequent winter wheat yield following perennial residue soil incorporation (A) and (B) total wheat yield plotted against residual total N incorporated in autumn ($r^2$=0.72). Values are the mean (n=8) ±SE. Asterisk mark significant differences between high and low fertilizer yield in total yield.




Total subsequent winter wheat yields was more or less independent of fertilizer and previous crop, except for red clover and white clover intercrops (Figure 1a). Subsequent wheat yields were strongly correlated with the perennial residual total N (TN) incorporated in autumn (Figure 1b).

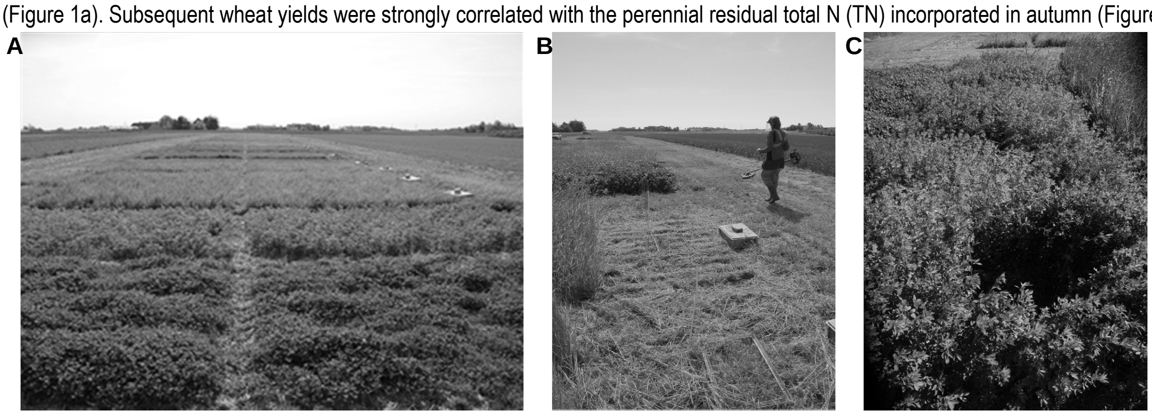



Figure 2. Picture A illustrate the fully randomized four replicate block design (plots measured 2.5m x 10m); picture B the subsequent cuts conducted throughout the "sward season"; picture C a close up on a ½$m^2$ hand cut in a sole crop alfalfa plot.

## Conclusion

The present study shows how a low N input system is able to compete with a highly N fertilized conventional system. Thus, productivity in low N input systems can reach satisfactory levels compared to high N input systems using leguminous $N_2$-fixation ability and catch crop effects.


## Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM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# Perennial grass-clover intercrops and total greenhouse gas emissions using LCA

## Effects of fertilization level on $N_2$-fixation, $N_2O$ emissions and N cycling

PETRA LACHOUANI[1], MARIE TRYDEMAN KNUDSEN[2], PER AMBUS[1], RENE GISLUM[2],HENRIK HAUGGAARD-NIELSEN[1]*

[1]Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU), Kgs. Lyngby, Denmark, www.eco.kt.dtu.dk, *hnie@kt.dtu.dk

[2]Department of Agroecology, Aarhus University, 4200 Slagelse, Denmark, www.dca.au.dk

**Key words:** biological nitrogen (N) fixation (BNF), N2O emissions, greenhouse gasses, LCA, sustainable agriculture

**Summary:** While the use of legumes can result in substantial N inputs into the cropping system by BNF, only a fraction of the legume N is generally recovered by subsequent crops. Using actual field data inclusion of more legume perennials into the cropping system are evaluated using LCA based assessment of different cropping strategies with regards to GHG emissions. LCA results showed that in terms of total GHG emissions in the low N input systems a clear advantage with 30-50% reduction was achieved compared to the high N input system per unit harvested crop using conservative calculations based on IPCC guidelines. Low N systems including perennial legumes are recommended for sustainable agriculture.

### Background

Several studies have observed how the amounts of legume N grown during the previous season have a beneficial effect on the subsequent crop yields due to improved N fertility (e.g. Jensen et al. 2012). In Denmark the tradition is to undersow the perennials in spring cereals offering the flexibility to either improve N scavenging when soil N is abundant, or increase growth and N accumulation when soil N is limited by BNF securing a dynamic and generally high pasture sink capacity across the field (Holdensen et al. 2007). However, only a fraction of the legume N is generally recovered by subsequent crops averaging <30% potentially increasing the risk for $N_2O$ emissions from soil known as a result of inefficiencies in crop recovery of fertilizer and other sources of N (Jensen et al. 2012). $N_2O$ is a very potent greenhouse gas (GHG) and small differences in $N_2O$ can have significant influence on the overall cropping system climate change impact. In the present study Life Cycle Assessment (LCA) will be used as the internationally widely accepted method to estimate the global warming potential or carbon footprint of a product along its life cycle (e.g. Knudsen et al. 2014). The objective of this study was to use actual field data produced on both N accumulation and $N_2O$ emissions for a LCA based assessment of the different cropping systems (treatments) with regards to N losses and total GHG emissions.

### Material and methods

A perennial experiment was conducted in two subsequent cropping sequences at the Aarhus University Research Center in Flakkebjerg (55°19'N, 11°24'E), Denmark, respectively. Barley (*Hordeum vulgare* L. cv. Quencha) was undersown with different perennial grass-clover mixtures including ryegrass (*Lolium perenne* L.) and the legumes white clover (*Trifolium repens* L.*)* and red clover (*Trifolium pretense* L.). The experimental design was a fully randomized four replicate block design. In the subsequent season (sward season) the perennials received 3 fertilizer dressings after each cut corresponding either to the conventionally recommended amounts for grass in Denmark (high; total 325 kg N $ha^{-1}$) or about a third of this (low; 90 kg N $ha^{-1}$). $N_2O$ emissions were measured in manual chambers (Figure 1) in campaigns during the growing season after fertilizer application and intensively after sward incorporation

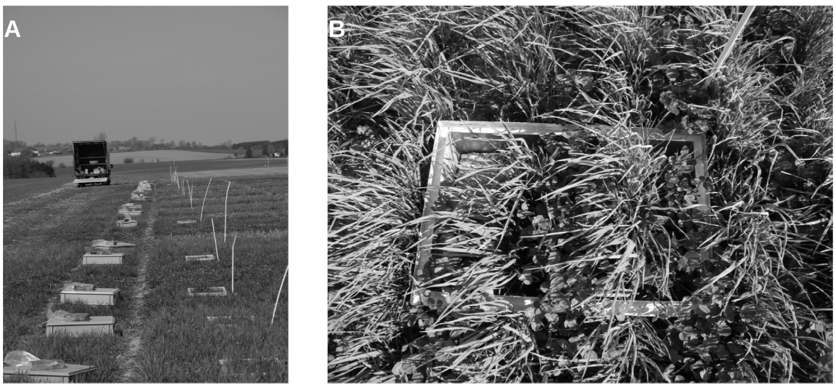


Figure 1. Picture A illustrate the experimental design (plots measured 2.5m x 10m) including the manual chambers for $N_2O$ monitoring in each individual plot; picture B a close up on the inserted metal frames defining the area for measurements.

## Results

The sole cropped ryegrass in the high fertilizer sections yielded the most, as expected. However, without considering specific chemical quality differences it was possible to produce about 15 t red clover DM $ha^{-1}$ and on the same time save about 350 kg mineral N fertilizer $ha^{-1}$ (data not shown). In addition, potential improvement in soil N fertility is introduced by red clover for the benefit of following crops. Following the fertilizer regimes and residual soil incorporation $N_2O$ emissions were highest in the treatments containing legumes with a linear increase in $N_2O$ emissions with residual N content (Figure 2).

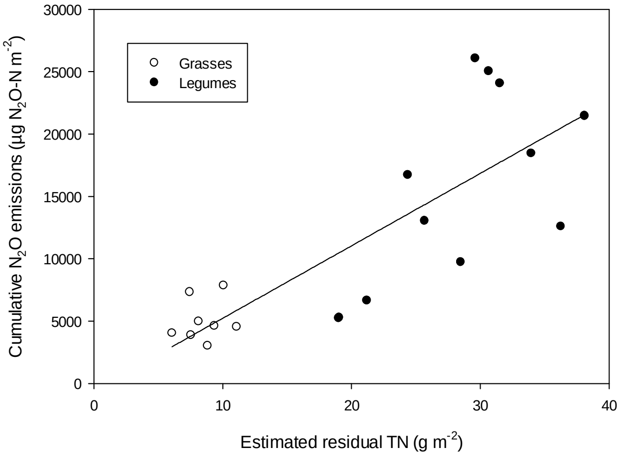


Figure 2. Cumulative N2O emissions after incorporation of the residual sward versus estimated total nitrogen (TN) content of the incorporated sward. Plotted line is a linear function (r2=0.656).

The LCA calculations showed that total greenhouse gas (GHG) emissions were higher for the high N input system (Table 1), primarily caused by the fertilizer production emissions and $N_2O$ emissions. In the sole crop grasses the difference is somewhat reduced due to increased root soil C storage in the high N input systems. The sole crop legumes, which were only included in the low N input system show the lowest total GHG emissions. Total GHG emissions as CO2 eq. $t^{-1}$ DM harvested crop are between 35 and up to 120% lower with the low N input system than with the conventional high input system. Net GHG sequestration was obtained in the sole crop legume systems and very low GHG emission for the low N input system in general.

Table 1: Carbon footprint (kg $CO_2$ eq. $t^{-1}$ dry matter harvested crop) for high and low nitrogen (N) input systems calculated using Life Cycle Assessment (LCA) based on IPCC recommendations, a 50:50 shoot-to-root biomass and N ratio distribution and measured $N_2O$ emissions. Difference in percentage (%) compare high (100%) and low N input systems relatively. IC = intercrop, SC = sole crop

| Input | Treatment | kg $CO_2$ eq. $t^{-1}$ DM | | | | |
|---|---|---|---|---|---|---|
| | | Fertilizer | Diesel | $N_2O$ | Soil C | Total GHG |
| High | Ryegrass | 137 | 8 | 15 | -109 | 50 |
| | Red clover IC | 138 | 11 | 18 | -91 | 76 |
| | White clover IC | 129 | 10 | 19 | -93 | 65 |
| Low | Ryegrass | 72 | 12 | 16 | -79 | 21 |
| | Red clover IC | 83 | 14 | 19 | -65 | 50 |
| | White clover IC | 68 | 12 | 18 | -83 | 15 |
| | Red clover SC | 62 | 11 | 18 | -90 | 0 |
| | White clover SC | 13 | 10 | 20 | -96 | -53 |
| % difference | Ryegrass | -47 | +50 | +7 | -28 | -58 |
| | Red clover IC | -40 | +27 | +6 | -29 | -34 |
| | White clover IC | -47 | +20 | -5 | -11 | -77 |

## Conclusion

In terms of GHG emissions the low N input systems show a clear advantage (30-50% reduction) over the high N input systems even with conservative calculations. Productivity in low N input systems can reach satisfactory levels compared to high N input and due to the clear benefits in terms of reduced GHG emissions such cropping systems needs more attention trying to reach the goal for more sustainable agriculture.


## Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM


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# Synthetic breeding scheme of durum wheat landraces for the development of cultivars with high yield performance under organic farming

ATHANASIOS MAVROMATIS[1], PARASKEVI MANTA[2], KOSTAS KOUTIS[3], VENIA SVINTRIDOU[4], DIMITRIOS VLACHOSTERGIOS[5], APOSTOLOS FYNTANIS[1]

[1] Aristotle University of Thessaloniki, Dept. of Field Crops & Ecology, amavromat@auth.gr
[2] University of Thessaly, Dept. of Plant Science & Rural Environment, Volos
[3] Aegilops, NGO, Lechonia Magnesias, Volos
[4] CCPMF Rodopis, Ministry of Agriculture , Komotini
[5] Fodder Crops & Pastures, Inst. Hellenic Agricultural Organization, Larissa

Landraces are local plant populations with genetic variability, which over time have incorporated desirable genes associated with resilience and adaptation to their creating environments. Their genome originated as an interaction of natural selection and non-systematic improvement intervention from the growers (Gepts, 2006).

Into this work, a small collection of old durum wheat landraces was used which has been maintained in Gene Banks of Gatersleben (Germany) and USDA.

The purpose of this study was focused on:

(i) characterization of these landraces according to morphological, agronomical, seed quality and technological traits
(ii) separation of interpopulation ecotypes
(iii) application of an intervarietal breeding program under organic growing environment
(iv)

Field experiments were established for two growing seasons (2010-2012) in the organic experimental field of the University of Thessaly and in the central farm of Fodder Crops & Pastures Inst. in Larisa (latitude 39o36'N, longitude 22o25'E) during the growing season 2012-2013.

Firstly, a honeycomb selection scheme (R-13) (Fasoulas et al., 1995) based on individual plant selection was applied to distinguish the most high yielding plants with better technological traits and also to determine the interpopulation ecotypes This scheme consists on, under assay conditions of the organic environment (Koutis et al, 2012). A total of 12 durum wheat lines were selected and cultured in the next season, at a CRB experimental design with a simultaneous application of (MA) method for evaluation both in conventional and organic conditions. Negative mass selection was applied to maintain or even increase the yield potential while an evaluation, in comparison to commercial durum wheat varieties (Mexicali, Meridiano), was performed. During the experiment, measurements were made (Murphy et al., 2008) concerning phenotypic uniformity, tillering, stage and time of maturation, plant height, number of ears and grains per ear and also the total yield. Furthermore, analysis on seed quality and technological traits were applied for all traditional and commercial cultivars, tested. At the third growing season, the most promising selective lines (B12 & B26 ) were cultured and evaluated in the organic farm of Fodder Crops & Pastures Inst. under a RCB experimental design with three replications in comparison to commercial varieties (Kordo, Simmeto, Meridiano).

The results of the experiments showed that through the application of this synthetic breeding scheme, it was possible to select durum wheat lines (B12 & B26) with significantly higher quality and technological traits and comparable yield performance, with commercial cultivars under organic environment. These observations are valuable and useful for the direct exploitation of these lines in organic farming (Wolfe et al., 2008) or for their participation or contribution as parents to design an effective organic breeding program for durum wheat in the near future.

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# Food Soybean Varieties in Low-Input Conditions

## Grain Yield and Quality from Three NE Italy Environments

Fabiano Miceli[1], Michael Centa[1], Riccardo De Infanti[1], Marco Signor[2]

[1]University of Udine, DISA, Udine, Italy, www.uniud.it/dipartimenti/disa, fabiano.miceli@uniud.it
[2]Friuli Venezia Giulia Region, ERSA, Pozzuolo del Friuli, Italy, www.ersa.fvg.it, marco.signor@ersa.fvg.it

**Key words:** soybean, food grade, low input, seed quality

**Summary:** Soybean has been diffusely grown in northern Italy since early 1980s. Indeed, at present the organic area (less than 3 % of the total) and the practical absence of certified non-GM productions are key issues for farmers and food processors. In 2013, four food-grade varieties were tested under organic or low-input conditions in three environments of Friuli, NE Italy. Environments had a large impact on grain yields, genotypes on grain composition. Late planting resulted in lower yields and high-protein seeds. Seed protein levels were associated to visual seed quality.

### Background

With approximately 40% of the EU-27 acreage, Italy ranks at the 15$^{th}$ place among producing countries for soybean production (Rüdelsheim and Smets 2012). The eastern part of the Po valley accounts for approximately 75% of the italian area (Miceli 2012). Indeed, organic farming is still of minor importance, reaching 4.5 % of the acreage in the EU and only 2.3% in Italy. Crushing plants are largely dependent upon imported (i.e. > 90% GM) seeds to sustain the feed industry huge requirements. Taking into account the non-GM issue, soyfood processors and selected feed industries are considering alternative, certified non-GM, seed sources. Knowledge on new soybean varieties adaptation to low-input and/or organic agriculture should facilitate farmers to enter into those production systems.

### Main chapter

In 2013 a small set of soybean varieties, tentatively suited for food production (large seeds, pale hilum and high seed protein) were tested in three locations of the Friuli Venezia Giulia region, within a latitude range within 45°43'25.60" N (Fossalon) and 46°02'16.23" N (Udine). Three varieties belonging to Maturity Group (MG) I (*Luna*, *Brillante* and *Prana*) and one MG 0 (*Energy*) variety were included in the test. Planting dates varied with locations, spanning from full-season crop (early May, at Fossalon) to double crop (early July, at Udine). Regimes, locations and planting dates were united as three distinct environments; additional data are presented in table 1. The experiment was arranged in blocks, with six reps for each environment.

Table 1. Locations, soil types and management information about the 2013 field experiment.

| Locations | Soil type | Agricultural system | Previous crop | Planting dates | Weed control | Irrigation |
|---|---|---|---|---|---|---|
| Fossalon | silty loam | organic | zucchini | May 9 | mechanical | No |
| Fiume V. | loam | low input | alfalfa | June 6 | mechanical | Yes, 7 app. |
| Udine | sandy loam | low input | winter wheat | July 6 | mechanical | Yes, 3 app. |

The environment *per se* caused large and significant impacts on most traits. On average, grain yields reached 2.78 t DM $ha^{-1}$ after 16 weeks (VE-R8, Fehr & Caviness phenological scale). Poor yields were obtained at Udine (1.45 t $ha^{-1}$) compared with the other environments. Possible drivers for such yields were the late planting, a lower crop density (17.5 plants $m^{-2}$ at harvest at Udine, 33.2 and 20.2 plants $m^{-2}$ respectively at Fossalon and Fiume Veneto), which in turn could be related to a higher weed density (data not present). No significant differences were observed among varieties for grain yields, thousand seed weight and other yield components. Indeed, seed composition was significantly influenced by both the environment and the genotype. *Energy* and *Prana* had a higher seed protein concentration (441 g/kg), compared to the other two genotypes (411 g/kg); the opposite was true for oil content. A visual inspection for seed quality pointed out that sound seeds, i.e. those with no sign of deterioration or discoloration, as percentage dropped in double-crop conditions (54 percent at Udine vs. 98 and 89 percent, respectively at Fossalon and Fiume Veneto).

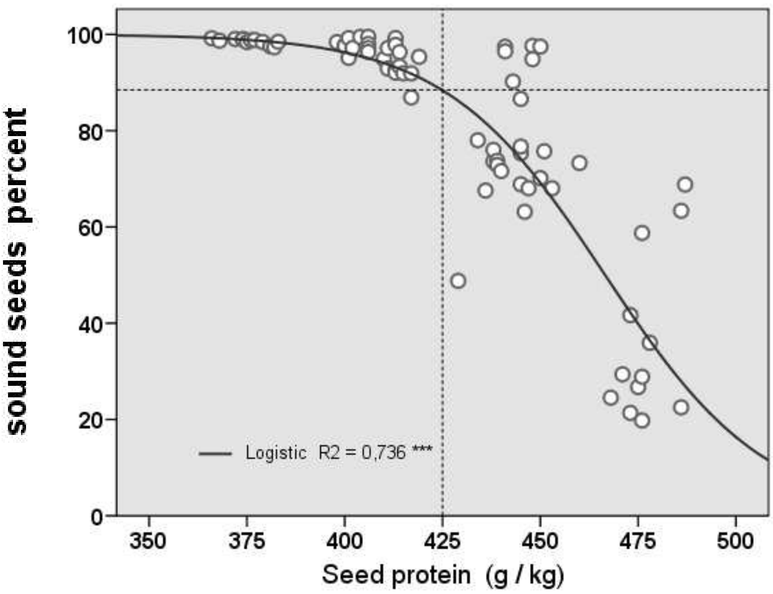


Figure 1. Relationship between seed protein content and seed quality from four soybean varieties grown in three environments of Friuli Venezia Giulia (NE Italy).

The increase of seed proteins, a known effect of late planting (Benati et al., 1988; Vollmann et al., 2000), was associated to seed quality degradation (figure 1). From the logistic regression model, a protein concentration above 425 g/kg was associated to a steep decline in seed quality. Additional work to validate these observations on a broader scale may be relevant for both breeders and farmers interested in food-grade soybean production.

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# Wheatamix

## Increasing within-field wheat diversity to foster ecosystem services in the Parisian basin

THE WHEATAMIX CONSORTIUM

[1]The Wheatamix Consortium: V Allard, B Andrieu, S Barot, J Borg, A Cantarel, C Cervek, F Coleno, C de Vallavieille-Pope, D Descoureaux, F Dubs, J Enjalbert, M Feret, N. Galic, A Gauffreteau, F Gilet, I Goldringer, M Hannachi, G Houivet, S. Jouanne, MH Jeuffroy, C Kerbiriou, P Labarthe, JC Lata, C Lecarpentier, L Lejars, B Lemain, S Lemarié, F Leny, X. Le Roux, I Le Viol, C Montagnier, A Niboyet, B Omon, S Piaud, F Poly, T Pommier, E Porcher, S Saint-Jean, S Salmon, D Tropée, T Vidal.

UMR de Génétique Végétale (UMR 0320) - Chemin du Moulon 91190 Gif-sur-Yvette, UMR Génétique Diversité et Ecophysiologie des Céréales (UMR 1095) - 5 chemin de Beaulieu 63100 Clermont-Ferrand, Ecologie Microbienne de Lyon (UMR 5557 USC 1364) - Univ. Lyon 1 43 Boulevard du 11 Novembre 1918 69622 Villeurbanne, UMR Agronomie (UMR 0211) - Bât. EGER avenue Lucien Bretegnières 78850 Thiverval-Grignon, UMR Laboratoire d'Economie Appliquée de Grenoble (UMR 1215) - Univ. Pierre Mendès France BP47 38040 Grenoble Cedex 09, UMR Sciences Action Développement Activités Produits Territoires (UMR 1048) - Bât. EGER BP01 78850 Thiverval-Grignon, UMR Institut d'Ecologie et des Sciences de l'Environnement de Paris (UMR 1392) - Univ. Paris 6 UPMC 7 quai Saint-Bernard 75005 Paris, UMR Centre d'Ecologie et de Sciences de la Conservation (UMR 7204) - 55 rue Buffon 75005 Paris, UMR Biologie et Gestion des Risques en Agriculture (UMR 1290) - Bât. BIOGER CPP avenue Lucien Brétignières BP01 78850 Thiverval-Grignon, UMR Environnement et Grandes Cultures (UMR 1091) - Route de la Ferme 78850 Thiverval-Grignon, Chambres d'Agriculture de l'Eure, Indre, Loiret, Loir-et-Cher et Seine et Marne, FDGEDA du Cher.

Key words: Variety mixture, low input, GxE interactions, ecosystemic services, paticipatory ideotyping

Summary: Crop genetic diversity should play an essential role in the context of Global Change, as it could promote various ecosystem services essential for yield stability, adaptation to climate change, and resistance to pests and diseases. In this context, the ANR research project WHEATAMIX studies the interest of mixing wheat genotypes to reinforce the sustainability of agricultural production in the Paris Basin, France. WHEATAMIX analyses the interactions among genotypes and with the environment, to develop new methods for breeding and/or combining wheat varieties to obtain performing blends, in terms of yield and quality, as well as other ecosystem services.

### Background

In the 20$^{th}$ century, agriculture has experienced major gains in productivity via homogenization and intensive use of input, two key components of the dominant model of agriculture in developed countries. This model is jeopardized by the awareness of rapid global change, increased environmental stochasticity and the need for greater sustainability of agriculture. A new paradigm is emerging, in which biodiversity is considered as a key asset for a sustainable agriculture, relying more on ecological functions within agroecosystems. Crop genetic diversity should play an essential role in this context, as a key element contributing to agriculture multi-functionality and to the resilience of agroecosystems under rapid climate change and decreased chemical inputs. However, the use of genetic diversity within agroecosystems faces ecological, socio-economic, organizational and regulatory challenges.

### Variety Mixtures for wheat production in the Paris bassin

The main goal of the project is to better evaluate the possible roles of within-crop genetic diversity to reinforce the multi-functionality and resilience of cropping systems under global change. WHEATAMIX focuses on a major cereal, wheat, in a central area of production, the Paris basin. The research is based on a highly multidisciplinary approach involving geneticists, agronomists, ecophysiologists, ecologists, economists, and management scientists, as well as key stakeholders ("Chambres d'Agriculture", farmers). It is structured in four complementary work-packages (fig. 1):

- WP1 characterises key morphological/ecophysiological traits and genetic variability of wheat genotypes. We examine the plastic response of these traits to plant-plant interactions and test how trait complementarity affects the performance of wheat genotypes in blends through experiments and modelling.

- WP2 quantifies multiple ecosystem services provided by variety diversity within wheat fields: yield (including grain quality) and its stability, regulation of foliar diseases, insect pest and weed biocontrol, maintenance of soil fertility, along with biodiversity conservation. We analyse trade-offs and synergies among ecosystem services, as well as links between particular baskets of services and bundles of traits of varieties.

- WP3 studies the techno-economic interest of blends and associated baskets of services for -and their acceptability by- key stakeholders. We explore the organisational and economic bases of blend choice by the wheat chain (from seed companies to millers), with a focus on the Paris basin. Existing lock-in to the use of associations of wheat varieties will be analysed.

These 3 WPs use common, complementary experimental approaches: i) individual plant phenotyping to characterize traits and their plasticity for 50 wheat varieties; ii) a main diversity experiment (65 100m$^2$ wheat plots with 1, 2, 4 or 8 varieties, under low input) to quantify variety diversity effect on ecosystem services; iii) replicates of the same diversity experiment in 5 sites across France using smaller (7m$^2$) plots, under low and high inputs, to test the robustness of wheat diversity under a wide range of environmental conditions; iv) a network of 50 farms, encompassing agro-climatic variability in the Paris basin, to compare the ecological and techno-economic performance of blends with that of monocultures, in direct link with key stakeholders.

- WP4 combines results from WP1-3 and mobilizes key stakeholders to build scenarios of the development of wheat variety blends in the Paris Basin considering various future climatic and economic contexts. Opportunities offered by and impacts of the introduction of wheat variety blends in the Paris production basin will be assessed on the basis of these scenarios. Further, new breeding methods will be developed for an efficient selection of genotypes with high combining ability in mixtures.

Figure 1

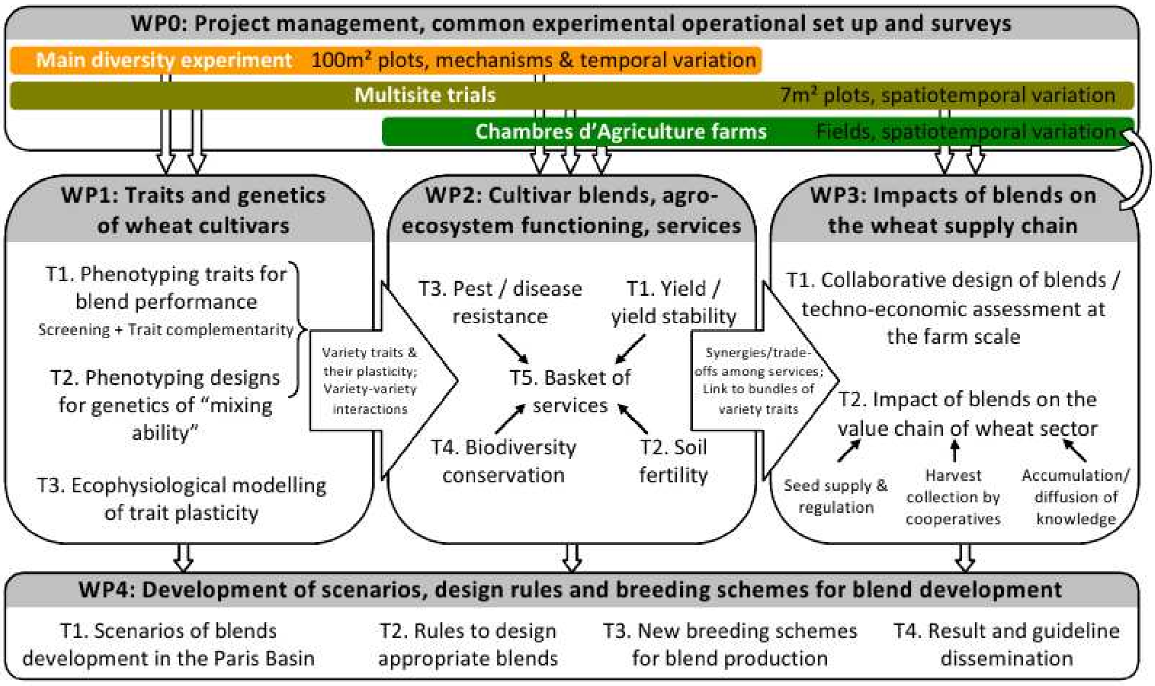


**Figure 1: General organisation of the WHEATAMIX project.**

**Description of the three common experimental designs** – Measuring ecosystem (dis)services associated with blends necessitates parallel work of the different teams on shared experiments. Three main designs will concentrate our experimental efforts: 1) one central diversity experiment, 2) a related multi-site experiment, 3) a network of on-farm experiments (

# Weed tolerance of common vetch genotypes under low-input farming

DIMITRIOS VLACHOSTERGIOS[1] , ANASTASIOS LITHOURGIDIS[2] , ATHANASIOS MAVROMATIS[3]

[1] Fodder Crops and Pastures Inst., Hellenic Agricultural Organization, 41335 Larissa, Greece, www.nagref.gr,

[2] Department of Agronomy, Aristotle University Farm of Thessaloniki, 570 01 Thermi, Greece

[3]Lab. of Genetics and Plant Breeding, Aristotle University of Thessaloniki, Greece

**Key words:** Vicia sativa, weed stress, competition, grain yield

## Introduction

Common vetch (*Vicia sativa* L.) is one of the most widely distributed annual leguminous crops throughout the Mediterranean basin. It is used as a protein crop, for hay or silage production and has interesting traits for organic or low input culture systems. Common vetch forms a strong fibrous root system that develops nodules at an early stage and fixes the atmospheric nitrogen into the soil. It is broadly used in crop rotation systems to manage diseases, weeds, improve soil fertility and contribute to increased yield and protein content in the following crops (Vasilakoglou et al., 2008). Weeds are the main obstacle to common vetch production. Breeding for weed tolerance is the most economic, feasible and environmental friendly method to control weeds (Rubiales et al., 2006). However, the experimental data on diversity for weed tolerance of common vetch are very limited. The objective of this work was to evaluate common vetch genotypes for grain yield under weed stress and identify promising genotypes when grown under low-input farming.

## Material & Methods

Field experiments were established under a replicated split-plot experimental design at the central farm of Fodder Crops and Pastures Institute (latitude 39°36'N, longitude 22°25'E) and at the University farm (latitude 40°32'N, longitude 22°59'E) of Aristotle University of Thessaloniki (AUTH) during the growing season 2011-2012. Weed-free and weedy treatments were considered as main plots and subplots were the genotypes. The genotypes evaluated consisted of 8 cultivars and 2 cultivar mixtures (Vlachostergios et al. 2011). The entries were planted at a seed rate of 180 kg $ha^{-1}$ in the last week of November, at a depth of 3 cm. Individual plots consisted of six rows spaced 0.25 m apart and 4 m long, occupying an area of 6 $m^2$. All plots in each replication were separated by 1 m buffer zone and replications were separated by 2.5 m buffer zone. The weeds were not planted; rather, a natural infestation was allowed to emerge and grow. Predominant annual weed species, as determined by systematic visual estimates in all plots, were wild mustard (*Sinapis arvensis,* >85% of the total weed population) in Fodder Crops and Pastures Institute (FCPI) and common fumitory (*Fumaria officinalis*, >65% of the total weed population), shepherd's-purse (*Capsella bursa-pastoris*) and field poppy (*Papaver rhoeas*) in AUTH. At grain maturity, the experimental plots were hand-harvested and threshed using a stationary Wintersteiger thresher in order to determine grain yield. Combined analysis of variance was performed and differences between means were compared at the 5% level of significance. Weed tolerance (WT) was determined as the ability of a cultivar to achieve high yields despite weed competition (Murphy et al. 2008) and was calculated as a percentage (%) by the formula: WT = 1 - D/Ywf, where D (D=Ywf-Yw) is the difference between the yield of the genotype under weed-free treatment (Ywf) and the yield of the same genotype under weedy treatment (Yw).

## Results & Discussion

Partitioning of treatments Sum of Squares (%) across locations indicated that location was the main source of variation, followed by weed-free vs weedy treatment and genotype. Differences between locations could be partially attributed to the different competition ability of the predominant weed species in each location. In AUTH, were the predominant weed species was common fumitory, the mean grain yield under weed competition was 1.65 tn/ha, whereas in FCPI were the predominant weed species was wild mustard the corresponding yield was 0.99 tn/ha. Genotype by location interactions indicated that the grain yield produced depended on the genotypic response in each location and thus resulted in different ranking order of the genotypes in the two locations studied. However, it must be noted that certain genotypes produced high yield in both locations. Significant differences were also detected between treatments (weed-free vs weedy). Common vetch genotypes produced 0.48 tn/ha (on average) less under weed competition. Weed tolerance values ranged from 60 to 91% across locations. Two cultivars illustrated WT values above 80%, while the two cultivar mixtures ranked in the top and gave WT values near 90%. It seems that the functional diversity observed in some culture mixtures could provide a buffering capacity in biotic and/or abiotic stresses (Wolfe 2005).

These preliminary results provide evidence of valuable diversity between common vetch genotypes for weed tolerance. Moreover, cultivar mixtures showed high weed tolerance and may be a useful alternative for cultivation under low-input farming. However, further research is needed to verify these results for more valid conclusions.

Table 1: Yield performance (tn/ha) under weed-free (Ywf) and weedy (Yw) treatment across two locations, difference between treatments and weed tolerance (WT) of ten common vetch genotypes under LI farming

| Genotypes | Ywf (tn/ha) | Yw (tn/ha) | Difference (tn/ha) | WT (%) |
|---|---|---|---|---|
| V-65 | 2.12 | 1.17 | 0.94 | 63 |
| V-233 | 2.27 | 1.27 | 1.01 | 60 |
| V-209 | 1.91 | 1.45 | 0.46 | 77 |
| V-216 | 1.77 | 1.18 | 0.59 | 68 |
| V-89 | 1.87 | 1.39 | 0.48 | 77 |
| V-64 | 1.51 | 1.18 | 0.33 | 81 |
| Leonidas | 1.68 | 1.26 | 0.42 | 77 |
| M-6900 | 1.52 | 1.30 | 0.22 | 86 |
| Mix1 (V-65+V-233+V-130) | 1.61 | 1.48 | 0.14 | 91 |
| Mix2 (V-233+V-89+M-6900) | 1.78 | 1.53 | 0.25 | 88 |
| Mean ± SE | 1.80 ± 0.12 | 1.32 ± 0.12 | | |

CV: 13,4%

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# Evaluation of non-GM cotton cultivars for bollworm resistance

## Participatory cotton breeding program for organic smallholders in Central India

SERAINA VONZUN[1, 2], MONIKA M. MESSMER[1], DHARMENDRA WELE[3], YOGENDRA SHRIVAS[3], THOMAS BOLLER[2], H. G. KENCHARADDI[4], S. M. MANJULA[4], SHREEKANT S. PATIL[4]

[1] Research Institute of Organic Agriculture (FiBL), Ackerstrasse 113, CH-5070 Frick, Switzerland, www.fibl.org, monika.messmer@fibl.org
[2] Plant Physiology, University of Basel, Switzerland, www.unibas.ch
[3] bioRe Association India, Kasrawad, Madhya Pradesh, India, www.bioreassociation.org
[4] University of Agricultural Sciences (UAS) Dharwad, Karnataka, India, www.uasd.edu

**Keywords:** Organic smallholders, Gossypium spp., cotton bollworm, seed-chain, Bt toxin

**Summary:** Organic cotton farmers in India face increased problems to find suitable non-GM cotton seeds on the market. Due to the fast adoption of genetically modified Bt cotton, non-GM seed production and breeding activities have been abandoned. This study compares the resistance against cotton bollworms of over 100 cultivars of different cotton species under organic conditions. On average 70% of the assessed capsules were damaged by cotton bollworms, with significant genotypic differences in the susceptibility. Thus, big potential for organic cotton production lies in the breeding for more pest resistant cultivars, the improved management and the re-establishment of seed sovereignty for smallholders.

### Background

Cotton ( *Gossypium spp* .) is an important cash crop for fibre and oil production and assures millions of farmers' families income. Cotton is like no other plant highly susceptible to various pests. Therefore, genetically modified (GM) cotton, expressing *Bacillus thuringiensis* (Bt) toxin, was introduced and is nowadays widely spread all over India. GM cotton is less susceptible to bollworms, which is the major pest, causing enormous yield losses word-wide. The fast adoption of GM cotton let to a neglect of breeding on non-GM cultivars for pest resistance, especially towards bollworms. This makes it difficult for smallholder of the organic sector to find suitable non-GM cultivars on the Indians seed market. An economically reasonable production of organic cotton is only feasible with an elaborated control of the cotton bollworm, based on inherent resistance and treatments with botanical pesticides. Therefore, a non-GM cotton seed-chain has to be re-established in India to sustain the organic cotton production.

### Main chapter

Even though India still is the world's largest producer of organic cotton, the area cultivated with organic cotton decreases steadily. This trend is accelerated through the impede access of farmers to high quality non-GM seeds and through the problem of GM contamination. To support organic cotton farmers in India participatory breeding projects and evaluation programs have been initiated in Madhya Pradesh in Central India realized in collaboration with the Research Institute of Organic Agriculture (FiBL), bioRe a local organic cotton producer and the University of Agricultural Science, Dharwad.

In this study the susceptibility of different cotton cultivars comprising 30 tetraploid upland *G. hirsutum* hybrids, 65 *G. hirsutum* varietal lines and 37 endemic diploid *G. arboreum* varietal lines, towards cotton bollworms was compared at two different sites (heavy soil, irrigated and light soil, rainfed) representing farmers' main organic growing conditions. The cultivars were planted in two replications per site in 4-row plots with cultivar type specific plant density. The total number of harvested bolls and the damaged bolls caused by bollworms of five selected plants per cultivar, replication and site were assessed during the picking period (October 2013 till January 2014). Yield components, fibre quality and morphological traits were also assessed.

The average infestation of bollworms across genotypes was much higher under the irrigated high fertile heavy soil site (68% of capsules) compared to the rainfed light soil site with shorter vegetation period and very low infestation (9%). At the heavy soil site, response of the different cultivars towards the bollworm differs significantly ranging from 39% to 91% infestation. Variation within cultivar type was higher than between species.

Therefore, breeding for pest resistant cultivars is essential for yield stability of organic cotton production, especially under favourable growing conditions. Increasing the genetic diversity of *Gossypium spp* . in India gains even more importance since other pests have emerged and since first Bt resistant bollworms have been identified. Resistant cultivars have economic benefits and are not harmful to the environment. Initiating decentralized participatory breeding programs for pest resistant non-GM cotton cultivars adapted to farmers' conditions and increasing the self-sufficiency of smallholders could account to a better choice of suitable cultivars and lead to a sustainable increase of yield in the organic cotton production.

### Acknowledgement

This project is supported by Mercator Foundation Switzerland, bioRe Foundation Switzerland and Coop Sustainability Fund.

# Session C

# Diversity for quality in organic systems

# 'soil to fork'

# Diversity for quality in organic systems "soil to fork"

## GxExM effects on organoleptic, nutritional and end-use quality

Marianna Rakszegi[1], Karolina Bede[1], Elsa Mecha[2], Andreia Bento Da Silva[2], Bruna Carbas[3], Carla Brites[3], Maria Carlota Vaz Patto[2], Maria Rosário Bronze[2,4], Pedro Mendes-Moreira[5], Rosalie Aebi[6], Jürg Hiltbrunner[6], Camille Vindras[7], Bruno Taupier-Letage[7], Véronique Chable[8]

[1] Centre for Agricultural Research, Hungary, www.agrar.mta.hu, rakszegi.mariann@agrar.mta.hu
[2] ITQB, Portugal, www.itqb.unl.pt, cpatto@itqb.unl.pt
[3] Instituto Nacional de Investigação Agrária e Veterinária, Portugal, carla.brites@iniav.pt
[4] iMED, Faculdade de Farmácia, Universidade de Lisboa, Portugal, mrbronze@ff.ul.pt
[5] ESAC – IPC, Escola Superior Agrária de Coimbra, Instituto Politécnico de Coimbra, Portugal, pmm@esac.pt
[6] FDEA-ART, Switzerland, www.agroscope.admin.ch, juerg.hiltbrunner@art.admin.ch
[7] ITAB, France, www.itab.asso.fr, bruno.taupier-letage@itab.asso.fr
[8] INRA de Rennes, France, www.rennes.inra.fr, veronique.chable@rennes.inra.fr

**Key words:** breeding, organic, cereal, bean, GxExM, organoleptic

**Summary:** Organoleptic, nutritional and/or end-use quality of cereal, bean varieties, that originated from different breeding programmes, and breeding lines developed under SOLIBAM WP3-6 were studied by taking into account the global and local needs and consumers' expectations. Properties were studied on seed of plants grown at different agro-climatic conditions with differing crop management systems. As a result:

- A methodology was developed in order to integrate organoleptic quality criteria in breeding programs of tomatoes, broccoli and bread.
- The effect of GxExM and the breeding strategy on the compositional and processing quality of 37 wheat and 15 durum were established.
- The beneficial nutritional properties of the new developed wheat lines, populations and/or variety mixtures were identified.
- High qualitative and quantitative variability in phenolic composition was identified in bean accessions as well as in maize and corresponding broa (a typical Portuguese bread), identifying interesting accessions for future development of healthier foods through organic or low input breeding.
- The effect of cooking and baking process on the final phenolic composition of bean and maize was studied. Favourable sensorial properties of maize broa bread and high quality maize accessions for, Broa, production were selected based on the instrumental quality measurements diversity and the consumers' preferences, defining new quality breeding objectives.

Due to the development of the organic sector and some local products meeting the expectation of the consumers, SOLIBAM tried to integrate quality assessment and evaluation in the breeding processes based on (1) diversity and (2) by developing tools for breeders and farmers for selection based on quality characteristics.

We were managing complexity at two levels from farm to fork: (a) the assessment of quality has several aspects in itself (sensorial, nutritional, end-use) while on the other hand (b) there are also several factors and their interactions influencing these quality characters, such as the genotype, the environment and the farming and food processing practices. SOLIBAM provided several examples of breeding strategies to cover demonstrative processes to improve qualities of food.

### 1 Creation of genetic diversity and breeding methods for quality

In some species, modern varieties were not able to provide all the requested quality traits. Within broccoli breeding programme of SOLIBAM, the aim was to re-introduce the sensory character of some traditional "sprouting" landraces. Modern varieties show larger curd and "crown" type but they taste very differently. From a broad collection of landraces, 6 were selected for the creation of CCP (Composite Cross Population). The selection of the plants included sensorial quality by participatory tasting assessment involving relevant actors. Methods were adapted to be able to test selected plants previously chosen for agronomical characters. Results to date indicate that environment had a stronger effect than the genotype on bitterness and sweetness. Nevertheless, specific 'regional' flavours can be detected between environments for a given genotype. Certain characteristics, such as a nutty aroma, seem to be more genotype dependent as they were observed uniformly across environments and as progenies from the same cross presents similar sensory characteristics. At the end of the project we have created flavour pools comprising plants exhibiting certain aromas (e.g. nutty, bitter, sweet) considering 'flavour criteria' as a breeding trait. Two breeding strategies will be then applied at the end of the project, i.e. the creation of new populations by the farmers and the creation of F1 hybrids by breeder. The same approach has been experienced for tomato. Both species would be exploited at the same time by professional breeders and participatory programmes with farmers.

Our next question was how to evaluate the breeding methods that provide new adapted varieties of cereals that fullfill the demand of the procucers and consumers. In order to answer this question 37 winter wheat (*Triticum aestivum*) and 15 durum wheat varieties (*Triticum durum*) were grown on 'low-input' and organic sites in Hungary, Switzerland, Austria and France in a three-year experiment. The varieties consisted of three sets: (1) varieties bred for conventional farming, (2) varieties selected under organic conditions for organic farming and (3) varieties selected under conventional conditions for organic farming (BFOA, bred for organic agriculture). The aim of our study was to identify the best breeding strategy for organic farming and to determine the effect of breeding and farming conditions on the agronomical and processing quality of wheat and durum.

Results showed that the quality of the varieties differed significantly between the low-input and the organic sites, but organically bred varieties could be separated well from the BFOA and the conventionally bred varieties, when their quality characters were analysed, both at organic and low-input sites. This three year study confirms that the organic varieties have their own quality characters well distinguishable from all the other varieties. Statistical analysis showed, that the physical properties of the seed, such as the thousand kernel weight and the test weight are the characters which were affected the most by the interaction of the genotype and the management (GxM). Other compositional and processing properties (protein, gluten-content, Zeleny sedimentation, Farinograph water absorption and quality etc.) were not influenced significantly by the GxM interaction when the complete dataset was evaluated. When analysis was carried out within variety groups, than the falling number of the conventional varieties and the flour yield and water absorption of the organic varieties were influenced significantly by the GxM interaction. After all, all the agronomical and quality results supported the fact, that BFOA varieties could be grown effectively both under 'low-input' and organic systems. The quality characters of the organic varieties were affected the most significantly by the G, E and M factors, indicating that organically bred varieties are best for growing at organic farming conditions where they were developed.

Another aspect of our research was trying to evaluate strategies based on within-population diversity. In order to increase the adaptability of wheat, genetically diverse variety mixtures and composite cross populations were developed. The physical, compositional, and processing qualities of 16 variety mixtures and 10 composite-cross populations, produced in Hungary, Austria and UK, were investigated in three consecutive years (2011-2013). The aim was to identify new genetic resources for organic farming purposes and to examine the effect of the compositional properties on the end-use qualities of the flour. As a result of our work, a new population (Elite-Composite) and a variety mixture (Mv-Suba: Elite-Composite, 1:2) were identified containing significantly higher water extractable arabinoxylan (WE-AX) content in the flour (8.1; 10, respectively) (dietary fiber), than most of the studied samples and than wheat average. The increased WE-AX content had significant effect on the water absorption of the flour ($r_{5\%}$=0.55*), too.

These newly created and genetically diverse wheat populations which have been analysed and were found to be appropriate for organic farming purposes, had weaker processing quality when used for the production of traditional bread or bakery products. Blending of the high-fiber flour with normal flour in a certain ratio could solve this problem and could contribute to the healthier human consumption at the same time by the increased level of dietary fiber in the flour.

**2 Participatory research and quality: diversification of the products, participatory evaluation of quality**

A new sector of artisanal bread making emerged in some EU countries by farmers-bakers. They make bread from their own wheat production, so bread quality directly relies on the quality of the harvested wheat. Some wheat populations and landraces seem well adapted for these organic farming and artisanal baking practices. Moreover, they show higher nutrients and minerals contents than modern varieties and have promising sensory potential. Farmers-bakers are confronted with quality variations, depending on the year and genotypes. They need to know how to adapt their breeding and baking practices to produce bread of good and stable quality. In order to get closer to the solution the following experiments were carried out in the frame of Solibam.

*PPB for nutritional and organoleptic qualities*

In order to identify sources of high nutritional, health beneficial (phenolic) or organoleptic components that might influence taste or aroma, and to incorporate those in future organic or low input breeding programs, quality data of different bean and maize accessions were collected. Altogether 32 common bean and 51 maize accessions were established in a Participatory Plant Breeding (PPB) program in Portugal (Central Region). Phenolic compounds were assessed using spectrophotometric and chromatographic assays. Different families of phenolic compounds were identified in beans (mainly hydroxycinnamic acids and flavonoids) and in maize (hydroxcinnamic acids). In common beans, total phenolic content (TPC) ranged between 1.00 ± 0.02 and 6.83 ± 0.31 mg of gallic acid equivalents/g. In maize TPC ranged from 100.30 ± 4.81 to 206.83 ± 9.55 mg of gallic acid equivalents/ 100g DW (dry weight). Total flavonoid content, in common bean, ranged between 0.09 and 2.50 mg of catechin equivalents/g, and a strong positive correlation ($r^2$=-0.876) was found between TPC, TFC and Antioxidant activity measured by ORAC (Oxygen Radical Absorbance Capacity) in common bean extracts. In maize flour and broa, the extraction of phenolic compounds was improved through hydrolysis assays, revealing that p-coumaric and ferulic acids are the most important compounds detected in maize flour and broa.

Colorimetric parameters (L*, a*, b*) were analysed for common bean flours, revealing L*, a* and b* average values of 85.07 ± 2.65, 1.62 ± 0.91 and 9.85 ± 1.02, respectively. Multivariate analysis of spectrophotometric, chromatographic and colorimetric data was conducted by Principal Component Analysis (PCA), followed by Cluster analysis allowing classification of common bean samples into three different clusters, which explain 77.70% of total variance. One of the clusters was composed of accessions with the higher values of TPC, TFC, ORAC, a* colour parameters and flavonoid derivatives. Another cluster included common bean accessions with higher values on L*colour parameter and the third cluster include the remaining common bean accessions characterized by a lower content of flavonoid derivatives analysed by chromatographic assays.

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. cookies, breads, cakes) is expected after incorporating a mixture of common bean and maize raw seed flour as food ingredients. Our results have helped to identify bean genotypes presenting an increased level of bioactive components in the flour which do contribute to the overall improvement of the human diet.

*PPB for end-use qualities*

Cooking process influenced common bean phenolic composition since first a soaking method must be implemented to reduce cooking time and increase common bean softness. In fact 58% of total phenolic content is released from common bean seeds into soaking water. Protein content of common bean accessions ranged between 21.6 and 27.1g/ 100g. Oil content, hydration capacity and viscosity parameters also reveal a great variability. The high diversity found among these common bean landraces qualities highlight the myriad of new opportunities to include them on attractive, convenient and tasty food formulations. Innovative formulas might include fortification of breads, pastries, curd-like products, soups, pasta, etc, increasing diets diversity. As a result of this targeted effort, common bean traditional landraces consumption and market demand will be enhanced, supporting their on farm production.

A consumer sensorial analysis with more than 50 assessors of bread obtained from 11 selected maize varieties allowed to improve the understanding of Portuguese traditional maize bread quality, considering the influence of the maize variety, and to develop specific consumer sensory descriptors (appearance, odour, texture and flavour) for this type of bread. The good correlation of the instrumental with the sensorial evaluation allowed sorting out the most important quality components valued by consumers (texture and colour) and easier to measure approaches have been set up to select for improved quality maize, especially on participatory breeding programs. These promising methodologies contributed to the identification of interesting high quality Portuguese participatory bred maize varieties eligible for quality certification (Protected Geographical Indication). This new participatory breeding approach based on both qualitative and sensorial criteria will surely sustain the demand for fine products such as the farm’s maize bread and promote open pollinated maize variety production.

# Agro-biodiversity and preservation of traditional food:
## Functional properties and perspectives.

GIOVANNI DINELLI[1], VALERIA BREGOLA[1], SARA BOSI1, ILARIA MAROTTI[1], ALESSANDRO DI LORETO[1], VERENA STENICO[1], RAFFAELLA DI SILVESTRO[1], STEFANO BENEDETTELLI[2]

[1] DiPSA, University of Bologna, Italy, www.scienzeagrarie.unibo.it, giovanni.dinelli@unibo.it;
[2] DiPSA, University of Bologna, Italy, www.scienzeagrarie.unibo.it, giovanni.dinelli@unibo.it;

**Key words:** Biodiversity, traditional food, functional properties, nutrition, traditional food production.

**Main text**

Within Europe, there are many different cultures, each with their own, often distinctive, dietary traditions.
According to the European Union EuroFIR Project, traditional foods include foods that have been consumed locally or regionally for many generations. The methods for preparation of these local specialties have been passed down from generation to generation and have become part of the fabric of life in many communities. In some cases, they are not formally documented recipes, but are often associated with positive health benefits and always with local history.
Recent surveys have evidenced that in Europe traditional food products (TFPs) are strongly associated with the attributes “good quality”, “consistent quality” and “good taste”.
Several researches emphasize benefits that accrue to a traditional food system, due to the linkage between food quality and agricultural biodiversity. In 2010, in the FAO report “Biodiversity in sustainable diets” was pointed out that “countries, communities and cultures that maintain their own traditional food systems are better able to conserve local food specialties with a corresponding diversity of crop varieties and animal breeds”. Moreover, the role of biodiversity for food quality and healthy status is well recognized: the common belief of the presence of a special taste in traditional food, together with a positive safety perception, a high nutritional value and healthiness make TFPs a growing segment within the European food market.
The present lecture is organized in three main parts which map out the most important issues and challenges.
After a brief introduction describing the complex force field of traditional food system, the first part focuses on available literature with the aim to verify the correspondence between the general “healthy” image of TFPs and scientific data. The analysis is carried out distinguishing: 1) traditional ingredients (old vs modern crop/vegetable genotypes); 2) traditional ingredient production (organic vs conventional cropping systems); 3) traditional food preparation (industrial vs traditional bakery). Particular attention is devoted to some controversial aspects of TFPs (ie microbiological and/or toxicological safety assurance systems) in relation to their presumed or demonstrated functional properties.
The second part deals with the potential role of traditional foods within the context of the worldwide “double burden” of malnutrition. As reported by WHO, at the start of the 21st century more than 50% of the world’s populations (3 billion people) were suffering one or other form of undernutrition, with women and children the most affected. A useful example comes from the Report of the 5th African Network of Food Data System (AFROFOODS) Meeting (2009), where it was reported that the degradation egradation of eco-system and the loss of local food diversity has greatly contributed to poverty and malnutrition in Africa. In addition it was pointed out that returning to local crops and traditional food systems is essential for the conservation of biodiversity for food and nutrition.
At the same time almost 30% of the United States and 20% in Europe suffer from obesity. In total, there are more than 300 million overweight people in the world and this phenomenon also increasingly concerns developing countries. The overnutrition causes severe pathologies, referred as non transmissible diseases (cardio-vascular illness, diabetes, cancer of the digestive tracts, osteoporosis) which generate considerable economic costs. Within the context of a balanced diet, the role of TFP functional properties and of biodiversity in contrasting obesity, food intolerance and some symptoms of malnutrition is discussed.
The third part illustrates the main perspectives and challenge of TFPs. Traditional food production has in the past adapted to new circumstances. The question is how TFPs can adapt in the next future to new consumers requirements and to large scale markets. The present and dominant agro-industrial food system, qualified as intensive, specialized, concentrated, financialized and on the road to globalization, deeply contrasts the production model of several traditional foods. Within this context, the role of researchers and technicians in supporting TFPs by providing tools to better understand the ongoing constrains and specific opportunities of the food sector is discussed.

# Manipulating protein content in diverse populations using NIRS single seed sorting

ANDERS BORGEN [1], PHILIPP STEFFAN [2], SØREN RASMUSSEN [2]

[1] Agrologica, Denmark, www.agrologica.dk, borgen@agrologica.dk
[2] University of Copenhagen, Department of Plant and Environmental Sciences, Thorvaldsensvej 40, 1871 Frederiksberg, Denmark

**Key words:** populations, wheat breeding, single seed sorting, baking quality

**Summary:** The experiment shows that it is possible to increase protein content and baking quality in divers wheat populations by single seed sorting of the seed, and that the effect remains in the harvested crop. Selecting pure lines in a pedigree system is therefore not the only way to develop wheat with good baking quality.

### Background

To increase robustness against biotic and abiotic stresses, organic population breeding wishes to maintain a high degree of diversity within crops. Therefore, alternative breeding techniques are needed to develop diverse crops with quality traits meeting high end user / market demands. We investigated if single seed selection can be used to increase protein content in bi parental wheat populations in order to develop high quality baking wheat populations.

### Main chapter

### Materials and methods

15 crosses were made between 12 different parents of spring wheat in 2007 and 2008. Parents of the crosses included both common red bread wheat (*Triticum aestivum*) and bread wheat with purple seed colour. Each cross was organically grown as separate populations until generations F5 or F6. In 2013, each population was sorted in 3 fractions using a single seed protein sorter based on NIRS (Near Infrared Spectrograf (IQ Grain Quality Sorter 1002, BoMill, Sweden). Fraction 1 contained the 20% of the seed with the lowest protein content, and Fraction 3 contained the seed with the 20% highest protein according to the calibration of this equipment. The middle fraction containing the remaining 60% of the seed was not used. Fraction 1 and 3 were sown in 2m2 plots without replications, and the harvested seed in generations F6 and F7 were analyzed on a Foss InfraTech 1221 for protein content and Zeleny value.

### Results

The protein content in the harvested seed was 13.5% (with a range of 12.1-14.5%) across the fractions with the lowest protein content in the sowing seed, and 14.2% (13.0-16.1%) protein in the grain harvested from the fractions with the highest protein content in the sowing seed. A few crosses reacted inconsistently with the others to the seed sorting, and this may be related to the purple seed colour of some of the parents, as the equipment is only calibrated to measure protein in grains with red seed colour. Removing one of the purple wheat varieties from the analysis increased the difference in protein content to 1.0 percent point. A t-test showed the two groups to be significantly different ($p=0.005$). Similarly, the Zeleny value reflecting the baking quality was increased from 52.5 (32.6-69.2) in Fraction 1 compared with 59.3 (38.1-81.6) in Fraction 3 ($p=0.04$)

### Conclusion

Our results show that it is possible to increase or decrease the protein content and Zeleny value in spring wheat populations by single seed sorting of the seed before sowing.

Protein content and baking quality of wheat grains is influenced by both genetic and environmental factors. Nevertheless, heritability of protein and Zeleny value is high enough for the effect of single seed sorting of bulk populations to carry on to the harvested grain, and might therefore be a useful tool to increase baking quality in diverse wheat populations.

The experiment shows the effect of sorting in only a single year. Repeated sorting for consecutive years may increase the effect. The test of this hypothesis is in progress along with a test of the yield effect of seed sorting.

The experiment was made with small amounts of grain grown in small plots, where border effects are likely to have had an impact of grain quality, including protein content, before sorting. It is therefore possible that the relative effect of the genetic factor would have been bigger if seed were used from a more homogeneous starting material.

Some populations with purple seed colour reacted differently to NIR seed sorting than grain with red seed colour, and was therefore excluded from statistical analysis. It is possible that special calibrations for the NIRS are needed for this type of purple wheat.

### Acknowledgment

The experiment was made with support from the COBRA project (Agrologica) and the BIOBREED project (Uni. Copenhagen).

# Peppers: soil dynamics, root architecture and fruit quality

ANA FITA[1], Mª DOLORES GARCÍA MARTINEZ[2], Mª DOLORES RAIGÓN[2], Mª DOLORES LERMA [1], ESTELA MORENO[1], ADRIÁN RODRIGUEZ-BURRUEZO

[1]Centro de Conservación y Mejora de la agrodiversidad Valenciana, Universidad Politécnica de Valencia, Camino de Vera SN, CP 46022,Valencia Spain, anfifer@btc.upv.es
[2] Dept Química, Universidad Politécnica de Valencia, Camino de Vera SN, CP 46022,Valencia Spain

**Keywords**: soil adaptation, capsicum peppers, bioactive compounds, rhizosphere, phosphatase activity

**Summary**: Despite the importance of root/soil interaction in plant productivity and fruit quality there is a lack of information on this issue for many vegetables. This work aims to study the genotype-soil interaction and fruit quality in *Capsicum* peppers under different crop managements. Eight pepper genotypes were cultivated in conventional and organic fields. The enzymatic activity of the rhizosphere, the root architecture and the levels of bioactive compounds of the fruits were evaluated. The results showed that there exist remarkable differences among *Capsicum* genotypes in their root architecture, root/soil interaction and fruit quality and their interaction with organic and conventional growing systems.

## Background

Plant root systems are an essential part of agricultural ecosystems and productivity. A healthy root system, adapted to the environment in which it develops, provides many benefits to the plant ecosystem, including more efficient use of water and nutrients, reduced soil erosion, the ability to better withstand the pathogens and interact with beneficial organisms. Therefore, the improvement of the root systems is a key issue in a sustainable farming (Kell, 2011, Lynch et al, 2007). To ascertain the quality of a soil is essential to study all kinds of physical, chemical, biological and microbiological properties. The physical and chemical components of the soil can be considered relatively stable, so that any change will take time to change these properties. However, biological components are highly dynamic. Unfortunately, due to the difficulty of studying this hidden organ, there is a lack of information on the root genetic diversity and root-soil interaction for many crops, particularly vegetables. *Capsicum* peppers, including bell peppers, chillies, ajies, etc. are one of the most important vegetables in the world. All these terms encompass a plethora of materials which belong to several cultivated species. *Capsicum annuum* is the most diverse and economically important cultivated species, although there are other close species such as *C. chinense* (e.g. Habanero, Bhut Jolokia, Scotch Bonnet) and *C. frutescens* (e.g. Tabasco) (DeWitt and Bosland, 1996). Such genetic diversity has enabled their adaptation to different agro-ecological conditions. In addition, these fruits contain remarkable levels in many bioactive compounds, including ascorbic acid and phenolics, which can be affected by growing conditions and also provide considerable added value (Bosland and Votava, 2000; Rodríguez-Burruezo et al., 2009).

## Main chapter

Objectives. Roots, which adapt to and modify the soil by different means, are important to plant productivity and fruit quality. The objectives of our work were: i) to study the way on which different *Capsicum* genotypes may modify soil chemistry by studying the alkaline phosphomonoesterase (phosphatase) activity (APA) in the rhizosphere, ii) to study the root architecture of these genotypes, iii) to estimate the content in ascorbic acid and phenolics in fully ripe fruits. Finally, considering that each agrosystem has its own dynamics, the experiment was performed under two different growing conditions: organic and conventional, to a better understanding of the real root-soil-quality interaction. This contribution shows the preliminary results of a broader study on genotype-soil interaction in various crop management systems.

## Materials and methods

The experiment was conducted in the Summer season of 2012 in: i) an organic farm located in the natural protected area of 'La marjal del Moro', Valencia (Spain), and ii) a close field managed according to conventional practices. Water and soil characteristics were the same for both fields. Eight pepper genotypes, including: i) 4 *C. annuum*accessions: Ancho, Pasilla and Serrano Criollo (from Mexico), Espellete (France) and Piquillo (Spain), ii) 1 *C. frutescens* accession: Bol 144 (Bolivia), iii) 1 *C. chinense* accession: Ecu994 (Ecuador) and iv) 1 *C. baccatum* accession: Bol 58 (Bolivia) were chosen for this experiment. Eight plants per genotype where transplanted to each field in a randomized block design (4 plants per block). At the end of the season, soil from the rhizosphere was sampled for enzymatic activity analysis. APA was measured with the method proposed by Tabatabai and Bermner (1969). In paralel, plants were harvested and their roots removed carefully from the soil. Roots were washed and escanned to evalute root length and diameter using Whinrhizo Pro software. Finally, fully ripe fruits harvested at the end of the season were also analysed for ascorbic acid content (AAC) and total phenolics (TP) as reported by (Rodríguez-Burruezo et al., 2009).

## Results

APA of the rhizosphere was highly variable among genotypes (Figure 1). Ancho, Pasilla and Piquillo peppers showed higher phosphatase activity in both conventional and organic cultivation than the other tested genotypes. Rhizosphere enzymatic activity was significantly higher under organic cultivation than in conventional. These results indicate that*Capsicum* genotypes may contribute differently to soil dynamics. Regarding the root systems, there were significant differences among genotypes but not among culture management. It was possible to identify different root architectures. Piquillo and Bol 58 showed the longest and thinnest roots among the assayed genotypes. Serrano and Bol144 had shorter root systems but with higher proportion of thick roots (higher in diameter than 3 mm). Differences in root architecture are related to different strategies to explore the soil. Long and thin roots have been described as efficient in water and nutrient uptake.Finally, the analyses of bioactive compounds also revealed that organic cultivation provides higher levels of AAC and TP. Thus, AAC was on average 20% higher under organic cultivation (168 vs. 139 mg/100 g) and most accessions, apart from *C. frutescens* Bol144 and *C. baccatum* Bol58, also showed higher AAC under organic conditions. In this regard, Ancho 101, Espelette and, particularly Serrano Criollo showed the most remarkable differences between growing conditions (increases of 50-60 mg/100 g). Similarly, organic conditions also increased, on average, TP levels (262 vs. 209 mg/100 g) and most accessions showed higher TP under these conditions, with the only exception of Ecu994. In this regard, the favourable effect of organic growing conditions could be due to the response of plants to stress conditions, which promote the accumulation of antioxidants such as ascorbic acid and phenolics (Rodríguez-Burruezo et al., 2009). Our results suggest that organic cultivation may provide stress to plants and, therefore, increase their content in bioactive compounds.

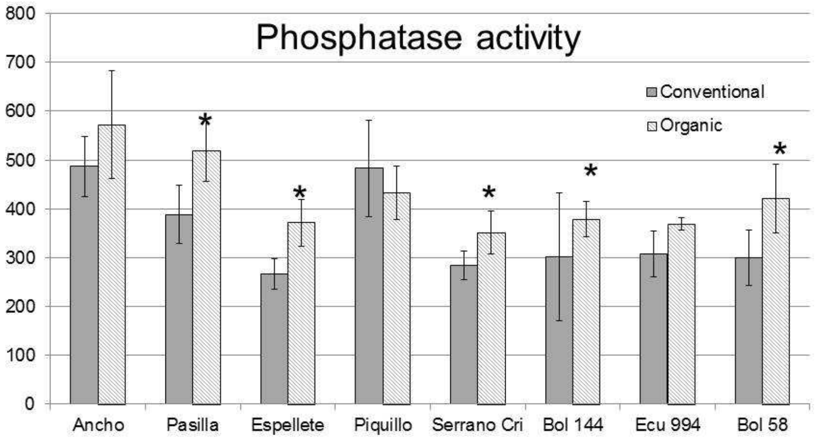


Figure 1. Phosphatase activity (µg *p* -nitrophenilphosfate g soil$^{-1}$ h$^{-1}$) in the soil affected by genotype at different sampling dates during the season. Each bar is the average of six samples. * Indicates significant differences among the phosphatase activity

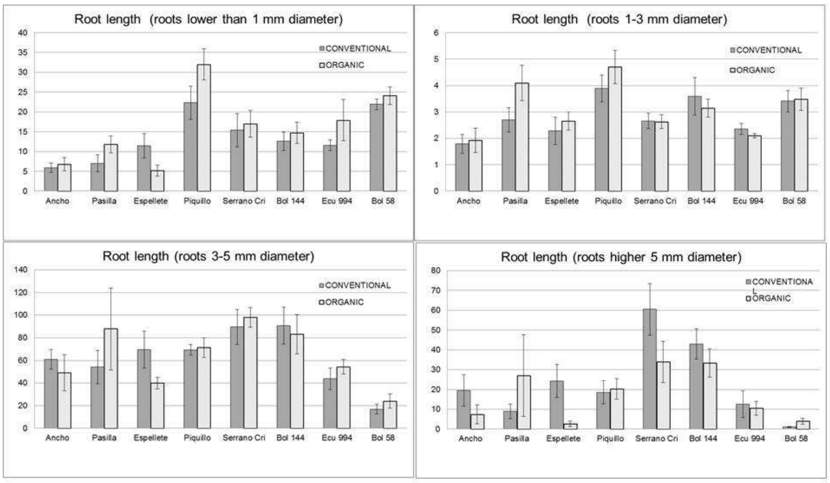


Figure 2. Root length of selected genotypes

Table 1. Ascorbic acid content (AAC, mg/100 g fw) and total phenolics content (TP, mg/100 g fw) in the studied accessions (mean ± standard error) under organic and conventional growing conditions.

| Accession | AAC (mg/100 g) | | TP (mg/100 g) | |
|---|---|---|---|---|
| | Organic | Conventional | Organic | Conventional |
| Ancho 101 | 227±10 | 189±12 | 232±12 | 220±15 |
| Pasilla | 184±12 | 163±12 | 291±17 | 246±12 |
| Espelette | 226±8 | 179±11 | 219±12 | 96±8 |
| Piquillo | 134±9 | 109±8 | 201±16 | 114±10 |
| Serrano Criollo Morelos | 179±14 | 111±11 | 237±21 | 176±16 |
| Bol144 | 113±8 | 123±12 | 438±24 | 339±18 |
| Ecu994 | 186±7 | 151±12 | 158±13 | 180±16 |
| Bol58 | 99±9 | 95±8 | 317±16 | 301±14 |
| Mean | 168 | 139 | 262 | 209 |

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# Integrative breeding strategies to improve sensory qualities of wheat bread

CAMILLE VINDRAS-FOUILLET [1], VÉRONIQUE CHABLE[2]

[1] INRA de Rennes, ITAB, France, www.rennes.inra.fr/sad-bcrp, camille.vindras@itab.asso.fr
[2] INRA de Rennes, France, www.rennes.inra.fr/sad-bcrp, veronique.chable@rennes.inra.fr

**Key words:** sensory quality, breeding criteria, integrated bread sector

**Summary:** The development of an innovative bread sector based on growing old wheat cultivars and artisanal baking practices relies on knowledge in agronomy, plant breeding, milling and baking technology. Experiments on the relative influence of genotype, environment and baker on the sensory quality of breads were developed to improve knowledge on quality processes. This led us to design a bread-making methodology that optimizes the cereal taste in the bread to ease the cultivar screening on sensory criteria. This protocol, completed with experimental design is providing an integrated methodology to develop decentralized participatory plant breeding initiatives with a strong focus on sensory quality improvement.

### Background

The industrialisation of the bread sector has led to the homogenization of the market, from the cultivated varieties (pure lines) to the end product. Last ten years, with the development of the organic sector and the expectation of local products suited by some consumers, a new sector of artisanal bread made by farmers-bakers emerged in some EU countries. They make bread from their own wheat production, so breads quality relies on the quality of the harvested wheat. Some old cultivars and landraces seem well adapted for these organic farming and artisanal-baking practices. Moreover, they show higher nutrients and minerals contents than modern varieties and promising sensory potential. Farmers-bakers are confronted with quality variations, depending on the year and genotypes. They need to know how to adapt their breeding and baking practices to produce bread of good and stable quality.
The sensory qualities of bread, like nutritional quality, are influenced by numerous factors. The influence of farming system, milling and baking technique including flour type and fermentation (Katina et al., 2006; Khilberg et al., 2004), and genetic structure have all been investigated (Ploeger et al., 2008; Starr et al., 2013). In order of importance, the factors identified are milling technique, baking practice (fermentation type and time, kneading intensity, etc.), genotype and finally farming system. None of these studies have assessed simultaneously genetic, environmental and baking factors.

### Main chapter

### Material and methods

To integrate sensory criteria in the breeding process of wheat bread, two experiments have been implemented in the framework of SOLIBAM
The first experiment aimed to evaluate the relative effect of the environmental, genetic and baker factors on the end-use qualities (technologic and sensory). Three genetics structures (a pure line, a population and a mix of population) were cultivated on four farms and compared. The quick and reliable Napping method was used for the sensory assessments (8 test sessions in 2 years). Each year, breads processed by five bakers with flour from one genotype grown in four environments were assessed. The last year session evaluated the genotype by environment interaction on end-use qualities.
The second experiment concerned the breeding levers. The objective was to identify and characterized genotypes of sensory interest. Farmer's knowledge and practices were questioned in the light of sensory analyses. Empirical knowledge was gathered from 11 grain farmers (farmers-bakers) via semi-structured interviews aiming at identifying breeding strategies linked to end-use quality. The morphological and sensory characterization of some farmers' wheat was then used to validate the patterns identified in the interviews. To evaluate the sensory properties of farmer's wheat mix, sensory profiles were established by a sensory panel composed of trained farmer-bakers

### Results

The first experiment revealed that the three studied factors (the environmental, the genetic and the baker) have a significant effect on the end-use qualities. However, the dominant factor remains the baker who impacts both textural and gustatory properties essentially through the fermentation process (sourdough quality, fermentation time…). But for the same baking practices, quality variations have been shown when different flours are used (figure 1) which supports the interest in breeding wheat in its own farm. The environmental factor appears to modify essentially textural properties and the genetic factor impacts the taste. The second experiment allowed us to identify phenotypic markers of quality. Their validation with further experiments should ease the integration of sensory criteria in the breeding process.
To optimize the sensory measures, parameters of the Napping method were studied and confronted with the consensus among sensory panellist (reliability indicator). This led us to design an "optimized" Napping test and to a bread-making methodology, that optimize the cereal taste in the bread to ease the cultivar screening on sensory criteria. This protocol, completed with experimental design provided an integrated methodology to develop decentralized participatory plant breeding initiatives with a strong focus on sensory quality improvement. A technical booklet with methodological guidelines from the experimental design to the sensory evaluation, including baking process will soon be published for stakeholders.

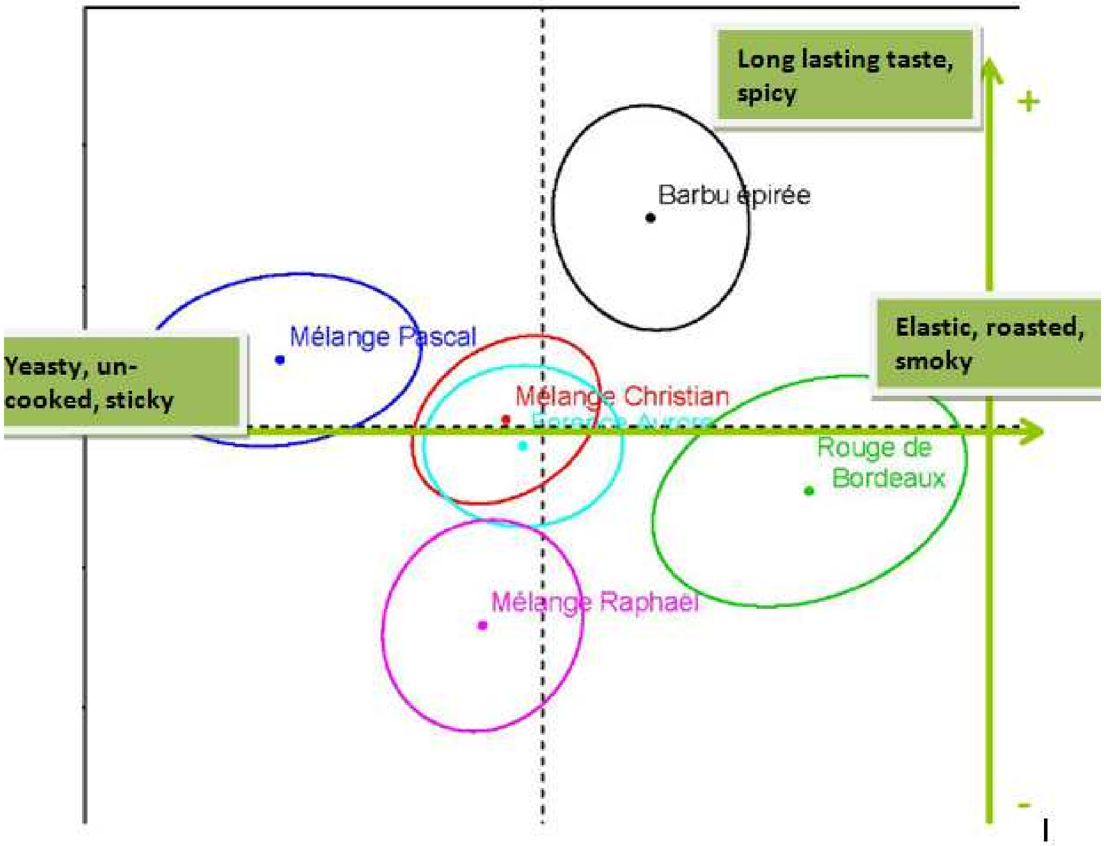


**Figure 1. Multidimensional profile of six breads made by one baker and from six “genotypes by environments” flours (loading plot of the PCA model on the discriminant descriptors for the two principal components PC1 et PC2 (53 and 31% respectively),**

Please make pictures as shown (figure 2).

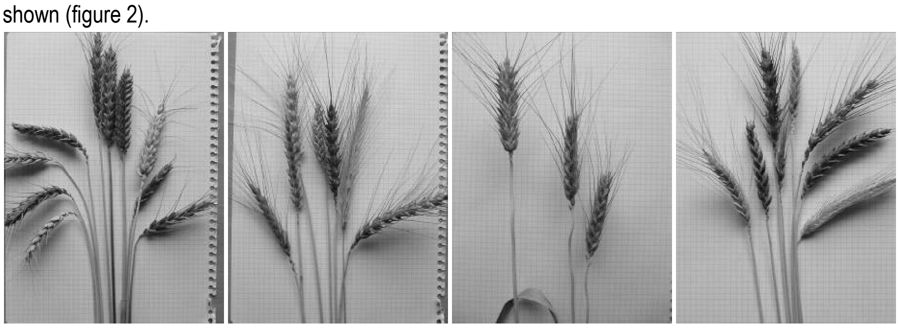

**Figure 2. Diverse farmer’s wheat mix characterised from interview (from left to right: ‘Mélange Christian’, ‘Mélange Stéphane’,’barbu d’épirée’, ‘Mélange Pascal’**

**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

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# Processing and Baking Quality of Organic Winter Wheat in Switzerland

## The influence of cultivar, environment and their interaction and stability analysis

SAMUEL KNAPP, ROSALIE AEBI, JÜRG HILTBRUNNER[1]

[1] Agroscope, Institute for Plant Production Sciences IPS, Reckenholzstrasse 191, 8046 Zürich, Switzerland, www.agroscope.admin.ch, juerg.hiltbrunner@agroscope.admin.ch

**Key words:** *Triticum aestivium*, organic farming, baking quality, stability, GxE interaction

**Summary:** Processing and baking quality traits of cultivars of winter wheat grown under organic conditions have been recorded. Analysis of variance has revealed that yield, protein content and zeleny are strongly influenced by the environment whereas the quality traits extensograph area and bread volume showed a high genotypic variance component and high heritability. This allows for efficient selection and cultivar recommendation. The considerably low environmental effect on these quality parameters indicate that also under low-input conditions flour of good quality can be produced if appropriate cultivars are chosen. Stability estimates showed high variation amongst cultivars and the usage of such estimates is suggested to be used in cultivar recommendation to enable more stable levels of yield and quality across environments and years.

### Background

Bread quality is dependent on the dough processing and baking properties of the flour used. Effects of cultivar, site specific environmental factors, management and their interactions on these properties have been investigated before, but rarely under organic conditions. Knowledge about the magnitude of the sources of variation is important for breeders as well as for extension to develop best strategies for an efficient recommendation. Traits with a high genotypic variance component facilitate common recommendation whereas traits with a high cultivar x environment (CxE) interaction hinder common recommendation but can be exploited by either local selection or specific recommendation. Since with increasing extensification site specific conditions have a greater impact, CxE interaction becomes more important (Cooper and Hammer, 1996). In order to evaluate, whether specific recommendation could increase overall levels of production and quality, the impact of wheat cultivar and the sites-specific factors were investigated.

### Main chapter

*Material and Methods*

Within the Swiss cultivar testing network of winter wheat for organic farming, 10 cultivars have been grown at 9 organically managed sites in the years 2011 - 2013. Processing and baking parameters have been recorded. Variance components and Shukla's stability variance (Shukla, 1972) were analysed with SAS 9.2.

*Results*

Analysis of variance components revealed a strong environmental effect, low heritability and a CxE interaction term of 13.9 to 22.3 percent for grain yield (GY), grain protein content (GP) and zeleny sedimentation value (SED) (Table 1). For these traits specific cultivar recommendation can lead to better performances at each site. Both, extensograph area (EAR) and loaf volume (LV), showed high levels of genotypic effect, which is also confirmed by the heritabilities of 0.71 and 0.64, respectively. The performance of these quality traits is thus mostly influenced by the cultivar and less by the environmental conditions meaning that common cultivar recommendation is possible for these traits.

Table 1: Variance components, percent of the sum of cultivar, environment and cultivar x environment interaction, and heritability for yield and quality traits[a] of 10 winter wheat cultivars grown at 9 organically managed sites in Switzerland over three years (2011-2013).

| Source of Variation | GY | | GP | | SED | | EAR | | LV | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variance components | | | | | | | | | | |
| Cultivar | 3.35 | *[c] | 0.22 | * | 10.54 | * | 849.14 | * | 27346.00 | * |
| Environment | 99.11 | *** | 1.30 | *** | 90.21 | *** | 142.45 | ** | 3559.12 | * |
| Rep | 8.35 | | 0.10 | | 1.80 | | --[b] | | --[b] | |
| Cultivar x Environment | 16.54 | *** | 0.44 | *** | 21.93 | *** | 197.40 | *** | 12130.00 | *** |
| Residual | 15.28 | | 0.26 | | 9.04 | | 1.04 | | 1.01 | |
| Percent of the sum of cultivar, environment and cultivar x environment interaction variance | | | | | | | | | | |
| Cultivar | 2.8 | | 11.2 | | 8.6 | | 71.4 | | 63.5 | |
| Environment | 83.3 | | 66.5 | | 73.5 | | 12.0 | | 8.3 | |
| Cultivar x Environment | 13.9 | | 22.3 | | 17.9 | | 16.6 | | 28.2 | |

| | | | | | |
|---|---|---|---|---|---|
| Heritability ($h^2$) | 0.03 | 0.11 | 0.09 | 0.71 | 0.64 |

[a] GY = grain yield, GP = grain protein, SED = sedimentation value, EAR = extensograph area, LV = loaf volume

[b] no term for replication was estimated as analysis was carried out on pooled samples per cultivar within trials

[c] significant ($H_0$:Var=0,Wald Z-test) at *:P<0.05, **:P<0.01, ***:P<0.001

Means and estimates of stability variance are presented in Table 2. There is significant variation between cultivars at each trait. The cultivar Ekolog, that has been selected for organic conditions, has the highest yield. The cultivars Runal and Suretta show the lowest GY but the highest GP. A very pronounced difference of means per cultivar is shown at LV: the best cultivar Runal having a LV of 1935 ml, almost 1.5 times greater than the cultivar with lowest LV, A7T, having a LV of only 1396 ml. No cultivar is among the best ones over all traits and vice versa.

Table 2: Means and Shukla's stability variance (S.V.) for yield and quality traits[a] of 10 winter wheat cultivars grown at 9 organically managed sites in Switzerland over three years (2011-2013).

| Cultivar | GY (dt/ha) | | GP (%) | | SED (ml) | | EAR (cm2) | | LV (ml) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S.V. | Mean | S.V. | Mean | S.V. | Mean | S.V. | Mean | S.V. |
| A7T.9 | 42.6 | 9.6 | 13.71 | 0.08 | 62.8 | 27.3 | 182.9 | 285.0 | 1396 | 42535 |
| Arnold | 43.8 | 26.6 | 13.70 | 0.52 | 65.9 | 11.3 | 141.4 | 467.0 | 1851 | 8581 |
| Butaro | 42.7 | 9.6 | 12.66 | 0.51 | 59.1 | 48.2 | 100.3 | 165.0 | 1709 | 10409 |
| Ekolog | 44.1 | 13.7 | 13.41 | 0.48 | 59.1 | 23.6 | 81.0 | 169.3 | 1767 | 4956 |
| Lorenzo | 41.3 | 0.9 | 14.02 | 0.25 | 67.9 | 5.9 | 150.3 | 229.7 | 1789 | 5573 |
| Montdor | 42.9 | 27.7 | 13.19 | 0.12 | 62.8 | 11.9 | 119.7 | 128.6 | 1777 | 5874 |
| Runal | 39.9 | 5.7 | 14.24 | 0.74 | 61.7 | 8.8 | 138.9 | 259.6 | 1945 | 17638 |
| Suretta | 39.2 | 32.0 | 14.29 | 1.17 | 58.2 | 21.4 | 79.1 | 130.8 | 1792 | 12649 |
| Titlis | 41.5 | 6.9 | 13.22 | 0.14 | 64.9 | 24.7 | 116.7 | 193.7 | 1885 | 8861 |
| Wiwa | 42.1 | 6.9 | 13.35 | 0.29 | 63.7 | 32.8 | 127.6 | 127.5 | 1765 | 9097 |
| s.e.[b] | 2.14 | | 0.26 | | 2.11 | | 4.83 | | 40.8 | |
| Mean | 42.0 | | 13.58 | | 62.6 | | 123.8 | | 1768 | |
| Nr. of trials | 27 | | 27 | | 26 | | 15 | | 12 | |

[a] GY = grain yield, GP = grain protein, SED = sedimentation value, EAR = extensograph area, LV = loaf volume

[b] s.e. = standard error of the cultivar means

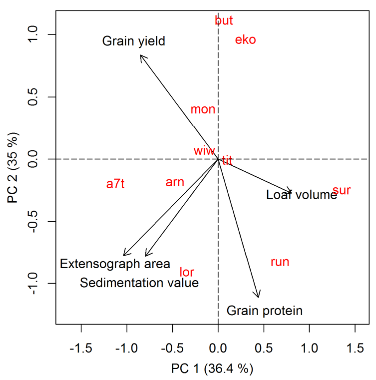


Figure 5 Principal component analysis of traits by cultivar means. Cultivars: a7t = A7T.9, arn = Arnold, but = Butaro, eko = Ekolog, lor = Lorenzo, mon = Montdor, run = Runal, sur = Suretta, tit = Titlis, wiw = Wiwa

This complex genetic tradeoff between traits is also confirmed by principal component analysis (PCA) over cultivar means (). GY is negatively correlated with GP and LV. The cultivars Lorenzo, Runal and Suretta group towards high GP and LV, whereas the cultivars Butaro and Ekolog are better in GY. EAR is strongly correlated with SED and LV is correlated with GP.

Stability analysis reveals pronounced differences between the cultivars investigated (Table 2). According to Lin et al. (1986) Shukla's stability variance corresponds to the Type II concept of stability: a genotype is stable if its response to environments is parallel to the mean response of all genotypes in the trial. Cultivar Lorenzo is the most stable at GY and SED. A7T.9, has the lowest mean LV and is the most unstable at LV. Similar to the cultivar means, cultivars that are stable at one trait are not necessarily among the stable ones at other traits and vice versa.

*Discussion*

In contrary to the strong influence of environmental factors on GY, GP and SED, it was found that quality characteristics like EAR and LV are strongly influenced by the cultivar and less by environmental factors. Although all trials in this study were under organic management the strong effect of cultivar on these baking quality traits suggest that sufficient baking quality can also be produced under low-input conditions if appropriate cultivars are chosen. However, the traits considered are only a subset of a multitude of traits related to processing and baking quality and the inter-relation of these is even more complex. In order to facilitate the identification of breeding goals and allow for classification of cultivars for recommendation, weighted index-schemes have been introduced (e.g. Saurer et al. (1991) for Switzerland).

Stability estimates did not correlate with the means of the corresponding trait and estimates did vary substantially among cultivars. As environmental variation between sites is assumed to be greater under organic management and due to seasonal variation and unpredictability, stability is of increased importance. Using stability estimates as an additional measure in breeding and recommendation could lead to more stable and secure levels of production.

For traits that show that show pronounced levels of CxE interaction, breeding for general adaptation to different environments and different management intensities as well as common cultivar recommendation is complicated. However, CxE interaction can also be exploited by breeding and recommendation for e.g. specific regions or management intensities. To identify groups of environments for which the same cultivars can be recommended, environments need to be characterized by climatic, soil and management properties and prevailing pests.


#### Acknowledgements

The project is partly funded by the EU Seventh framework programme „Food, Agriculture and Fisheries, Biotechnology“ FP7 KBBE- 245058; and by Fenaco, Swissmill, Swisssem and BioSuisse (Switzerland).


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# The identification of wheat genetic resources with high dietary fiber content

KAROLINA BEDE[1], MARIANN RAKSZEGI[1], PÉTER MIKÓ[1], MÁRIA MEGYERI[1], LÁSZLÓ LÁNG[1], ZOLTÁN BEDŐ[1]

[1] Centre for Agricultural Research, HAS, Hungary, www.agrar.mta.hu, bede.karolina@agrar.mta.hu

**Key words:** wheat, organic, breeding, dietary fiber, arabinoxylan

**Summary:** The quality properties of different variety mixtures and composite cross populations were studied with the aim of identifying genetic resources with high dietary fiber content for organic farming purposes and in order to cultivate and examine the effect of these components on the end-use qualities. We could detect two populations and variety mixtures which had significantly higher water extractable arabinoxylan (WEAX) content, than most of the studied samples, with positive effect on the human health. These populations are promising dietary fiber resources and suitable for organic farming purposes.

## Background

Arabinoxylan (AX) is quantitatively the most important dietary fiber polysaccharide in wheat (Izydorczyk and Biliaderis 1995). Soluble AX has the good property of reducing the risk for coronary heart disease and type II diabetes (Moore et al., 1998, Lewis and Heaton, 1999). Furthermore insoluble AX particularly lowers transit time and augments fecal bulk, defecation frequency (AACC, 2001) and binding of carcinogens (Moore et al., 1998).
Apart from their nutritional relevance, AX is also important from a technological point of view as it strongly affects wheat functionality during cereal processing, for example, in breadmaking (Courtin and Delcour 2002, Goesaert et al. 2005). AX primarily influence gelation procedure and water absorption.
In this study the aim was to identify new genetic resources with high dietary fiber content and suitable for organic farming purposes and to examine the effect of these components on the end-use qualities.

## Main chapter

Physical, compositional and breadmaking properties of Mv-Emese, English-Composite, Elite-Composite, YQ-CCP, YQ-MIX, INRA-60parent-CCP, NIAB-Elite-CCP, and NIAB-Elite-MIX samples grown in five countries (A, CH, FR, UK,HU) at low-input and organic sites in three consecutive years (2011-13) were analysed. According to the results two populations (Elite-Composite and English-Composite) were identified, which had significantly higher WEAX (mg/g) content (9,23; 8,52; respectively), than most of the studied samples. The increased WEAX content had significant effect on the water absorption of the flour. The higher WEAX content resulted higher water absorption of the flour too. Here, we show the results of the Hungarian growing site, but similar tendencies were registered at the other countries and their sites.

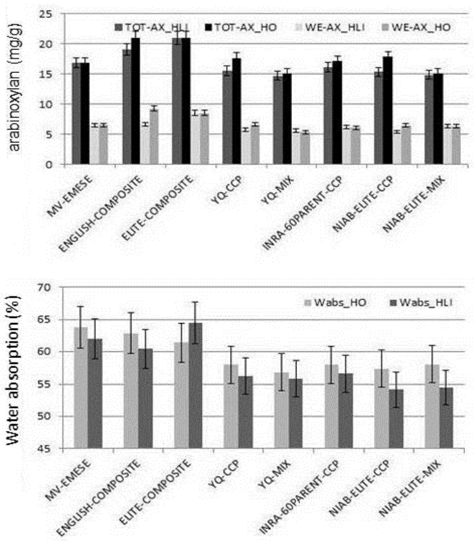


Figure 1. Arabinoxylan content (mg/g) and water absorption (%) of different composite populations in three consecutive years (2011-13) at organic and low input growing sites (HU) (TOT-AX: Total arabinoxylan content, WE-AX: Water extractable arabinoxylan content, Wabs: water absorption, H: Hungary, LI:low input growing site, O: organic growing site)

YQ-CCP wheat population (ORC, UK) was mixed in 1:2 and 2:1 ratio with Stefanus or Midas in Austria, with Mv-Suba or Mv-Regiment in Hungary and with Alchemy or Solstice in the UK. Elite-composite was also mixed with Mv-Suba or Mv-Regiment. Mixes of genotypes were planted in the country where they were produced and were analysed together with the controls. The physical, compositional and breadmaking quality traits of these variety mixtures were studied in 3 consecutive years (2011-13). As Mv-Suba, Elite-Composite and English-Composite have significantly higher WEAX content at organic site, the mixtures of these also have significantly higher WEAX content than the other varieties and mixtures. The TOTAX content of Mv-Suba and Elite-Composite was also high at organic site resulting high TOTAX content in the mixtures too. No significant differences were recognised in WEAX content of the parental lines or the mixtures at low-input sites. The increased WEAX content had significant effect on the water absorption of the flour.

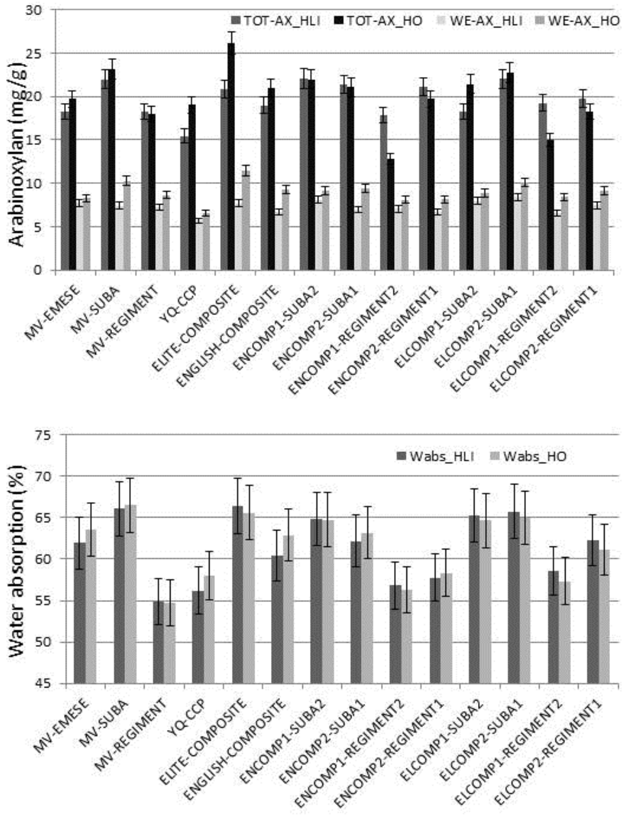


Figure 2. Arabinoxylan content (mg/g) and water absorption (%) of different variety mixtures in three consecutive years (2011-13) at organic and low input growing sites (HU) (TOT-AX: Total arabinoxylan content, WE-AX: Water extractable arabinoxylan content, Wabs: water absorption, H: Hungary, LI:low input growing site, O: organic growing site)

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# Application of FTIR-ATR to maize flour and breads
## Is it possible to predict the total phenolic content and antioxidant capacity?

ANDREIA BENTO DA SILVA[1*], MARIA FRANCESCA GRECO[2], ANA LIMPO[3], CLÁUDIO ALMEIDA[4], ELSA MECHA[1], ANA TERESA SERRA[1], ADELE PAPETTI[2], MARIA CARLOTA VAZ PATTO[1], MARIA DO ROSÁRIO BRONZE[1,3,4]

[1] Instituto de Tecnologia Química e Biológica, Oeiras, Portugal,
[2] Dipartamento di Scienze del Farmaco, Università di Pavia, Pavia, Italia,
[3] Faculdade de Farmácia da Universidade de Lisboa, Lisboa, Portugal,
[4] Instituto de Biologia Experimental e Tecnológica, Oeiras, Portugal

**Key words:** maize, *broa*, polyphenol content, antioxidant capacity

**Summary:** Maize is one of the most consumed cereals worldwide and, in Portugal, it can be used to produce "*broa*", a traditional maize bread. In order to develop a prediction model for determination of total phenolic content and antioxidant capacity in maize flour and *broas*, Fourier transform infrared spectroscopy (FTIR) attenuated total reflectance (ATR) analyses were performed. Results show that the proposed method may be used for a rapid screening of total phenolic content in maize flour.

**Background**

In Portugal, maize bread is consumed mainly in the form of a traditional bread named *broa* (Vaz Patto *et al.* 2007). Phenolic compounds, mainly hydroxycinnamic acids (ferulic and *p*-coumaric acids) represent important maize constituents (Lopez-Martinez *et al*., 2011) which exhibit antioxidant capacity (Ramos-Escudero *et al*., 2012).
Total phenolic content of samples can be determined using *Folin-Ciocalteu* colorimetric method (based on oxidation of phenolic compounds by *Folin-Ciocalteu* reagent) and by HPLC (high performance liquid chromatography) analyses, considering chromatogram total areas at 280nm.
The antioxidant capacity can be determined by ORAC (Oxygen Radical Absorbance Capacity) assay. In this method, the antioxidant capacity of samples is evaluated by the inhibition of fluorescein (FL) oxidation by peroxyl radicals (ROO·) originated by AAPH – 2',2'-Azobis (2-amidinopropano) dihydrochloride (Ou *et al*., 2001).
FTIR-ATR, prediction models for total phenolic content and antioxidant capacity, in maize flours and maize breads, were developed, using Partial Least Squares (PLS). Infrared spectrometry is an excellent tool for screening foods, since it is a rapid and simple method (Lu and Rasco, 2012).

**Main chapter**

*Introduction*

Eleven maize varieties cropped by farmers in the central region of Portugal were selected based on a diversity criteria, and they were used to produce *broa*, a Portuguese traditional maize bread, produced with more than 50% of maize flour, and 20 to 50% of rye and wheat flours. A commercial flour was also studied for comparison. The same recipe was used in all breads prepared. The total phenolic content and antioxidant capacity of the extracts prepared from the 12 flours and breads were determined, and FTIR-ATR analyses were also performed.

*Material & Methods*

Total phenolic content of both maize flours and maize breads were determined using *Folin-Ciocalteu* method and HPLC analyses. Concerning the *Folin-Ciocalteu* assay, the absorbance of the resulting blue colour originated by $Na_2CO_3$ was measured at 725nm using a Beckman_DU®–70 Spectrophotometer. For the HPLC analyses, the total phenolic content was determined by measuring the total peak areas detected in the chromatograms at 280nm, using a HPLC Thermo Finnigan (model Surveyor) equipped with a RP-18 (5µm) 250×4–Lichrocart® column and a RP-18 (5µm) pre-column.
Antioxidant capacity by ORAC assay was also performed. The fluorescence emitted by the reduced form of FL was measured and read per minute at 515 nm after excitation at 493 nm (fluorescence spectrophotometer with thermostatic bath, model Cary Eclipse, Varian Ltd, Surrey, UK) during 30 minutes.
The 12 maize flours and 12 maize breads were analysed using a Thermo Scientific FTIR Spectrometer (San Jose, USA), Class 1 Laser Product Nicolet 6100, which include an accessory with a ZnSe ATR crystal. All the data were imported to *Unscrambler X* software. PLS regression was used to analyse data from FTIR spectra, in order to predict total phenolic content and antioxidant capacity. It was considered the spectral region from 1700.935 to 649.9039 $cm^{-1}$ to avoid water interference.

*Results*

Maize breads showed higher total phenolic content and antioxidant capacity than maize flours. Using *Folin* method, the total phenolic content of maize flours ranged from 66.33 to 101.74mg GAE (gallic acid equivalents)/100g dw (dry weight). The total phenolic content of maize breads ranged from 152.16 to 225.08mg GAE/100g dw. The antioxidant capacity of maize flours ranged from 931.46 to 2358.59µmol TEAC (trolox equivalents antioxidant capacity)/100g dw and maize breads from 1674.02 to 3776.19 µmol TEAC/100g dw. Traditional maize breads showed more antioxidant capacity than the commercial variety.

As expected, it was possible to strongly correlate the total phenolic content determined by HPLC and *Folin* method ($r^2 = 0.925$). Antioxidant capacity was moderately correlated with phenolic content ($r^2$=0.584 and $r^2$=0.677 for *Folin* method and HPLC areas at 280nm, respectively).

It was also possible to correlate the total phenolic content of maize flour obtained by *Folin-Ciocalteu* method and FTIR data, using the PLS calibration model. However, it wasn't possible to correlate FTIR data with ORAC assay.

*Discussion*

FTIR-ATR analyses of maize flour may be used for a rapid screening of total phenolic content in maize flour, since it was possible to obtain a good correlation between FTIR data and *Folin-Ciocalteu* method. However, FTIR-ATR analysis may not be useful to predict antioxidant capacity determined by ORAC assay. Since ORAC and Folin methods aren't strongly correlated, the antioxidant compounds present in samples may not interact with peroxyl radicals, but instead with other oxidant reagents. These are preliminary results and a higher amount of data must be used in order to validate this model.

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# Maize diversity in farmers' hands.
## A comparative analysis of SinPre

CLAUDIA BRITES[1], MARA L. ALVES[2] , JOANA LAIRES[1], DANIEL GASPAR[1], GRACIANO SPENCER[1], MARIA CARLOTA VAZ PATTO[2], PEDRO MENDES-MOREIRA[1,2]

1 ESAC, Portugal, www.esac.pt, pmm@esac.pt
2 ITQB, Portugal, http://www.itqb.unl.pt, cpatto@itqb.unl.pt

**Key words:** Synthetic population, *Zea mays*, participatory plant breeding

**Summary:** Synthetic populations can be generated through several methodologies. In this specific case ‘SinPre’ was obtained through the crossing of 12 maize populations using a polycross method. The 12 maize populations were intermated in natural isolation from 2006 to 2010. The 2010 cycle were distributed to farmers in different environments for mass selection. Evaluation of ‘SinPre’ was made after one to two cycles of selection in five locations. Data were analysed via descriptive statistics, ANOVA and Sheffe methods. The results indicate that the second cycle of ‘SinPre’ selected at “Quinta da Conraria” was significantly higher both for initial population and for the other selections.

### Background

The increase in public awareness and growing demands of germplasm adapted to different climatic conditions and farming systems can be attributed to the increasing importance of sustainable farming systems like organic and low input, that need specific adapted varieties. The creation of composite populations and its introduction into different agroclimatic areas can result in a stable population highly adapted after some cycles of selection. The population adaptation to a specific environment through mass selection it is a simple breeding process that can easily be done by farmers in participatory plant breeding.

The Participatory Plant Breeding project VASO that started in 1984 give rise to the development and improvement. of several maize populations (e.g. ‘Pigarro’, ‘Fandango’, ‘Amiúdo’). From 2006 to 2010 a synthetic maize population ‘SinPre’ was obtained. Under the SOLIBAM project, WP6, ‘SinPre’ was distributed to farmers. Farmers selected ‘SinPre’ during one to two years and its evolution was evaluated in multilocation trials.

### Introduction

A composite variety is obtained by making a mixture of the parental components and then by randomly matting the mixture. A composite variety of maize – ‘SinPre’, was obtained through the crossing of 12 maize populations (10 Portuguese landraces and 2 American populations) using a polycross method based on 'Nutica' experience (Mendes-Moreira et al., 2009). The 12 maize populations were intermated in natural isolation (from other maize) from 2006 to 2010. Two equal sets of twelve rows were organized from the earliest to later flowering population and vice-versa for the second set. Per each row, we have selected three to five ears to be used in the next season. The border was constituted by the equal amount of seed of each population. In 2010, a bulk of the best ears was obtained and distributed to farmers in different agroclimatic regions of Portugal.

The purpose of this new synthetic population was to provide farmers a new variety, with high levels of diversity that could be adapted to their needs. Farmers applied mass selection procedures under participatory plant breeding and a sample of each farmer cycle of selection was kept in cold storage. The last cycle of selection obtained by the three farmers was compared among them and with the initial population.

The aim of the present work was to evaluate and compare the ‘SinPre’ evolution done by the farmers in different agroclimatic conditions.

### Material and Methods

A sample of ‘SinPre’ obtained in 2010 at Braga was distributed to three farmers in three different agroclimatic conditions for selection. Selection was done during two years for Braga and for Quinta da Conraria and only one year at Lousã because of a wild boar attack. Seed samples were cold stored. The entries used were the initial cycle and last cycles of selection per each location.

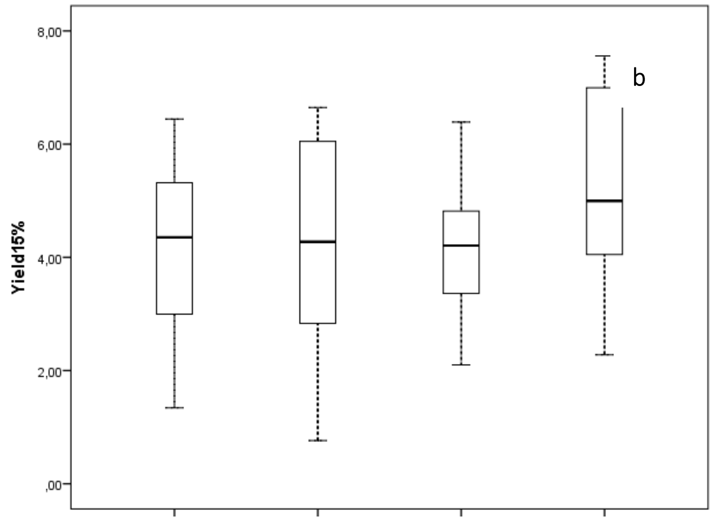
To proceed with selection cycles, comparison trials were established in five locations (Montemor, Lousada, Caldeirão, Vouzela and Tomar). In each environment, a complete randomized block design, with three replications, was used.

Each plot consisted of two rows with 6.4 m planted row with an inter-row distance of 0.75 m. Each plot was overplanted by hand and thinned at the V7 growth developmental stage for a stand of approximately 50000 plants/ha. Plots were mechanically and/or hand-weeded and managed following common agricultural practices for maize in the region. The HUNTERS method (High, Uniformity, aNgle, Tassel, Root lodging and Stalk lodging) plus grain yield at 15%moisture (Yield), ears per ha and cob/ear ratio at harvest were measured. All the plots were harvested by hand.

Data were analysed using descriptive, ANOVA and Sheffe test.

### Results and discussion

Significant differences for environment were observed for tassel, root and stalk lodging so as moisture content. For G x E root lodging was the only observed trait. For the genotype significant differences for were observed for grain yield and ear placement (Figure 1 and Table 1). The cycle C2 of Quinta da Conraria was significantly different from the initial cycle (C0 Braga) for ear placement. In addition we observe approximately 14% of gain per cycle per year both for C1 Carmen and C2 Q. da Conraria. For grain yield, C2 Q.Conraria was significantly different from the other cycles and had a 14% gain per cycle per year of selection.




**SinPre** **C0 Braga** **C2 Braga** **C1 Carmen** **C2 Q. Conraria**

Figure 1. Initial population of SINPRE obtained at Braga (C0 Braga) compared with three cycles of mass selection obtained by three farmers under mass selection.

Table 1: Traits where significant differences were observed for genotype, respective means coefficient of variation, Sheffe test and percentage of gain per year obtained.

| Trait | Cycle | Mean | CV | Sig. Dif. | %G/Y |
|---|---|---|---|---|---|
| E | C0 Braga | 3.929 | 18.6 | a | |
| | C2 Braga | 4.385 | 17.5 | ab | 0,00 |
| | C1 Carmen | 4.467 | 23.7 | ab | 13,70 |
| | C2 Q. Conraria | 5.000 | 16.9 | b | 13,64 |
| Yield15% | C0 Braga | 4.085 | 37.0 | a | |
| | C2 Braga | 4.670 | 35.5 | a | 7,16 |
| | C1 Carmen | 4.081 | 29.0 | a | -0,11 |
| | C2 Q. Conraria | 5.234 | 31.7 | b | 14,06 |

* Different letters indicate significant differences at P<0.05
CV - Coefficient of Variation
%G/Y - indicate the gain of selection per year

## Conclusions

The results obtained indicate that potential exist to increase yield of 'SinPre' and that under different selection environments the results can be different.

## Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM To Solibam Portuguese farmers.

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# Khorasan wheat case study

## Variability of phytochemical profiles in organic wheat production

GIOVANNI DINELLI[1], ALESSANDRO DI LORETO[1], ILARIA MAROTTI[1], RAFFAELLA DI SILVESTRO[1], SARA BOSI[1], VALERIA BREGOLA[1], VERENA STENICO[1], ROBERT QUINN[2]

[1] Department of Agricultural Sciences, University of Bologna, Italy, www.scienzeagrarie.unibo.it, giovanni.dinelli@unibo.it

[2] Kamut International Ltd, Montana, USA, www.kamut.com, bob@quinnorganic.com

**Key words:** khorasan wheat, antioxidants, fibre, bioactive compounds, organic

**Summary:** recently, KAMUT®Khorasan wheat (*T. turgidum* ssp. *turanicum)* has attracted great attention because of its better health-related composition. The research aimed at determining the nutrient, fiber and antioxidant composition of KAMUT® grain as a function of the growing location and understanding the environmental dynamics affecting the phytochemical profile. The research underlined the strong influence of the environmental factors on crop productivity and quality. The choice of a growing location in which the accumulation of health-promoting compounds is stimulated by specific climatic conditions may be a key factor for the production of organic wheat foodstuff in the functional food scenario.

### Background

It raises a great deal of recent interest that organic wheat constitutes valuable nutraceutical raw material for healthy food production and special dietary uses. In particular, KAMUT®Khorasan wheat (*T. turgidum* ssp. *turanicum)* has attracted great attention because of its better health-related composition, especially regarding to minor components of the grains (dietary fibers, resistant starch, phenols) and its specific functional properties (antioxidant, antitumoral and prebiotic activities).

Dietary fiber (water soluble fraction, SDF and water-insoluble fraction, IDF) is beneficial to human health; in particular, SDF is known to decrease serum cholesterol, prostprandial blood glucose and insulin levels in human, while IDF has direct effects on the colon by preventing constipation and cancer. Dietary fiber includes also resistant starch, classified as the starch fraction that is physically inaccessible to enzymes and resists to digestive processes. Resistant starch has high prebiotic activity, indeed it can resist digestion and reach the colon thus functioning as substrate for intestinal microbial flora.

The bran layer of wheat grains is relatively rich in antioxidants compounds. Polyphenols are a large group of phytochemicals including flavonoids (the most representative in wheat kernel), phenolic acids, coumarins, tannins, lignans and stilbens. All polyphenols present high antioxidant activity, arresting the damaging oxidative chain reaction caused by free radicals (peroxide, $O_2$), thus preventing many degenerative human diseases (i.e. heart disease and cancer).

Literature reports evidenced the effects of genotype and environmental conditions on bioactive compound composition in wheat kernels (Mpofu et al, 2006; Shewry et al, 2010). Currently, few data about fiber composition and antioxidants of KAMUT®Khorasan grains are available in literature and, as far as we know, the changes of those compounds as a function of year of cropping and growing location have been never investigated. This is the first study in which an organically grown crop is investigated in a region of such broad extension (180000 $km^2$) including several different environments.

### Main chapter

The research aimed at determining the nutrient, fiber and antioxidant composition of KAMUT® grain as a function of the growing location and understanding the environmental dynamics affecting the phytochemical profile. The study involved an area covering approximately 180000 $km^2$ (Canada and USA, Figure 1) which included several different farms and environments.

The grain collection consisted of 115 samples harvested at 109 different locations in 2010. Each grain sample was analyzed for the antioxidant compounds (polyphenols, flavonoids) and dietary fiber components (soluble and insoluble dietary fibers, resistant starch) and results were elaborated using Geographic Information System (GIS) to develop quality maps. Moreover, the elaboration of data concerning grain yield, test weight and protein content allowed a comparison between the agronomic performance and the nutritional/nutraceutical profile of KAMUT® grain.

Concerning the agronomic performance, the results evidenced high heterogeneity among samples; in fact yield, test weight and protein content varied within the intervals 0.28-2.81 t/ha, 62.4-79.6 kg/hl and 10.9-15.8 g/100g, respectively.

The quality map showed that KAMUT® grains with low test weight were collected at the western and eastern margin of the production area. Furthermore, comparing the map obtained for the productivity and that of the protein levels, it can be observed that the farms located in the East area provided the lowest yield but the highest protein levels. Differently, the farms of the West margin provided the KAMUT® grains richest in proteins while maintaining high productivity.

Mpofu et al, 2006 and Shewry et al, 2010 reported as the content of health-promoting compounds is strongly influenced by environmental conditions. In facts, the investigated wheat grains showed great variability for the beneficial compound investigated: total polyphenol and flavonoid contents varied between 91.1-2.46 and 20.6-93.2 mg/100g, respectively, the insoluble fibre content varied between 11.2 and 19.2 g/100g, while the soluble dietary fraction showed less heterogeneity (11.2-4.9 g/100g). As concerns starch, statistically significant differences were observed among farms both considering the resistant and total starch amounts (0.22-1.78 and 52.2-69.2 g/100g, respectively).

Quality maps that showed the variability of the phytochemical amounts among the North American farms were elaborated and allowed the identification of areas in which bioactive compounds were highly accumulated in the wheat grains. Locations with high free polyphenol content exhibit low bound polyphenol amount and viceversa. Considering that, free polyphenols are not lost during sieving, while bound phenolic compounds are discarded as mainly present in the bran, farms located in the eastern region of the investigated area are suitable for the production of sieved flour/semolina caracterized by high content of free polyphenols. As regards soluble dietary fibre and resistant starch content, several farms located throughout the production area, provided wheat grains characterized by high value of this compounds. Therefore Kamut® grains collected at these locations are suitable for the preparation of specialty products with enhanced prebiotic properties.

The research underlined the strong influence of the environmental factors on crop productivity and quality, in terms of nutritional and nutraceutical value. According to the present results, the choice of a growing location in which the accumulation of health-promoting compounds (i.e. polyphenols, fibres) is stimulated by specific climatic conditions may be a key factor for the production of organic wheat foodstuff in the functional food scenario.

**Figure 1. The highlighted area represent  the region of origin of the grain collection analysed in the study**

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# Bioactivity profile of grain legumes:
## Potential organic source for nutraceutical applications

GIOVANNI DINELLI[1], SARA BOSI[1], ILARIA MAROTTI[1], VALERIA BREGOLA[1], RAFFAELLA DI SILVESTRO[1], ALESSANDRO DI LORETO[1], VERENA STENICO[1], STEFANO BENEDETTELLI[2]

[1] DiPSA, University of Bologna, Italy, www.scienzeagrarie.unibo.it, giovanni.dinelli@unibo.it;
[2] DiSPAA, University of Firenze, Italy, www.dispaa.unifi.it/, stefano.benedettelli@unifi.it

**Key words:** grain legumes seed**,** α-amylase activity, α-glucosidase inhibitor, anti-nutritional factors, phenol content, thermal processing

**Summary:** The importance of including a legume crop in organic system rotations is well recognised from numerous studies; benefits include improved soil fertility and structure, weed reduction and pest prevention. In this regard, studies aimed at the setting up of agronomic techniques able to guarantee high and constant *in planta* yields of health-promoting compounds may concur at re-launching legume production. In this context, 22 accessions of grain legumes were screened with the aim of identifying genotypes rich in health beneficial phytochemicals (α-amylase inhibitors, α-glucosidase inhibitors, polyphenols) and with low anti-nutritional compounds (lectins).

### Background

Recently, the presence of bioactive compounds related with health-relevant functionality is raising interest among food processor and consumers. The consumption of legumes has been associated with a decrease risk for a wide variety of chronic and degenerative, such as cancer, obesity, diabetes and cardiovascular diseases.

Legumes are considered as a good source of dietary fiber, carbohydrates, protein and minerals. In addition to these nutritional value, legumes are rich in phytochemical compounds with important biological activities such as antioxidant, antimutagenic, and anticarcinogenic effects (Reynoso-Camacho et al., 2006) In addition, in recent years, extracts from grain legumes have commonly been used in dietary supplements intended to control weight by providing an α-amylase and/or α-glucosidase inhibitor that reduces the adsorption and prevent the digestion of carbohydrates. The hypoglycemic effect of bean extracts may also be utilized as a dietary therapy management for type 2 diabetes. However, these extracts may contain significant levels of certain anti-nutritional components (e.g. lectins and trypsin inhibitors) and as a result may cause adverse effects on human health. When beans are consumed raw or only lightly cooked, the phytohemagglutinin (PHA) fraction, a member of the lectin family, agglutinates red blood cells and induces serious consequences for metabolism and health. A recent study has demonstrated that technological processing treatments used in the production of some commercial supplements decrease but do not effectively remove the anti-nutritional components (Boniglia et al., 2008). For these reasons, the present research evaluates also the influence of thermal processing on food composition and health-relevant functionality .

### Main chapter

22 Accessions of grain legumes (17 *Phaseolus vulgaris*, 3 *Phaseolus coccineus*, 1 *Vigna unguiculata* and 1 *Glycine max* genotypes), grown under organic farming conditions, were screened for beneficial phytochemicals (α-amylase inhibitors, α -glucosidase inhibitors, polyphenols) and anti-nutritional compounds (lectins). In addition, the effect of the thermal processing on bioactive profiles was investigated.

As regards the inhibition of α-amylase activity, the results indicated a slight variability among the white-type and the coloured-type accessions (22.64 ± 10.04% and 22.59 ± 10.44%, respectively) (table 1). The α-amylase inhibitory activity were not correlated with total protein, phaseolin and PHA content. Four accessions of common bean (three coloured-type and one white-type) showed a α -amylase inhibitory activity significantly higher (approximately 30% more) than all other tested accessions. In addition, these genotypes were characterized by unique PHA electrophoretic profiles.

**Table 1: Polyphenol content and % of inhibition activities in white and coloured-type legumes.**

| | Polyphenol content (mg/g seed DW) | | Inhibition of α-glucosidase activity (%) | | Inhibition of α-amilase activity (%) | |
|---|---|---|---|---|---|---|
| Legumes | *raw* | *cooked* | *raw* | *cooked* | *raw* | *cooked* |
| White - Type | 0.88 ± 0.29 | 1.32 ± 0.43 | 23.00 ± 10.44 | 24.76 ± 17.03 | 22.64 ± 10.04 | 27.01 ± 15.09 |
| Coloured - Type | 3.34 ± 0.96 | 2.25 ± 0.44 | 83.64 ± 22.07 | 43.68 ± 11.67 | 22.59 ± 10.44 | 30.35 ± 7.90 |

Conversely, the analysis of α-glucosidase activity showed that dark-colored seeds had a mean inhibitory activity of 83.64 ± 22.07%, whereas light-colored seeds had mean values of 21.11 ± 9.36% (table 1). In addition, the α-glucosidase inhibitory activity was positively correlated with grain color, polyphenol and flavonoid content (figure. 1).

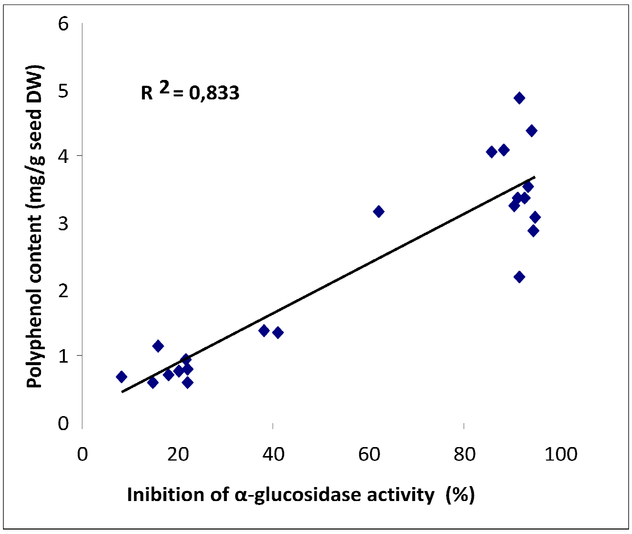


Figure 1. Correlation between α-glucosidase inhibitory activity and polyphenol and content.

For the entire set of accessions, the mean index of erythroagglutinating was 23.4 ± 20.4, without significant differences between the white and the coloured-type legumes. However, besides the *Vigna* spp and *Glycine* spp accessions, one *Phaseolus vulgaris* genotype (DG) did not show any agglutination activity.

Thermal processing resulted in a slight increase in α-amylase inhibition, but a strongly reduced α-glucosidase inhibition and total phenolic content (table1).

Results showed that several of the genotypes investigated represent an intriguing genetic resource for organic nutraceutical applications. Furthermore, the common bean accessions Verdone, Kidney Cina, Roviotto and DG may offer added nutraceutical value, suggesting their use in the development of organic health-promoting products.

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# Proanthocyanidins in common bean (Phaseolus vulgaris L.) genotypes

## Application of Liquid Chromatography and MALDI-TOF-MS!

Elsa Mecha[1] *, Andreia Bento da Silva[1] , Maria Carlota Vaz Patto[1] , Maria do Rosário Bronze[1,2,3]

[1] Instituto de Tecnologia Química e Biológica, Oeiras, Portugal,
[2] Instituto de Biologia Experimental e Tecnológica, Oeiras, Portugal, [3]Faculdade de Farmácia, Universidade de Lisboa, Lisboa, Portugal
[3]Faculdade de Farmácia, Universidade de Lisboa, Lisboa, Portugal

**Key words:** Proanthocyanidin, common bean, HPLC, MALDI-TOF-MS, polymerization degree

**Summary:** Plant genetic diversity influence phenolic composition. Proanthocyanidins represent one of the most important families of phenolic compounds in common bean seeds, being related with degenerative diseases prevention. In order to characterize proanthocyanidins content in 32 different Portuguese genotypes of common bean, chromatographic approach by HPLC (High Performance Liquid Chromatography) was applied, using MALDI-TOF-MS (Matrix-assisted laser desorption/ionization time-of-flight mass spectrometry) for qualitative analysis.

### Background

Portuguese common bean varieties have high genetic diversity with interesting characteristics for plant breeders and consumers. Such diversity is also reflected in phenolic composition. Phenolic compounds, produced as protector agents against biotic and abiotic stress, have been related to chronic diseases (e.g. diabetes, cancer) prevention (Pandey KB and Rizvi SI 2009). Proanthocyanidins, also known as condensed tannins, are one of the most representative families of phenolic compounds in common bean seeds (Kennedy JA and Jones GP 2001). Some authors relate consumption of varieties rich in proanthocyanidins with the prevention of cardiovascular diseases (Živković J et al 2009). Spectrophotometric methodologies have been used, to determine proanthocyanidins content, however with several limitations (Hagerman AE 2011).

### Main chapter

In order to improve accuracy in proanthocyanidins quantification and ensure information about polymerization degree (Vallejo F et al 2012), chromatographic approach by HPLC, using fluorescence and UV-Visible detectors, was applied to 32 extracts of different common bean genotypes collected from farmers in the central region of Portugal. MALDI-TOF-MS methodologies, using different instrument settings were, also, applied to characterize proanthocyanidins oligomers structure, allowing detection of compounds with high mass.

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# Functional compounds of einkorn and emmer genotypes

## Antioxidants and trace elements

Mária Megyeri[1], Péter Mikó[1], István Molnár[1] Jana Taborská[2], Xénia Pálfi[2], Sándor Dulai [3], Sándor Rapi[3], Marietta Korózs[3], Péter Forgó[3], Márta Molnár-Láng[1*]

[1] Department of Plant Genetic Resources and Organic Breeding, MTA ATK Agricultural Institute, Martonvásár, Hungary, www.agrar.mta.hu, megyeri.maria@agrar.mta.hu

[2] Department of Plant Pysiology, Faculty of Science, Eszterházy College, Eger, Hungary

[3] Egerfood Regional Knowledge Center, Eszterházy College, Eger, Hungary

**Key words:** einkorn, emmer, trace element, α-tocopherol, α-tocotrienol, β-carotene

**Summary:** Three einkorn and two emmer genotypes were analysed for concentration of microelements (Fe, Zn and Se) and lipid soluble antioxidants (α-tocopherol, α-tocotrienol and β-carotene). A diversity was observed in micronutrient content, but most of the genotypes have significantly higher trace element and antioxidant contents than the control wheat variety. The emmer genotypes contain lower Fe and β-carotene concentration than einkorn genotypes. The einkorn genotypes have significant higher antioxidant content than the wheat control. On average einkorn has more than three times more β-carotene than the wheat variety. Our results are useful for variety choice in organic food production.

### Background

Einkorn (*Triticum monococcum* L.) and emmer (*Triticum turgidum* L. subsp. *dicoccum*) are hulled wheat, their domestication began more than 10 000 years ago and they were staple crops for millennia. The production of einkorn and emmer were replaced with naked species and now they are minor crops, cultivated mainly in limited and marginal regions for producing traditional foods and products and for animal feed (Perrino 1996).
Their main value lies in yield stability and resistance to fungal diseases. Hulled wheats are becoming more important crops of the expanding organic agriculture. On the basis of their agronomic and resistance characteristics, einkorn and emmer are ideal low-input crops.

### Introduction

Cereals are important sources of micronutrient minerals and antioxidants. The most important microelements for human nutrition are Fe, Zn and Se (Zhao et al. 2009). Among the numerous antioxidant compounds present in foods lipid soluble antioxidants (tocols and carotenoids) play an important role in disease prevention (Halliwelll et al. 1995). The main objective of the present study was to investigate the variation in the micronutrient content. Modern plant breeding has been historically oriented towards high agronomic yield rather than the nutritional quality. Increased grain yield may have resulted in a lower density of certain minerals (Zn) in grain (Zhao et al. 2009). In bread wheat, however, the concentration of carotenoids and tocols is low, but they are more abundant in hulled wheat. Emmer and einkorn are also an excellent source of several other functional compounds (Hidalgo et al. 2006, Zaharieva et al. 2010), and are very useful in organic farming practice.

### Materials and methods

Three einkorn (*Triticum monococcum* L.) and two emmer (*Triticum turgidum* L. subsp. *dicoccum*) genotypes were selected for analysing their trace element (Fe, Zn, Se) and lipid soluble antioxidant (α-tocopherol, α-tocotrienol and β-carotene) content. All genotypes are organically bred varieties and breeding lines. The control was a conventional bred Martonvásár winter wheat variety (Table 1). The different genotypes were cropped during the 2011/2012 growing season at Martonvásár (Hungary).
The trace element determination measurement was carried out by Varian SpectrAA-50/55 instrument. Determination of tocols was carried out by HPLC experiments using Shimadzu LCMS-2010EV instrument coupled with fluorescence detector (RF-20A). Determination of β-carotene was carried out using Shimadzu HPLC system coupled with diode array detector (SPD-M20A). The trace element and antioxidant determinations were carried out by Eszterházy College.
Differences in trace element and antioxidant content were assessed by one-way ANOVA using Breeder Software.

### Results

The concentration of trace elements and lipid soluble antioxidants were determined (Table 1).

*Microelements*

Differences in microelement content between the einkorn and emmer genotypes were observed. The einkorn genotypes have higher content of Fe, Zn and Se, than the control wheat genotype, except the Se content of Mv Alkor. The Fe contents of two einkorn genotypes (Mv Menket and Mv Alkor) were significantly higher than that of the control wheat variety. The Zn and Se contents of the emmers were higher than that of the wheat control, but their Fe content was similar to wheat.

*Antioxidants*

All einkorn genotypes showed higher content of tocols (α-tocopherol and α-tocotrienol) and β-carotene than the wheat control. On average einkorn had more than three times more β-carotene than the wheat variety and six times more than the average of tested emmer genotypes. The significantly high levels of fat soluble antioxidant content provides an evidence for that these einkorn varieties are nutritionally outstanding cereals, giving an excellent source for functional food production and for the production of natural antioxidants for the food industry.

The emmer genotypes had lower tocol content than the einkorn wheats but in the most cases their tocol content was significantly higher than that of the wheat control.

**Table 1: Trace element (Fe, Zn, Se) and antioxidant (α-tocopherol, α-tocotrienol, β-carotene) content of einkorn and emmer genotypes, standard deviation (STD) in parentheses**

| Genotype | Species | Fe (mg/kg) | Zn (mg/kg) | Se (mg/kg) | α-tocopherol (mg/kg) | α-tocotrienol (mg/kg) | β-carotene (mg/kg) |
|---|---|---|---|---|---|---|---|
| MvA6-13 | einkorn | 29.59 (3.57) | 55.06*** (1.55) | 0.603** (0.057) | 24.93*** (0.13) | 5.48*** (0.30) | 0.85*** (0.04) |
| Mv Alkor | einkorn | 37.02*** (1.89) | 66.91*** (2.81) | 0.465 (0.061) | 25.72*** (0.11) | 8.96*** (0.02) | 1.13*** (0.09) |
| Mv Menket | einkorn | 38.08*** (0.85) | 33.73 (7.11) | 0.742*** (0.032) | 20.84*** (0.15) | 10.47*** (0.02) | 1.04*** (0.05) |
| Mv Hegyes | emmer | 24.44 (0.49) | 63.41*** (9.25) | 0.547 (0.063) | 15.46*** (0.09) | 2.35 (00.02) | 0.17 (0.01) |
| MvE5-14 | emmer | 27.49 (0.64) | 45.47** (3.57) | 0.767*** (0.017) | 19.00*** (0.09) | 3.77*** (0.01) | 0.15 (0.03) |
| Control | winter wheat | 27.16 (0.65) | 27.46 (3.88) | 0.474 (0.024) | 11.94 (0.10) | 3.21 (0.04) | 0.31 (0.05) |

*** significant difference at P=0.1%; ** significant difference at P=1%


**Acknowledgements**

This work was supported by the National Science and Technology Office (ALKOBEER OM00363) and by the TAMOP-4.2.2.A-11-1-KONV-2012-0008 project.


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# Session B

# Diversity for specific adaptation and evolutionary processes

# Diversity for specific adaptation and evolutionary processes

## Improving Food Security by Cultivating Diversity

SALVATORE CECCARELLI[1]

[1]ICARDA

**Key words:** climate change, diversity, food security, human health, seed, genetically modified crops, organic agriculture, participatory and evolutionary plant breeding

Five of the most frequently debated global problems are biodiversity, hunger, poverty, water and climate changes. They are often discussed as separate problems while in fact they are closely interrelated.

Among these, hunger is particularly important because it represent the failure to fulfil one of the fundamental human rights, i.e. the right to food. Today extreme hunger still affects about 842 million people: this figure does not consider undernourishment and micronutrient deficiencies. Over 165 million children are stunted and 2 billion people globally lack vitamins and minerals essential for good health. As a contrast, the frequency of obesity doubled in the last 30 years, and by 2008 1.4 billion adults were overweight, including 400 million who were obese [1]. Eradicating hunger is a moral obligation before being a scientific challenge.

The importance of biodiversity and the dangers associated with its decline are frequently emphasized in the scientific literature [2, 3]; this is in contrast with the pursuit of uniformity by both public and private plant breeding, the science which develops the plant varieties which eventually produce our food [4]. Not only the continuous decline of agro-biodiversity in the field increases the vulnerability of our crops [5, 6, 7] but, as also our food becomes progressively less diverse, increases our vulnerability to diseases such as asthma and several types of cancer [8]. This contradiction appears even more striking in the light of climate change. Climate change poses an interesting challenge to plant breeders because, contrary to the usual target objectives of a breeding program, it represents a still imprecise and "moving target" [9, 10].

Climate change is expected to have major effects on food security and agricultural production, mostly by increasing uncertainty and thus increasing the vulnerability particularly of small farmers who are producing 70% of the world's food. These expected effects of climate change are made worse by the approximation of the current prediction models which leaves individual farmers not knowing exactly which type of change to expect in their fields [11]. Therefore the tendency towards uniformity of modern plant breeding, by causing a continuous decrease of agro biodiversity, is exactly the opposite of what is required to adapt crops to climate change.

The tendency of modern plant breeding towards few, widely adapted, uniform varieties (pure lines, hybrids, clones), also reduced the diversity of the crops providing our food: today we depend on just 15 crops for 90% of our calories and on only 3 crops (maize, wheat and rice, not even the more nutritious) for 60% of our calories. This is also associated with a monopoly of the seed market (63% of the world market is controlled by four companies), paralleled by a monopoly of the pesticides market (76% of the world market is controlled by six companies). Therefore, the prevalent lack of diversity in our crops and in our food is likely to prevent or to severely limit, the possibility of adaptation of crops to the climates of the future. Also there are already alarming indications that the yield of major crops, such as wheat, rice, maize and soybean, no longer continues to increase, and is stagnating or collapsing in more than a quarter (24 – 39%) of the respective growing areas [12, 13]. Another alarming report is the greater sensitivity to drought associated with maize yield increases in the U.S. Midwest [14]. These reports raise major concerns that we may not be able to feed the 9 billion people projected for 2050 and we may not be able to cope with climate change which, according to some, could be worse than anticipated [15].

Adaptation is a term widely used in plant breeding, and terms such as specific and wide adaptation have been and are still matter of controversy among breeders [16]. Yet, adaptation is one of the driving force of evolution; one of the best examples of the extraordinary ability of plants to adapt is the appearance of leaves—the first plants were leafless, and it took about 40–50 million years for the leaves to appear as an adaptive response to a dramatic decrease in $CO_2$ content from a level 15 times higher than today, and which took place 350 million years ago [17]. A further proof of this extraordinary adaptive ability is that, as a consequence of the post-industrial increase in $CO_2$ content, plants have already started responding with a decrease in the number of stomata [18].

A more recent example of man-driven adaptation is offered by the diffusion of the crops from their original domestication centres. When people migrated from one place to another, they brought with them seeds and livestock, and because both seeds and livestock were not genetically uniform, they were able to adapt to the new places. Farmers continued to use that diversity by selecting for specific adaptation to the climate, soil, agronomic practices and uses of the crops. This process, done by very many farmers in very many places with different crops, led to the formation and continuous evolution of landraces [19]. With the advent of scientific plant breeding, at the beginning of last century, what was being done by very many farmers in very many different places, started to be done by relatively fewer people (the breeders) in relatively fewer places (the research stations); this lead to a change in breeding strategy from specific to wide adaptation which found its international expression in the "Green Revolution". The strategy gradually led to the displacement of landraces and as the varieties were bred for optimum conditions, it was the foundation for industrial agriculture.

Adaptation has emerged as a central area in climate change research, in country-level planning, and in the implementation of climate change strategies [11]. The adaptation to climate changes cannot come from genetically modified (GM) crops. GM crops suffer of the same weakness of varieties produced by conventional methods and which carry a single gene resistance to a specific pest (disease, insect or weed). This is because they ignore the Fundamental Theorem of Natural Selection (FTNS). The FTNS, formulated by Sir R.A. Fisher in 1930 [20], predicts the increase in population mean fitness as the ratio of its additive genetic variance in absolute fitness, $V_A(W)$, to its mean absolute fitness (W) [20]. In simpler terms, the ratio indicates a population's capacity to adapt to current conditions given its present genetic composition. Contrary to the belief of early evolutionists, who considered rates of adaptation too slow relative to human lifetime for direct study, there is now a large and growing body of evidence documenting cases of quite rapid evolutionary response to abrupt, drastic environmental alteration [21,22]. Simulation studies show that change in selection regime can lead to a considerable increase in $V_A(W)$, supporting more rapid adaptation that would the $V_A(W)$ of the base population [23]. When a resistant and genetically uniform variety, such as those which are now predominantly grown in modern agriculture, is planted, whether GM or conventional, the rare fungus, insect or weed able to overcome that resistance will suddenly become the only one capable of reproducing responding to a drastic change of the surrounding environment; because all the plants of the variety are genetically identical, they will spread very rapidly. The next generation will be mostly made by the new types capable of attacking the host. If the host variety does not change, we will have an epidemic and extensive crop losses. This has already happened with most of the currently available GM crops.

One of the major implications of climate changes is the need for a major shift in agricultural research from the industrial type of agriculture to agro ecological modes of production [1] as it is now widely recognized that industrial agriculture is associated with several penalties which have to be borne by society [24]: extension of monocultures, significant loss of agro biodiversity, accelerated soil erosion, and, as one of its most potentially devastating impact, a contribution to increased greenhouse gas emissions, which amounts to 30-32 per cent of total man-made greenhouse gas emissions attributable to food systems [1,25].

Organic or biological farming can then provide that shift by using integrated biological pest management, cropping systems that minimize soil erosion and reduce water loss, use of organic fertilizers and green manures, and crop rotations to minimize build-up of weeds, diseases and insect populations [26]. An advantage, not often recognized, of organic agriculture is its ability to mitigate the ecological damage caused by pest management practices based on the use of pesticides which alter the food web structure so that communities becomes dominated by a few common species, which together contribute to pest outbreaks. Organic farming methods promote evenness among natural enemies, by incorporating evolutionary concepts, thus avoiding the selection of new, often more aggressive strains of fungi, insects or weeds. They continue to appear in nature as a consequence of mutations, but they will not have any the advantages found in agricultural systems depending on the use of chemicals and based on uniform varieties.

The combination of agro ecological models of crop production with varieties development methods such as evolutionary and participatory plant breeding described later, appears the way ahead to insure availability and accessibility of healthy food, increase agro biodiversity and continuous adaptation to climate changes.

Participatory plant breeding (PPB) differs from conventional plant breeding (CPB) because a) the objectives are established in communication with the farmers [27], who often express their preferences for the type of genetic material to use in the program (e.g., landraces vs. modern varieties, populations vs. fixed lines) and for specific traits (e.g., seed colour, plant height, fodder quality); b) the breeding material is tested in farmers' fields at a much earlier stage than in a CPB program; c) farmers are involved in all major decisions and particularly in deciding which material to carry further and which material to discard at the end of each cropping season; d) locations, chosen to sample as extensively as possible the target populations of environments, management and users, are treated as independent units of selection, i.e., selection is done within each location regardless of how the best breeding lines in that location perform in other locations. Thus, selection is fully decentralized and is for specific adaptation; e) the agronomic management of the trials is established with the farmers' consent, and different agronomic options, including organic farming, can be incorporated into the breeding trials; f) the objectives of the program are continuously monitored with the participating farmers.

There are several ways of implementing participatory breeding programs [28,29, 30,31, 32] in several different crops, but by using the principles listed above, it can be shown that PPB is more efficient than CPB when the efficiency is measured as a) the ratio between the number of varieties adopted and the number of crosses made, b) the response to selection, and c) the benefit/cost ratio, and not only as often done by public breeding programs, by the number of varieties released [32]. Other advantages of a PPB program include the increase of agro biodiversity, because of the rapid spatial and temporal turnover of varieties, the possibility of producing varieties specifically adapted to organic agriculture and the contribution to food security because it makes the seed of new varieties readily available to farmers.

However, the weak point of PPB is that it usually receives no or little Institutional support, and often the support is unpredictable and mutable. Therefore, if the flow of germplasm from the participating Institution into the PPB program comes to an end, the entire PPB program ends. An alternative, which makes farmers independent from Institution, while not excluding Institutions from participating, is evolutionary plant breeding [34, 35, 36, 37, 38]. Evolutionary plant breeding, which becomes evolutionary-participatory plant breeding (EPPB) if Institutions and farmers collaborate, uses the capacity of crops to evolve to our advantage [39] and assumes that, following the FTNS, while the population evolves, it maintains sufficient genetic diversity in fitness for the evolution to proceed.

Evolutionary plant breeding has been put into practice recently and hard data showing that it actually works are not available, with the possible exception of extrapolating to plants the results of the Morran's experiment on nematodes [40]. However, similar concepts are used in population breeding and have been applied with success to the management of mixtures in relation to resistance to diseases and insects [41, 42, 43, 44].

Evolutionary populations of different crops are currently grown by farmers in Jordan, Ethiopia, Iran, UK, Germany, France, Hungary and Italy on cereal crops (maize, barley, bread and durum wheat), grain legumes (common bean) and horticultural crops (tomato and summer squash). Research activities on evolutionary populations are ongoing in a number of European countries [38].

Evolutionary-participatory plant breeding, being a relatively inexpensive and highly dynamic strategy to adapt crops to a number of combinations of both abiotic and biotic stresses to climate change and to organic agriculture, is the most suitable method to generate, directly in farmers' hands, the varieties that will feed the current and the future populations.

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# Diversity for specific adaptation and evolutionary processes

## Evolutionary mechanisms and breeding strategies in SOLIBAM

ISABELLE GOLDRINGER[1], PIERRE RIVIÈRE[2], ABDUL REHMAN KHAN[3], SALLY HOWLETT[4], PÉTER MIKÓ[5], CARLOTA VAZPATTO[6], SALVATORE CECCARELLI[7], VALERIA NEGRI[8], SIMONA CIANCALEONI[9]

[1] INRA, France, http://moulon.inra.fr/index.php/en/team/deap, isabelle.goldringer@moulon.inra.fr
[2] INRA, France, http://moulon.inra.fr/index.php/en/team/deap, pierre.riviere@moulon.inra.fr
[3] COMSATS, Institute of Information Technology, Pakistan, abdulrehmankhan84@gmail.com
[4] ORC, UK, sally.h@organicresearchcentre.com
[5] Agricultural Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Hungary, www.agrar.mta.hu, miko.peter@agrar.mta.hu
[6] ITQB, Portugal, cpatto@itqb.unl.pt
[7] ICARDA, S.CECCARELLI@CGIAR.ORG
[8] UNIPG, Italy, valeria.negri@unipg.it
[9] UNIPG, Italy, simona.ciancaleoni@gmail.com

**Key words:** genetic diversity, participatory plant breeding, evolutionary breeding, organic breeding, local adaptation, molecular markers.

**Summary:** SOLIBAM has placed particular emphasis on diversity both as a source for breeding and as a means for obtaining locally adapted and adaptable populations / varieties. To obtain a range of diverse varieties adapted to various farming systems (organic or low-input) embedded in different food chains and meeting farmers' expectations, broad genetic bases and different breeding strategies were used. Molecular markers (genetic neutral, in candidate genes and epigenetic markers) were used to analyze how diversity was maintained in the different breeding approaches and how diversity was mobilized to allow crop populations to respond to selection and to adapt to a range of contrasted environments and management practices.

### Introduction

Genetic diversity is the basis for breeding. But the SOLIBAM project has placed particular emphasis on diversity both as a source for breeding and as a means for obtaining locally adapted and adaptable populations / varieties. To obtain a range of diverse varieties adapted to various farming systems (organic or low-input) embedded in different food chains and meeting farmers' expectations, broad genetic bases and different breeding strategies were used.Taking into account the G (genotype) x E (environment) x M (management) interaction, SOLIBAM developed breeding approaches that are closely connected to the farming management practices, such as (1) professional breeding under both conventional low-input and organic conditions, (2) breeding for heterogeneous populations, (3) on farm decentralized participatory breeding. Molecular markers (genetic neutral, in candidate genes and epigenetic markers) were used to analyze how diversity was maintained in the different breeding approaches and how diversity was mobilized to allow crop populations to respond to selection and to adapt to a range of contrasted environments and management practices.

### Assessing different professional breeding strategies based on diversity

First in WP5, a bread wheat European ring test revealed significant differences between the organic and conventional professional breeding examining already registered bread wheat varieties developed with these strategies. This trial resulted in the identification of traits which were integrated in breeding schemes based on their response in terms of G x M interaction.The inclination of leaves and the vigor of growth both had acritical importance in organic and low input agriculture based on their effect on early shading ability and increased weed competitiveness. It was also found that the maintenance of the diversity of the populations in the early generations was important in the case of these specific traits, and their direct selection should be only carried out later in the target environment, i.e. organic or low input field.
SOLIBAM also assessed several schemes of professional breedingfor small grain cereals, maize, tomato, faba bean, broccoli either under organic or under low input conventional (or both) growing conditions using early stage generations, where all trials were based on an increased use of initial genetic diversity (composite cross populations [CCP], crosses with landraces, synthetic amphiploid populations). As a first step, hundreds of landraces and gene bank accessions of these autogamous and allogamous species were examined to select the crossing partners that could result in new hybrid populations with increased genetic diversity. According to the example of bread wheat, after the implementation of very strict spike-row selection, some of the CCP derived wheat lines performed over the pure variety control, indicating that the utilization of complex populations in the organicand low input breeding procedures would be highly reasonable and promising for breeders. One of the post-harvest technologies also proved to be efficient in the breeding of wheat CCPs: using seed cleaners with appropriate sieve-adjustment as a tool for specific mass selection resulted in an increased percentage of the harvested seeds above 3 mm in diameter at the following generation.

### Breeding for heterogeneous populations

Introducing in-field diversity should allow for continuous evolution and adaptation to global change. In WP3 and WP6, heterogeneous populations were submitted to various low-input and organic management practices in order to select for adapted, resilient and adaptable crop stands.In these so-called evolutionary plant breeding approaches, the potential of mixtures, CCPs and populations derived from crosses between landraces was investigated for

different crop species. The objective was to obtain a self-sustaining process in which the evolutionary populations can be grown in farmers' fields for production or can be the source for further breeding by plant breeders or under participatory plant breeding.
A number of crops were trialled across a range of countries in WP3. A particular example indicating the potential for adaptation is worked with common bean. Breeding lines from crosses between a dwarf landrace ("Gnochetto") and an indeterminate climber were grown in France, Italy and the UK under organic or low-input environments for three seasons. Results identified two distinct clusters within the lines, which were better adapted to either organic or low-input management. Analyses of molecular variance showed that the best adapted lines for organic systems contained the highest percentage of introgressed landrace germplasm. In another set of trials, winter wheat entries differing in their level of diversity (pure lines, mixtures and CCPs) were grown in parallel across five partner countries (Austria, France, Hungary, Italy and the UK). Multivariate analyses of the data from France indicate that in both organic and low input conditions, the three most productive entries were the same and consisted, in rank order, of a mixture, a CCP and then another mixture; however the least productive varieties in both conditions were also CCPs. In relation to diversity levels, this highlights the importance of choosing appropriate parental varieties in determining the success of population breeding.
In WP6, a barley evolutionary population was assembled by mixing the seeds of 798 $F_2$ including crosses in which one or both parents were Ethiopian landraces. After multiplication, the seed was planted in 2012 in 5 locations in Ethiopia during two generations. In 4 of these locations, eight farmers selected 5 spikes each for a total of 40 spikes / location. The 160 head-rows are currently grown in the off-season at the experimental station for seed multiplication. They show a considerable diversity and represent the first step linking the evolutionary populations with the participatory breeding program (PPB) as these head rows will become, by 2015, the entries in the first stage PPB trials.
In WP6 also, two maize open pollinated varieties (OPV) ('Amiúdo' and 'Pigarro') plus a composite population were distributed to different farmers covering a range of seven target environments in Portugal, using farmer's agronomic practices and levels of inputs.Stratified mass selection was applied during one to three years using as selection criteria quality traits, such as flavour or nutritional value, pest and disease resistance and enhanced capacity to survive in highly changeable environment, typical of low input/organic farming systems (yield stability), through genetic diversity maintenance or enhancement. SOLIBAM WP2 studied the middle term (15 to 25 years) effect of mass selection in 'Amiúdo' and another maize OPV ('Castro Verde') on genetic diversity using neutral markers and showed that diversity was maintained over time and that inbreeding did not increase showing that the evolutionary potential was maintained in these populations.
Finally, we studied the evolutionary potential of bread wheat populations / varieties with different level of diversity, such as landraces conserved *ex situ* or on farm, farmers' mixtures and modern pure line varieties.WP2 showed that conservation on farm led to much more genetic diversity maintained within landraces than *ex situ* conservation, while mixtures of landraces or of varieties maintained on farm allowed to increase the available genetic diversity by recombination even though wheat is mainly selfing. As expected, phenotypic differentiation for adaptive traits (e.g. earliness and plant height) among populations / varieties grown in contrasted environments was much larger for genetically heterogeneous landraces and mixtures than for pure lines, although some evolution was also found in the latter. Epigenetic variation (e.g. DNA methylation) could explain part of the differentiation among genetically homogeneous landraces samples.

**On-farm decentralized breeding and selection for local adaptation**

More emphasize was put on local adaptation and adaptation to specific management practices and marketing in decentralized participatory plant breeding (PPB) approaches in WP6. SOLIBAM developed methods and tools that allow for (i) decentralized on farm evaluation and (ii) participatory assessment of agronomic and quality traits for bread and durum wheat, barley, maize, bean and broccoli.In WP2, molecular markers were used to decipher the genetic structure of the populations submitted to selection, to analyze the response to selection and to detect loci submitted to selection in order to understand the genetic / epigenetic bases of adaptation to contrasted environments and low-input and organic farming practices. In WP6, the effect of farmers' selection practices on phenotypic and genetic diversity was characterized.
More than 90 new wheat populations have been created in 2005 based on a farmer's decision by crossing landraces, old varieties and modern varieties and were distributed to farmers from the Réseau Semences Paysannes in 2008 in France to be submitted to selection in a collaborative breeding program. In each farm, populations were submitted to natural selection due to the climate, to local environment and to the farming practices and to farmers' selection among and within populations. The molecular genetic characterization in WP2 showed that all initial populations had a high level of within-population genetic diversity and that after three to five generations of selection, sub-populations of each population became strongly differentiated in response to the local conditions and to farmers' mass selection. No within-sub-population decrease in genetic diversity could be detected.

**More understanding on the genetic and epigenetic mechanisms underlying differentiation at adaptive or quality traits**

Analyzing the genetic structure and differentiation over time and space among populations submitted to natural selection or to farmers' breeding using molecular genetic markers allowed to better understand the evolutionary mechanisms involved. For instance, genetic distance values suggested high variability amongst Portuguese common bean traditional landraces, while low variance within landraces indicates a high degree of uniformity within each landrace, reflecting their predominantly self-pollinated nature. While there seems to be no evident connection between geographic and genetic distances, a clear population structure, with 2 separated clusters, was identified, being most of the Portuguese landraces placed closer to the Andean domesticated gene pool representatives. Those clusters are in accordance with the phaseolin patterns found among the common bean landraces.
In wheat landraces conserved *ex situ* or on farm, farmers' mixtures and modern pure line varieties, WP2 studied phenotypic differentiation at adaptive traits. For differentiated populations, the contrast between differentiation at neutral markers and at candidate genes allowed to detect a few candidate genes that had been submitted to selection, among which some were found associated with variation of adaptive traits, such as *Vrn1, FT, Ppd*. Using a much higher genotyping density (the Illumina Wheat 90K SNP platform) gave an increased accuracy to detect association with agronomic traits in a set of durum and improved landraces evaluated in Ethiopia.

Differences in methylation state of two genetically homogeneous broccoli genotypes grown in respectively three and four contrasted environments in Italy in 2010-2011 and 2011-2012 respectiveley, were studied applying the Methylation-Sensitive Amplified Polymorphism technique (M-SAP). Although a high level of methylation was detected in both genotypes, no correlation was found among the two years' patterns. While in the first year, differences were larger among plants sampled at different times during growing cycle, in the second year, differences were more important among plants from different environments. This suggested that more similar climates among environments in the second year had less impact on methylation of these genotypes while this allowed to reaveal more sensitive phenological stages. While epigenetic is increasingly advocated as an adaptive mechanism, it seems to be highly unstable and therefore more difficult to detect and characterize.

**Conclusion**

SOLIBAM results highlight that participatory plant breeding and evolutionary breeding are part of the dynamic management of genetic resources and they allow for the maintenance of among populations / varieties and within population genetic diversity. All the breeding strategies investigated make the best possible use of a high initial genetic diversity to obtain a rapid response to various agro-climatic conditions and farming practices. A range of breeding strategies involving professional breeders, farmers and other stakeholders is the key to answer the various needs of organic and low-input farming systems.

**Acknowledgment**

This abstract is based on the work of the numerous scientists, technicians, PhD and master students from the SOLIBAM partners' teams during 4 years.

# Microbial communities associated to common bean seed
## A mechanism of local adaptation of plants?

STEPHANIE M. KLAEDTKE[1,2], MATTHIEU BARRET[3,4,5], VÉRONIQUE CHABLE[2], MARIE-AGNÈS JACQUES[3,4,5]

[1] INRA de Rennes, France, www.rennes.inra.fr/sad-bcrp, stephanie.klaedtke@rennes.inra.fr
[2] SEED, Université de Liège campus Arlon, Avenue de Longwy 185, 67000 Arlon, Belgium
[3] INRA, UMR1345 Institut de Recherches en Horticulture et Semences, Beaucouzé, France
[4] Agrocampus Ouest, UMR1345 Institut de Recherches en Horticulture et Semences, Beaucouzé, France
[5] Université d'Angers, UMR1345 Institut de Recherches en Horticulture et Semences, SFR4207 QUASAV, Beaucouzé, France

**Key words:** *Phaseolus vulgaris*, artisanal seed production, fungal communities, bacterial communities

**Summary:** The effects of crop genotype and cultivation site on microbial communities associated to seed of *Phaseolus vulgaris* were assessed on 33 seed lots. These seed lots were obtained by multiplying 5 initial seed lots of different cultivars in two contrasting environments for 2 years in 3 replicates. An additional commercial control lot was introduced the second year. The diversity of fungal and bacterial communities was analyzed by high-throughput sequencing of the bacterial 16S rRNA gene and the fungal ITS1 region, respectively. Results showed that the structure of the fungal and the bacterial communities is significantly affected by the cultivation site.

### Background

Small scale organic artisan seed producers generate and market seed of traditional cultivars of common bean (*Phaseolus vulgaris*) in Western Europe. Several seed-borne pathogens represent phytosanitary challenges for common bean seed production. In particular, the agents responsible for the common bacterial blight of bean such as *Xanthomonas axonopodis* var. *phaseoli* and *X. fuscans* subsp. *fuscans* are listed in European Council Directive 2000/29/EC, Annex II A II, as harmful organisms. We emit the hypothesis that different conceptions of plant health are confronted in debates concerning the problem of managing these agents as quarantine pests. While some stakeholders define plant health as "absence of disease" and as objective entity, others argue for a salutogenic position “focusing on more complex interactions between plants and pathogens, such as induced resistance phenomena” in order to “move towards health” (Döring *et al.*, 2011). The application of beneficial microorganisms to seeds for bio-control of plant pathogens has become an important research topic (Berg, 2009). However, the role of indigenous seed microbial communities in plant adaptation to local environments has not been studied. Whereas seed-borne pathogens are frequently quantified on commercial seed lots, the presence and potential functions of other microorganisms are left aside. These microorganisms may be of particular importance when seed lots are multiplied on the same farm year after year. In a research project in cooperation with the *Croqueurs de Carottes*, an association of French and Belgian artisan seed producers, we analyzed the diversity of microbial communities on common bean seed from two cultivation sites to investigate the possible influence of microorganisms on the adaptation of plants to contrasting environments.

### Material and Methods

The influence of the seed production site on the structure of the seed microbiota was assessed on 33 seed samples obtained from two cultivation sites. These seed samples were obtained by multiplying 5 initial seed lots in two organic farms in Brittany and Luxembourg in three replicates in 2012 and 2013. Four of these seed lots consisted of farm seeds of traditional cultivars; one was seed of the commercial variety 'Calima' obtained from a breeding company and used as a commercial control. The initial seed lots were thus exposed to contrasting biotic and abiotic environments for two consecutive years. In addition, commercial seed of 'Calima' was again sown in 2013. One cultivar ('Rognon de Coq') did not yield sufficient seed for sampling in Luxembourg. Total genomic DNA extraction was performed on 200-seeds subsamples collected from each seed lot. The composition of the bacterial and fungal communities was analyzed by high-throughput sequencing (Illumina MiSeq v. 2.0 platform, 250 bp paired-end reads) of the bacterial 16S rRNA gene and the fungal ITS1 region, respectively. Low quality reads were removed using the standard operational procedure of Mothur (Schloss *et al.*, 2009; Kozich *et al.*, 2013). High-quality sequences were then grouped in operational taxonomic units (OTUs) at a genetic distance of 0.03. Only OTUs with a minimum threshold of 1 ‰ relative abundance were conserved for further analyses and defined as abundant OTUs (aOTUs). Variation of bacterial and fungal diversity across samples was assessed by calculating unweighted Unifrac and Yue & Clayton distances, respectively. Non-metric dimensional scaling (NMDS) ordinations were used to observe sample clustering. Analysis of molecular variance (AMOVA) test was performed to test if the observed clustering was statistically significant. The effect of sampling was verified by taking 3 sub-samples each from 2 large seed lots.

### Results and Discussion

A total of 169 aOTUs were detected in the fungal communities, with 123 aOTUs present in Brittany and 106 in Luxembourg. *Sordariomycetes* (relative abundance of 34,5%), *Tremellomycetes* (22,3%), *Dothideomycetes* (17,8%), *Wallemiomycetes* (7,8%) and *Eurotiomycetes* (3,6%) were the most abundant fungal classes observed in Brittany, while *Dothideomycetes* (25,6%), *Sordariomycetes* (22,8%), *Leotiomycetes* (18,7%), *Eurotiomycetes* (11,6%) and *Agaricomycetes* (9,5%) were most abundant in Luxembourg. A total of 217 aOTUs were detected in the bacterial communities, with 176 aOTUs present in Brittany and 136 in Luxembourg. *Gammaproteobacteria* were by far the most abundant bacterial phylum in both cultivation sites, with a relative abundance of 89,6% in Brittany and 78,6% in Luxembourg. *Alphaproteobacteria* (5,9% and 4,4%, respectively), *Betaproteobacteria* and (4,6% and 1,5%) *Bacteroidetes* (3,2% and 3,0%) were strongly represented in both sites. On contrary, *Firmicutes* were enriched in Brittany (4,6% and 0,5%, respectively).

In the case of the analyses of the fungal ITS region, sub-sampling of 200 seeds was considered sufficient due to a high proportion of OTUs common to the 3 subsamples of both tested seed lots (54% and 67%, respectively). However, limitations to the subsampling were detected for the analyses of bacterial 16S RNA genes, as 1 sample out of 3 had very few OTUs for both seed lots. We conclude that larger sub-samples would be required to avoid sampling effects for the analyses of bacterial communities.

The effect of cultivation site on both fungal and bacterial communities was found to be significant at $p$=0,001 (Figure 1). Seed microbial communities were thus shaped by the cultivation site within two reproduction cycles. Further research steps are required to investigate whether these differences in microbial communities between sites may involve an adaption to local environmental conditions. This could be done through an analysis of the functions of abundant OTUs found in the seed samples.

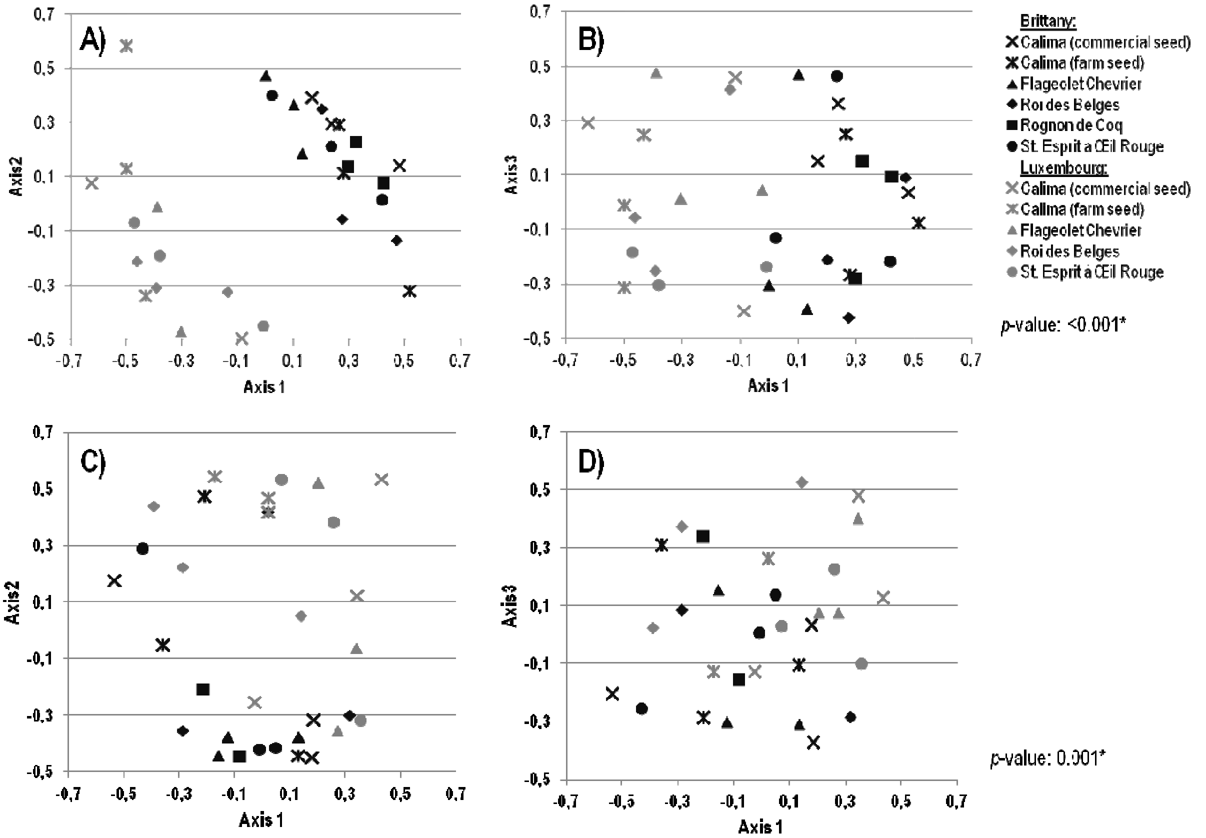


Figure 1. Diversity of microbial communities associated to common bean seeds of different varieties and cultivation sites. β-diversity of fungal communities calculated by unweighted Yue & Clayton distance and visualized in 3 dimensions by NMDS (lowest stress: 0.16, $R^2$: 0.82), A) and B). β-diversity of bacterial communities calculated by unweighted Unifrac distance and visualized in 3 dimensions by NMDS (lowest stress: 0.15, $R^2$: 0.88), C) and D). *P*-values (AMOVA) indicate the significance level of the effect of cultivation site on microbial communities.

**Acknowlegements**


SOLIBAM (Strategies for Organic and Low input Integrated Breeding and Management, 2010-2014) is funded by the European Community's Seventh Framework Programme (FP7/2007–2013) under the grant agreement n. 245058. This PhD research is supported by the Fonds National de la Recherche, Luxembourg (project 5126594).


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# Performance of wheat composite crosses on-station and on-farm
## Diversity, N-uptake, baking qualities, and resilience.

MARIA R FINCKH, SVEN HEINRICH, SARAH BRUMLOP [1]

[1] Faculty of Organic Agricultural Sciences, group Ecologicla Plant Protection, University of Kassel, Germany. Example: INRA de Rennes, France, http://www.uni-kassel.de/fb11agrar/en/sections/oekologischer-pflanzenschutz/home.html, mfinckh@uni-kassel.de

**Key words:** evolutionary breeding, winter survival, adaptation

**Summary:** The $F_{11}$ of 14 winter wheat composite cross populations (CCPs) were compared in replicated field trials to the mixture of the 20 parents and three commercial wheat cultivars in replicated field trials. In addition, one population was given to farmers for on-farm testing. In 2012 severe frost killed 16 out of the 20 parental varieties of the CCPs. In contrast, the mixture of these varieties and the CCP populations survived well. The CCPs with high yielding parents yielded still highest in the $F_{12}$ and quality in the CCPs with high quality parents was highest. CCPs on-farm were comparable in performance with farmers reference varieties.

### Background

In order to be able to adapt to changing environmental conditions, crop plants need a certain degree of diversity (Stevens 1942, Finckh 2008). The development of genetically diverse populations (composite cross populations, CCPs) instead of breeding entirely homogeneous pure line varieties by standard pedigree breeding methods is a strategy that aims at creating flexible varieties.

In 2000, 20 modern wheat varieties were intercrossed in all combinations in the UK to create three composite cross populations (CCPs). These are the intercrosses of 12 high quality varieties (Q) or 9 high yielding parents (Y) and the crosses of the Q by Y parents (All) were used. Since the $F_5$ the CCPs have been grown under organic (O) and conventional (C) conditions in two parallel sets at the University of Kassel without artificial selection applied. In addition, since the $F_8$ two A populations have been maintained as broadcast sown populations without mechanical weed control to select for weed suppressiveness.

### Materials and Methods

In 2011/12 and 2012/13 the $F_{11}$ of all 14 populations were compared in replicated field trials to the mixture of the 20 parents and three commercial wheat cultivars Achat, Akteur, and Capo in a replicated field trial. N-uptake of the plants was measured at the beginning of stem elongation, at the flowering stage and in the ripe seeds and straw. Samples of fresh plants were cut and dried for 72 hours at 60 °C. Seeds and straw were dried after harvesting and all samples were milled and analyzed for N-content using a CHN analyzer. Nmin in the soil was measured in early spring, at the flowering stage and after harvest. Morphological diversity, Yield and yield components, and raw protein contents were determined in both years, Baking tests were performed in the second year only.

One population (OA) was given to five farmers in 2011 and grown by the farmers since then in comparison to their main variety. Data were collected on yields and where relevant diseases.

### Results and Discussion

Resilience of the populations with respect to frost and drought stress

In February 2012 after a very mild winter without severe frosts within one day temperatures dropped to -20 °C without snow cover for two weeks followed by six weeks of severe drought. The parent varieties that had been grown for seed increase suffered severe damage with only four varieties surviving reasonably well (Figure 1 left). Of these Bezostaya is of Ukrainian origin, Monopol and Renan are German and French, respectively, Herward is an English variety. These varieties were apparently better adapted to harsh winters. In contrast, the populations, the parental mixture and the modern reference varieties survived much better (Figure 1 right). The populations also recovered reasonably well. They all produced low but comparable numbers of head bearing tillers. Despite the relatively poor performance of the mean of the parents the parental mix also recovered although to a lesser extent than the populations. The modern varieties Achat, Akteur, and Capo used in the experiment are well adapted to the potential climatic extremes in Germany and performed well.

In 2012, yields of the populations were 3.77 t/ha for the Y CCPs to4.1 t/ha for the A CCPs 4.17 t/ha for the Q CCPs with the yield of the A and Q significantly higher than Y. In 2013, yields were 6.29 t/ha for the Y and 5.96 and 5.95 t/ha for A and Q, respectively, with no significant differences among populations. In both years, the same seed was used for the experiment. The pattern in 2013 is as it was observed in previous generations with generally highest yields in the Y CCPs and no differences between A and Q CCPs for yield (Finckh et al. 2010). The reason for the poor performance of the Y CCPs in 2012 is most likely due to the higher susceptibility of the Y parents to the freezing damage.

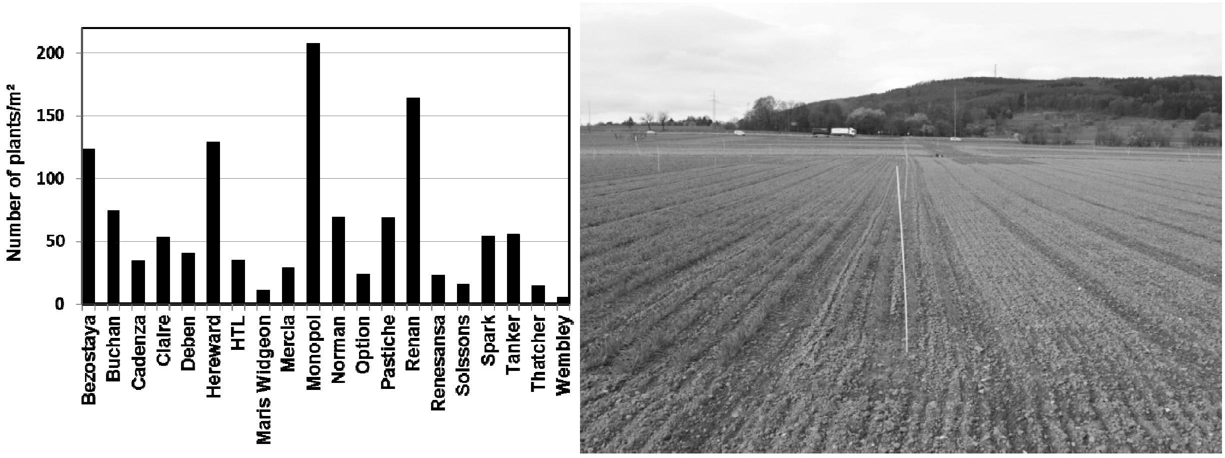


Figure 1. Left: Winter suvival of the parental varieties in 2012. Right: Photograph of the populations on the left side of the field and the parental varieties on the right side on April 16 2012. The surviving plot of Monopol is pointed out.

Overall, the differences among the populations in N-uptake were small. There were no statistically significant differences between the conventionally (C) and organically (O) grown populations. However, in both years at flowering the O-populations had taken up approximately 6% more N than the C-populations. These differences were not visible in early cut samples or in seeds and straw. In contrast, grain N contents of Q populations were in both years significantly higher than in the Y populations (Table 1). Thus, the genetic differences for quality were well conserved into the F11.

Table 1: N-contents (%) in grain in the F11 of three wheat CCPs in two years

| | % N-content in grains | | | Linear contrast | | |
|---|---|---|---|---|---|---|
| Year | All (A) | Quality (Q) | Yield (Y) | A vs Q | A vs Y | Q vs Y |
| 2012 | 2.1 | 2.2 | 2.1 | * | | ** |
| 2013 | 2.0 | 2.1 | 1.9 | | | * |

* significant at $P<0.05$ and ** significant at $P<0.01$

On-farm results

In two of the five participating farms wheat was completely killed in February 2012. In two sites the populations performed as the reference varieties, in one site performance was below. In 2013, all populations did well and performed comparable to the farmers' varieties with good quality properties. By summer 2014 farmers will have saved and regrown seed of their populations for two or three years. These populations will be compared on-station with the population that stayed on-station during that time in 2014/15 in the frame of the Core-Organic II project COBRA.

**Acknowledgements:**

The work reported here was supported from 2011-2014 by the German Ministry within the project 2810OE082 (PopZuchtDIVA) and from 2013-2016 through the project 2812OE021 (COBRA)

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# Using diversity of Ethiopian durum wheat to challenge climate change: a three-pronged approach

DEJENE KASSAHUN MENGISTU[1,2], YOSEF G. KIDANE[1,3], CHIARA MANCINI[1], MARCELLO CATELLANI[1], MATTEO DELL'ACQUA[1], CARLO FADDA[4], M. ENRICO PÈ[1]

[1] Scuola Superiore Sant'Anna, Pisa, Italy, dejenekmh@gmail.com; marioenrico.pe@sssup.it
[2] Mekelle University, Makalè, Ethiopia
[3] Sirinka Agricultural Research Center, Sirinka, Ethiopia, yosefgk@yahoo.com
[4] Bioversity International, Nairobi, Kenya, cfadda@cgiar.org

**Key words:** durum wheat, SNP, NAM population, farmers' participatory selection

**Summary:** Durum wheat is a strategic crop for food security and livelihood improvement of smallholder farmers in Ethiopia. Several studies report the uniqueness of Ethiopian tetraploid wheat germplasm that has not been fully exploited yet. **Our** medium-term objective is to contribute to the identification and development of better adapted genotypes to be either distributed to farmers or to be used both for gene discovery and fine mapping and as advanced pre-breeding germplasm. Our research, conducted within the SOLIBAM project, is organized in three complementary research lines: i) characterization of Ethiopian tetraploid wheat accessions; ii) development of a NAM Population and iii) farmers' participatory selection in Northern Ethiopia.

**Background**

Current climate change projection models show that both temperature and precipitation are expected to increase in the Horn of Africa, and that climate uncertainty and frequency of extreme events will most likely increase the vulnerability of the rural poor in the region, Ethiopia included. Genetic diversity in crops represents a crucial resource for adapting local farmers' systems to climate change. Durum wheat (*Triticum turgidum* spp. *durum*) is one of the officially announced strategic crops for contributing to food security and livelihood improvement of smallholder farmers in Ethiopia. Several studies witnessed and reported the uniqueness of the Ethiopian tetraploid wheat germplasm for different useful traits. Such diversity, if properly evaluated for adaptation to climate change, used in breeding programs and made easily accessible, can provide farmers with more adapted genotypes.

**Main chapter**

We followed a three-pronged approach aimed at the characterization and exploitation of Ethiopian tetraploid wheat germplasm to tackle the challenges posed by climate change: i) phenotypic and genotypic characterization of Ethiopian tetraploide wheat landraces; ii) development of a Nested Association Mapping (NAM) population of tetraploide wheat; iii) farmers' participatory selection. These activities were stimulated by the SOLIBAM project and were developed in its framework.

***1. Germplasm Characterization***. The goal was to characterize both at the phenotypic and genotypic level a set of landraces from the Intitute of Bioversity Conservation. We started in December 2010 by growing 476 accessions at Mekelle University (Makalè) classified as durum wheat, collected in various regions of Ethiopia and for which at least partial passport data were available. Further purifications of true to type seeds was made and a total of 373 accessions were selected for characterization, which were complemented by 27 improved cultivars released by the agricultural research system of Ethiopia. Those 400 genotypes were grown for two years in two differently characterized agro-ecological zones of Northern Ethiopia: Hagereselam (2,590 meters above sea level), in the western part of the Tigray Region, and Geregera (2,890 masl), in the eastern part of the Amhara Region. Several morphological and agronomical traits were collected and analyzed. Extensive phenotypic variation was present among accessions. Several landraces outperformed improved varieties for traits considered, indicating that i) those improved varieties may not be the best choice for cultivation under northern Ethiopia condition and, most important, ii) landraces could be useful either by direct distribution or as starting materials in breeding schemes for the development of new varieties since they contain favorable genetic combinations for most traits. All accessions, together with a number of improved durum wheat varieties approved for cultivation in Ethiopia, accessions from several Countries of the Mediterranean Basin and a few bread wheat varieties were genotyped using the Illumina Wheat 90K SNP platform.This platform allowed the testing of 81,588 Single Nucleotide Polymorphisms (SNP), of which only 5,582 failed in more than 75% of the samples and where discarded, whereas 50,582 were polymorphic. It is worth noting that the number of solid polymorphism SNPs is extremely high, much higher than predicted considering that the SNPs were mostly developed in bread wheat.SNP genotypic data were used to build a phylogeny of the studied samples. Ethiopian tetraploid accessions were clearly separated from bread wheat and durum wheat from the Mediterranean basin. Considering only Ethiopian germplasm, Principal Component Analysis of the genetic diversity identifies three distinct groups, one comprising all improved varieties and a few landraces, one formed by most of landraces and one including bread wheat (Figure 1). Genome-wide association (GWAS) mapping identifies suggestive genomic loci linked to several agronomic traits.

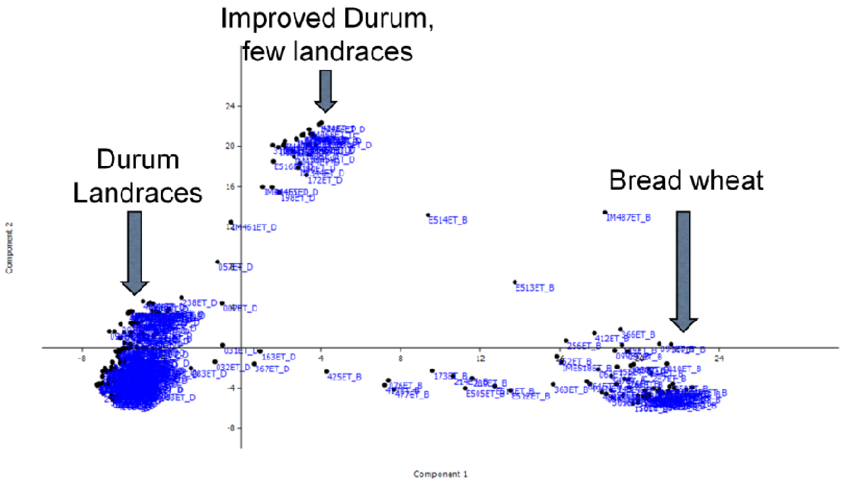


Figure 1. PCA of genetic diversity among Ethiopian wheat germplasm. PCA1 separates bread from durum wheat, PCA2 separates landraces from improved **varieties.**

***2. NAM Population development***. A sub-set of 50 landraces, chosen to represent most of the phenotypic variation identified, were crossed to the elite cultivar Asasa in order to derive a large NAM population of recombinant inbreds (about 250 lines from at least 25 original $F_2$), to be used both for gene discovery and as pre-breeding material. The scheme for the NAM population development is summarized in Fig 2. All 50 $F_4$ are currently in the field for reproduction. Considering two generations per year, we expect to reach RIL-$F_6$ at the end of 2014. In addition, the heterotic performance of 8 landraces is being evaluated on the crosses with the 3 elite cultivars Asasa, Quamy and Ude.

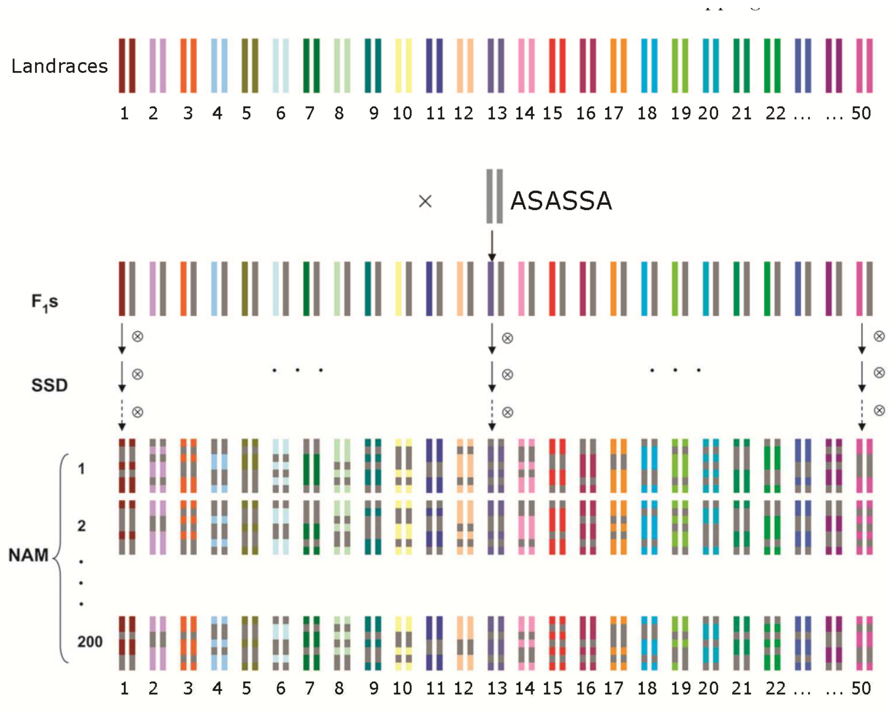


Figure 2. Scheme for the development of a NAM population. Fifty landraces were crossed to the recurrent parent Asassa. Cycles of single-seed descent are producing 50 families of RIL, each a genomic mosaic of the two parents.

***3. Farmers' participatory selection.*** All the 400 varieties were evaluated in the two locations) by 30 local farmers (15 males and 15 females) for each location before harvest. Through focus group discussion with the farmers traits the farmers use to evaluate wheat varieties were identified and ranked. Earliness, tillering capacity, ear morphology and overall plot characteristics were evaluated, giving a score from 1 to 5. More than 200,000 data points were collected and analyzed. Forty landraces were selected on the basis of metric measurements and farmers' scoring, amplified and distributed to the farmers for further analysis.

# Building-up faba bean cultivars for low-input farming

## A crop-pollinator inter-play approach

M. J. Suso[1], R. del Río[1], C. Márquez[2], F. Ruiz[2], I. Solís[2.]

[1] Instituto de Agricultura Sostenible, Córdoba, Spain, www.ias.csic.es, ge1susom@uco.es
[2] Agrovegetal S.A., Sevilla, Spain, www.agrovegetal.com, isolis@faeca.es

**Key words:** Breeding for low-input – evolutionary processes – functional biodiversity - pollinator-mediated selection - specific adaptation- Vicia faba

**Summary:** Decline in bee populations has increased the interest in the ecological services of faba bean because a group of bee species is associated with their flowers. Faba bean has a great potential to be served by bee pollinators, as agents of crossing, to increase heterozygosity and heterogeneity for heterosis-mediated yield and resilience in open-pollinated varieties (OPVs). Information on how the inter-play crop-pollinator contributes to crop performance is explored to develop ecosystems services and improved OPVs for low-input (LI). We test whether phenotypic selection exerted by pollinators is associated to differences among plants in dynamic adaptation and in crop seed production patterns.

### Background

Creating OPVs based on diversified germplasm and using pollinators as agents of crossing should be considered to make the beneficial effects of heterosis available to low-income farmers in a timely manner. Pollinators are natural breeders of highest importance. One of the main constrains in our capacity to utilize heterotic potential is the lack of high efficient pollination technologies on species-specific basis (Fu et al. 2014). Open pollination is a method of crossing well adapted to farmer management as well as to site-specific requirements (Weltzien et al. 2005). Two basic approaches are used to manage pollination by farmers at field level: a) in farming for alternative pollinators (FAP) the approach targeted at pollinators have focused on appropriate semi-natural habitats management along field margins (Christmann and Aw-Hassan 2012); b) in Crop-Design System, breeders and farmers develop, by Participatory Plant Breeding (PPB), cultivars with enhanced heterosis–mediated yield and resilience as a result of the provision of floral resources within the crop for supporting insect pollinator populations to be used as agents of crossings to increase heterozygosity (Palmer et al. 2009). Additionally, this approach could be a promising strategy to develop crop environmental services and to provide a platform for connecting small-scale agriculture with biodiversity conservation tasks. Moreover, initiatives at European level, (Cost Action FA1307 on Sustainable Pollination) and at world level, (the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) on the assessment of pollination and pollinators associated with food production) confirmed that the management of wild pollinators is an issue of paramount importance to our food supply system and encourage crop breeders to consider crop floral attributes of interest to pollinators when developing new varieties. This approach requires the understanding and management of complex crop-pollinator interactions.

### Main chapter

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 LI farming in pollinator density and diversity. Bee pollinators intensify selection on floral traits related with discovery, attraction and reward but their behaviour may also select traits that enhance seed production patterns through outcrossing and aided selfing. Two pollination environments (open-pollination , local native bees present, *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 to the inter-play crop-pollinator and each seed production component, gene-pool and pollination environment. This comparative approach, as well, may contribute to understand the underlying effects resulting from the steep decline on pollinator availability (IPBES 2013).

Different levels of heterogeneity have been described. The temporal level was described by the variance associated to Principal Components in Principal Components Analysis (PCA). Heterogeneity at the management level, which consists in the diversity among plants because of their cultivation under different pollination environments, was explored by the Discriminant Function Analysis (DFA). Gene-pools diversity in production patterns was analyzed by Multivariate Regression Analysis (MRA) testing whether pollinator-mediated selection eventually turns into significant differences among plants in seed production patterns.

Architectural and floral patterns are the result of natural selection and they reflect local adaptation to factors of the environment and adaptations to differences in pollination environments. PCA showed a large proportion of the temporal variation accounted by plant height and number of open flowers and by floral shape and sexual component dimensions. DFA indicated that plant architecture and floral traits related to pollinators are also the result of selection for particular patterns in each pollination environments (Suso and Río 2014). The response to selection under different pollination environments is characterized by a series of plant architecture and flower structural changes that could result in mismatches between crop and pollinator. Thus, decreasing the ecological services provided by faba beans and consequently, reducing the ability of the crop to benefit from pollinators for increasing genetic diversity.

MRA showed that seed production patterns changed to different extend with the gene-pool in regard to the pollination environment. The underlying floral mechanisms are specific to the gene-pool and largely unrelated among gene-pools. However, critical traits in the performance of faba bean such as pod and seed dimensions and weight, are pollinator-dependent and are under pollinator-mediated selection through sexual component dimensions, floral display, and vector matching traits in most gene-pools. Furthermore, there is no evidence of pods and seeds per plant to be pollinator-dependent through the functional floral traits under study. However, pollinators are crucial for a higher number of seeds per plant, main predictor of crop yield. Though, we did detect interaction between pollination environment and gene-pool. Thus, to take advantage of the pollinators in LI farming our results suggest that evaluation and selection should be carried out in the particular pollination environment. Moreover, in order to understand the beneficial effects of pollinators on seeds per plant, further studies on the inter-play crop-pollinator should be focused on additional floral traits related to the recruitment by advertising and to the management by payment of reward. We caution against dismissing pollinator-mediated selection as direct driver of seed production patterns variation. Taking into account that LI farming relies largely on locally available resources, such as bees, our work has stressed the relevance of traits enhancing the inter-play crop-pollinator to realize LI full potential.

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# Genetic distance and heterosis on open-pollinated maize populations

## Yield and yield-related traits evaluated through a half diallel mating design

Mara Lisa Alves[1]*, Pedro Mendes Moreira[1,2*], Cláudia Brites[2], Daniel Gaspar[2], Graciano Spencer[2], Zlatko Šatović[3], Maria Carlota Vaz Patto[1]

[1] Instituto de Tecnologia Química e Biológica, Universidade Nova de Lisboa, Av. da República, 2780-157 Oeiras, Portugal. mara@itqb.unl.pt

[2] Escola Superior Agrária de Coimbra. Departamento de Ciências Agronómicas, 3040-316 Coimbra, Portugal. pmm@esac.pt

[3] Faculty of Agriculture, Department of Seed Science and Technology, University of Zagreb, Svetosimunska 25, 10000 Zagreb, Croatia.

* Both authors contributed equally to this work

**Key words:** maize hybrid populations, genetic distance, panmictic midparent heterosis

**Summary:** Heterosis is the increased performance of a hybrid relative to its parents. Heterosis expression depends on differences in allele frequencies between parental lines. Here we check for correlations between the genetic distance of maize parental populations, calculated using DNA-based markers and the heterosis of the hybrid populations from a half diallel mating design. All populations were evaluated in multilocation trials for a set of yield-related traits. We detected a significant correlations between genetic distances and the level of heterosis of the hybrid populations. We conclude that the genetic distance can be used as a complementary tool for maize hybrid population development.

### Background

Heterosis, or hybrid vigor, is the increased performance of a hybrid relative to the parents. Heterosis expression is highly dependent on specific combinations of the parental lines used. This brings along a severe burden to breeders as traditionally the best parental combinations for the development of new cultivars/races are determined by a series of testcrosses and field evaluations of particular traits.

Based in the linear relation between the hybrid expression of heterosis and the genetic distance of the parental lines, considering all genomic regions involved in the expression of the trait of interest, it has been proposed, for hybrid populations performance prediction, to use the genetic distances of the parental populations and the panmictic mid-parent heterosis shown on the hybrid populations (Reif et al. 2003 and refs. therein).

### Main chapter

Enclosed in genetic diversity is the key to the future of breeding. This premise constitutes one of the pillars of the European project SOLIBAM.

One of the aims of SOLIBAM WP2 was, through the use of molecular techniques, to develop a set of tools to assist the breeders' work. Here we study the potential of microsatellites, a type of DNA-based marker, as a complementary tool in the selection of the best parental combinations during of the development of new open pollinated maize hybrid populations.

Under SOLIBAM WP3, 12 maize Portuguese populations, selected based on farmers empirical knowledge, data on flour viscosity and protein content, cycle duration, kernel color and yield, were used in a half diallel mating design. Hybrid populations and parents evaluation trials were established across 7 environments (Coimbra, Lousada, Montemor-o-Velho, Valada do Ribatejo, Tomar, Vouzela and Celorico de Basto) in Portugal, during 2012.

The main objectives of this study were: (1) test if a significant correlation exists between the parental populations' genetic distance and the heterosis of the resulting hybrid populations, for a set of yield-related traits; (2) evaluate if the genetic distances between parental populations can be used as a complementary molecular maize hybrid populations breeding tool.

With this purpose, the parental populations were molecularly characterized using 20 microsatellite markers uniformly distributed throughout the genome, on 30 individuals of each population. This data was used for measuring the genetic distance among populations using Nei's standard genetic distance.

From the multilocation populations evaluation trials, only the first 5 environments and 8 of the parental lines were considered in the current analysis, given the lack of harvest seed. Yield and yield-related traits (grain yield - YH, number of ears per plant - PR, ear weight - EW, cob weight - CW, cob and ear weight ratio per ear – CWEW, and kernel weight per ear - KW) were evaluated on the 8 parentals and respective 23 hybrid populations considered.

For the analysis of the hybrid populations' performance we did not consider the reciprocal crosses because our interest was on testing more new combinations than reciprocals. This choice was also necessary due to the lack of reciprocal crosses seed. Analysis of variance was used to test for differences among populations, for each trait, across environments. The ANOVA showed highly significant ($P < 0.001$) differences among the 31 populations (8 parental and 23 hybrid populations) for all the traits except PR (significant at $P < 0.05$). The comparison of parents vs. hybrids was highly significant ($P < 0.001$) in case of EW, CW and KW, significant ($P < 0.01$) in case of CWEW and YH, and non-significant in case of PR.

The panmictic midparent heterosis (PMPH, Reif et al. 2003) of each hybrid was calculated as the difference between the hybrid populations mean and the respective midparent mean across the environments. The resulting values were then used to perform a linear regression analysis to study the relationship between PMPH of each hybrid and Nei's standard genetic distance among pairs of respective parental populations. A significant positive mild correlation (38-45 %) was found for ear weight, ratio between cob and ear weight and for grain yield (Table 1).

Table 1: Correlation coefficients (r) and coefficients of determination (R2) between Panmictic Midparent Heterosis of each maize hybrid population and Nei' standard genetic distance among pairs of respective parental populations. The significance of the linear regression was determined by randomizations.

| Code | Trait | r | R2 | P |
|---|---|---|---|---|
| PR | Number of ears per plant per ha | 0.460 | 0.211 | * |
| EW | Ear weight, g | 0.617 | 0.381 | ** |
| CW | Cob weight, g | 0.317 | 0.101 | ns |
| CWEW | Cob weight/Ear weigh | 0.656 | 0.431 | ** |
| KW | Kernel weight, g | -0.399 | 0.159 | ns |
| YH | Grain yield (15% moisture), Kg $ha^{-1}$ | 0.669 | 0.448 | ** |

Heterosis is an important concept that has allowed major improvements in maize production. Its expression depends on differences in allele frequencies between parental lines. With this work we were able to detect a significant positive, although mild, correlation between the genetic distance and the level of heterosis present in maize hybrid populations for yield and yield-related traits. This was somehow anticipated since in maize hybrid populations derived from open pollinated populations, given the intra-population heterozygosity it is expected that the level of heterosis potentially obtained will be lower when compared to inbred lines hybrids. Nevertheless it is this genetic diversity that allows for these populations to be more resilient to a wider range of environmental conditions. In this way we conclude that the genetic distance can be a useful complementary tool for planning and manage future maize hybrid population breeding schemes.

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# 3A – Umbria Agro-food Technology Park: new tools for biodiversity

Luciano Concezzi[1], Mauro Gramaccia[2], Livia Polegri[3]

[1] 3A – Agrofood Technology Park (3A-PTA), Todi, Italy, www.parco3a.org, lconcezzi@parco3a.org
[2] 3A – Agrofood Technology Park (3A-PTA), Todi, Italy, www.parco3a.org, ricerca@parco3a.org
[3] Agronomist, 3A-PTA consultant, Italy, ricerca1@parco3a.org

**Key words:** biodiversity, autochthonous genetic resources, regional act, ex situ conservation, on-farm conservation

**Summary:** The 3A-PTA Company is a non-profit consortium with public funding conducting activities in the agro-food and environmental sector. The Company has been designated by Umbria Region as the subject responsible for the actuation of the Regional Act 25/2001 “Protection of autochthonous genetic resources of agronomical interest”. In this role, the company set up the Regional Register of Autochthonous Genetic Resources and manages their *ex situ* and *in situ*/on-farm conservation. Among all the actions planned, the most hard and challenging refers to the on-farm conservation: with the aim of approaching all the critical issues concerned in this topic, four experimental projects are carried out.

**Background**

The 3A-PTA Company is a non-profit consortium with public funding conducting activities in the agro-food and environmental sector. Three areas are operative inside the Company: Innovation and Research, Certification and Professional Training.

**3A-PTA activities on biodiversity protection**

Inside the Innovation and Research Area, 3A-PTA carried out several actions to protect and valorise the autochthonous biodiversity of agricultural interest. The company holds two collection orchards with ancient and local varieties of fruit trees; the same varieties are conserved in an *in-vitro* germplasm bank inside the Biodiversity laboratory. With the collected varieties, 3A-PTA implanted five experimental orchards in five Umbrian farms to evaluate their adaptability to different types of managements (conventional vs. organic, intensive vs. extensive, different rootstocks etc.).

**Figure 1. Some activities carried out by 3A-PTA for the protection of autochthonous fruit tree varieties: an experimental orchard in Perugia (under conventional, intensive management with dwarfing rootstocks) and the *in-vitro* Gene Bank.**

3A-PTA manages also a seed bank of Umbrian landraces, a microbiological bank of cheese and wine yeast and a genomic zoo-bank of DNA samples belonging to individuals of a typical Umbrian beef breed (Chianina).

**The Regional Act on biodiversity in agriculture**

Umbria Region recently designated 3A-PTA as the subject responsible for the actuation of the Regional Act 25/01 "Protection of autochthonous genetic resources of agronomical interest". In this role, the company set up the Regional Register of Autochthonous Genetic Resources and provides for their *ex situ* and *in situ*/on-farm conservation.

Thirteen are until now the genetic resources inscribed in the Regional Register. For these, 3A-PTA is providing a path of diffusion and valorisation, taking advantage from the derogations allowed by Regional Act to the specific regulations in force for the spreading of reproductive material.

The Conservation and Safety Network, provided by the Regional Act and coordinated by 3A-PTA, is the principal tool to allow harmonizing *ex situ* and *in situ*/on-farm conservation. In order to encourage especially the on-farm conservation and to face the possibly emerging critical issues, four specific projects are carried out:

- the setting up of a "seed house" created inside an organic farm for the germplasm collected by the University of Perugia on a specific Umbrian area around the Trasimeno Lake (Figure 2);
- the rescue, re-planting and valorisation of ancient olive tree varieties traditional of the South-Western Umbria for their typical organoleptic characteristics;
- the rescue and valorisation of ancient poultry breeds threatened by extinction and reputable for organoleptic and nutritional characteristics of their eggs;
- the protection and diffusion of the Italian autochthonous bee (*Apis mellifera ligustica* Spin., worldwide known as "Golden Bee") as a main tool to valorise its characteristics of adaptation, rusticity and resistance facing the new biotic and abiotic threatens.

Figure 2. The Trasimeno seed house: the physical isolation in the demonstrative garden for reproducing bean and tomato seeds and part of the seed collection.

3A-PTA involves also primary and secondary schools in specific projects on agro-biodiversity and organizes congresses, seminars and workshops on this topic addressed to farmers and technicians.

**Innovation in biodiversity, biodiversity as a key to innovate**

3A-PTA is also leader in several projects funded by Rural Development Plan (measure for innovation in agriculture) based on the development of new tools to valorise autochthonous genetic resources, in cooperation with both research companies and farmers. In this context, as an example, a project on the rescue and valorisation of old wheat varieties for their nutritional values is carried out. Another project deals with the setting up a spinneret of natural fibres, from the hemp to a forgotten dying plant as the indigo (*Isatis tinctoria*).

**Exchanging experiences**

3A-PTA has been involved in several EU projects on the agro-biodiversity sector. Among them, the project REVERSE, recently concluded, aimed to involve 7 EU countries on the drawing up of specific recommendations for EU policymakers concerning the impact on biodiversity of policies in agriculture, tourism and land planning. 3A-PTA coordinated the drawing-up of the agricultural & biodiversity charter.

# Genetic resources data management for participatory evaluation and breeding

## Experiences from a European project on quality of *Avena* genetic resources for quality in human nutrition

CHRISTOPH ULRICH GERMEIER[1]

[1] Julius Kühn-Institut, Federal Research Centre for Cultivated Plants, Institute for Breeding Research on Agricultural Crops, Erwin-Baur-Str. 27, D-06484 Quedlinburg, Germany, christoph.germeier@jki.bund.de

**Key words:** plant genetic resources, crop information systems, online project management, field evaluation, quality traits

**Summary:** Plant genetic resources are the basis on which diversity strategies for agriculture and breeding can build. Of high importance for their use is access to trait data. Multi-location studies and documentation of experimental contexts are required to unravel specific adaptation. Participatory evaluation and breeding involve multiple actors, operating geographically distributed under diverse conditions. An open source web application is presented, which supports project management (generation of field plans, lists, templates for taking observations) and acquisition of data and pictures under these conditions. Modularity and software patterns in application design facilitate its re-use.

### Background

Plant genetic resources for food and agriculture and their collections are the basis on which diversity strategies for agriculture and breeding can build on. The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 2010) highlighted, that a lack of access to information, especially related to characterization and evaluation data is still the most important limiting factor for increased use of plant genetic resources in food and agriculture. To acquire information on specific adaptation of genetic resources to environmental conditions, multi-location studies within different ecological and management conditions and a proper documentation of the experimental context are required. Participatory evaluation and breeding can involve multiple actors operating under diverse conditions. It can further enhance the acceptance of and readiness to use the results in practice (Ceccarrelli and Grando 2007).

Participatory research and breeding involves geographically distributed partners (e.g. farmers), who are not affiliated to one and the same institution, hence are not within a coherent information and communication infrastructure. This means that coordination, information, planning and data acquisition have to be supported via the internet by web applications. Owing to the limited experimental resources at farms, experimental designs involving many actors (e.g. farms as replications) and geo-statistical approaches have to be implemented. This calls for a well defined role of each participant, which has to be documented and implemented. Descriptive data from each actor needs to be documented in a comparable way.

### Main chapter

*Introduction*

Since the 1980s the Julius Kühn Institute and its predecessors have been engaged in the European Cooperative Programme for Plant Genetic Resources (ECPGR) with the management of Central Crop Databases (CCDBs) for *Avena* (oats) and *Beta* (beets, including garden and leaf beet). Based on these data resources characterisation and evaluation projects for *Avena* and *Beta* genetic resources have been coordinated. AVEQ, a European project targeted to quality traits of oats in human nutrition (protein, fat, carbohydrates like dietary fibre and β-glucan, antioxidants like tocols and avenanthramides), potential of mycotoxin contamination from *Fusarium* disease, and frost tolerance, involved fifteen partners from nine European countries. Six field experiments in different European countries were established to sample for chemical analyses of nutraceuticals and additional three for artificial inoculation with *Fusarium*. A working collection with 567 accessions of hexaploid cultivated oats (*A.sativa*), including 126 current commercial cultivars from 13 European countries, 46 accessions of *A. strigosa*, 5 accessions of *A. abyssinica* and 34 wild species accessions were tested. Based on experiences and data structures developed for the CCDBs, web applications have been developed for the online management of field experiments and laboratory analysis and the acquisition of trait data with the respective metadata of this project.

*Material & Methods*

The European *Avena* Database (EADB) is available in a relational design of 75 tables on an Oracle Relational Database Management System (RDBMS). It has a PHP query interface. An additional project database (AVEQ) with 39 tables has been developed and set up on a MySQL RDBMS. Project web applications span over both databases and an additional archive database to store changed or deleted stock data for the EADB (institution addresses, traits, observation methodology, accessions etc.). They have been developed in Java Enterprise Edition technology, using the frameworks Hibernate, JSF and SEAM. SeamGen was used to generate a crude web application, which was then refined.

*Results*

Fig.1 shows some work flows, which are implemented in the application. It allows generation of field plans, field lists, field books for taking observations and notes in the field, spreadsheet files for data input, which finally can be easily imported into the database with the web application, and upload of pictures, which are assigned to accessions and field plots. Further it supports input and editing of all relevant metadata (experiment, experiment design, experiment site, location, responsible institution and person, experiment treatments, inocula in case of artificial inoculation in resistance tests and observation methodology. Statistical analysis systems can query the databases via standard interfaces (ODBC, JDBC). A technical documentation, a user manual and the application can be found at http://aveq.jki.bund.de

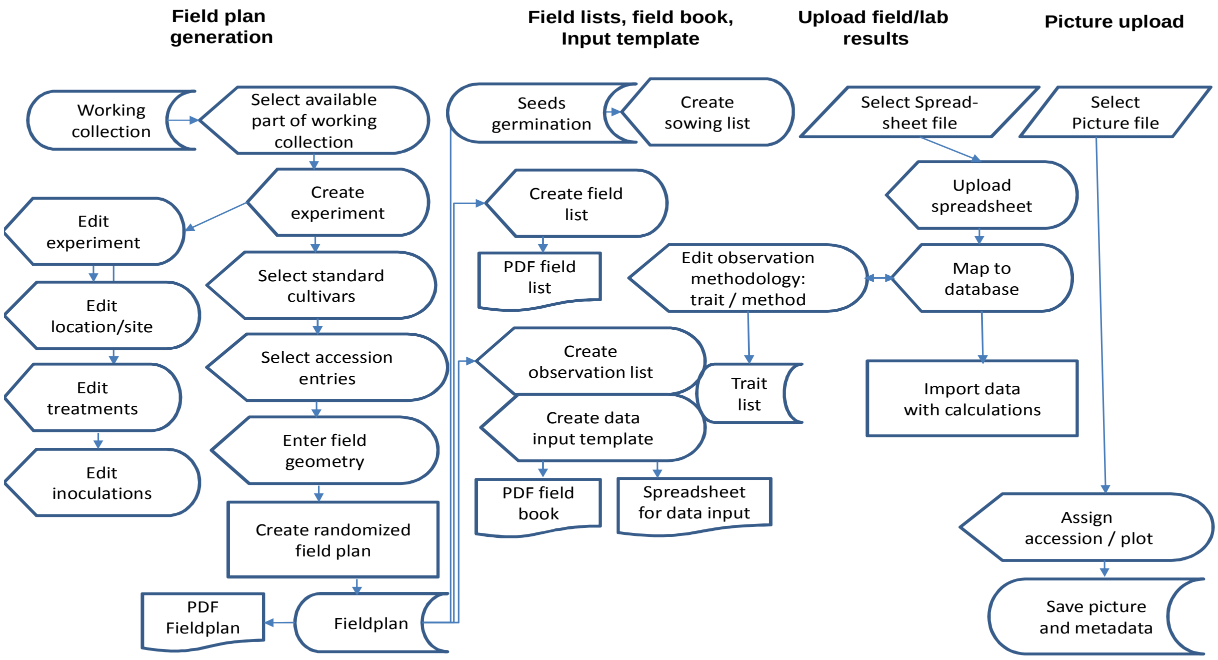


Fig.1 Some work flows in the AVEQ project management web application

*Discussion and Outlook*

Plant genetic resources are the major source of variability in traditional and organic breeding approaches, as these rely on naturally originated instead of artificially induced variability. Evaluation of genetic resources or breeding material have much in common, could be combined and should be done in multi-location trials, ideally in environments close to farming. This strongly suggests creating a link between the genetic resources and the participatory and organic breeding communities. Web based documentation and data acquisition is mandatory in programmes with many geographically distributed actors. To elucidate adaptation to environments and management practices the proper documentation of the experimental context is of high importance. With respect to participants with limited financial resources, and also to meet requirements of fluctuating consortia it is important to focus on software, which can be released within an open source project free of costs. Modern object-oriented approaches in software engineering are targeted to enhance development productivity, code standardization and re-usability based on software patterns (Bouhours et al. 2009). A pattern approach has been used in the AVEQ application development. This provides a basis for re-use and adaptation.

## Acknowledgements

AVEQ was co-funded by the European Commission (Agri Gen Res EC N° 870/2004), Peter Koelln KGaA, Elmshorn, Germany, Emco spol. s r.o., Prague, Czech Republic, and Gemeinschaft zur Förderung der privaten deutschen Pflanzenzüchtung e.V, Bonn, Germany. Further we thank all project partners providing their data and C. Höhne, A. Henning, G. Weber and S. Unger, who were involved in developing the web application

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# Participatory plant breeding strategy for buckwheat

## Assessment of phenotypic and genetic diversity of French common buckwheat

SABINE MEYRUEY[1], LUCIE LE JEANNE[1], MATHIEU THOMAS[2], FRANCK-EMMANUEL LEPRETRE[1], VERONIQUE CHABLE[1]

[1] INRA, UR980 SAD-Paysage, 65 rue de Saint Brieuc, 35000 Rennes, France
[2]CNRS, Centre d'Ecologie Fonctionnelle et Evolutive, 1019 Route de Mende, 34000 Montpellier, France
Corresponding author : Veronique.Chable@rennes.inra.fr

**Key words:** *Fagopyrum esculentum*, phenotypic and genetic diversity, *in situ* (on-farm) and *ex situ* conservation, participatory research

**Summary:** Few buckwheat varieties are available on seed market and many transformers, farmers and beekeepers are looking for local varieties. Buckwheat diversity is a major source for participatory plant breeding in order to improve agronomic performances, ecosystem services and quality of products. Phenotypic and genetic diversity were assessed within and among French buckwheat populations from three origins: *on farm* conservation, *in situ* conservation from French gene banks, and 2 available certified varieties. The first results show a high level of inbreeding, a little differentiation among the populations and a higher genetic diversity at intra-population level than at inter-population.**Background**

Buckwheat pancakes ("galettes") are part of cultural and gastronomic heritage of Brittany (Bretagne, Western part of France). Nevertheless the major part of buckwheat transformed in France today is imported.
Buckwheat cultivation declined sharply in the XXth century but has recently known a renewed interest, particularly for organic and low-input farming. Buckwheat (*Fagopyrum esculentum), a* cross-pollinated Polygonaceae, has agronomic, ecological and nutritional qualities (attractive plant for pollinators, requiring few inputs and manure, with a short cycle, allelopathic effect, nutritional qualities) and various uses (production of flour, honey and hulled grains, gluten-free food or beer, cover crop, green manure, use of buckwheat hulls for upholestery filling…). However some bottlenecks limit development of buckwheat cultivation. The main factor is a strong year in, year out yield irregularity, but also a late harvest in automn which requires an efficient grains drying management, and crop contamination in fields by tartary buckwheat (*Fagopyrim tataricum*) which is very hard to sort out without specific material.
Selection and research on buckwheat are not carried out by public research nor by private companies in France. « La Harpe », selected by INRA in the 1960's, is currently considered as the only marketed variety available in Brittany. This variety is the only one giving right to the « Blé Noir Tradition Bretagne » label, a PGI (protected geographical indication). Today, many farmers, beekeepers and transformers are willing to diversify local varieties of buckwheat.

**Main chapter**

**Introduction**

Characterization of genetic diversity of buckwheat is necessary in order to initiate on farm breeding strategy. The objective is to increase agronomical performances and product quality mainly for low input and organic agricultures since very few varieties are available on seed market. Phenotypic and genetic diversity were assessed within and among French buckwheat populations from three origins: on farm conservation, in situ conservation from French gene banks, and few available certified varieties. The aims were to determine: i) the structure of genetic diversity within buckwheat populations according to their origin; ii) the genetic relationship among buckwheat populations and marketed varieties. Knowledge of diversity within and among buckwheat populations will help in the development of appropriate breeding strategies for participatory plant breeding and genetic resources (*in situ* and *ex situ*) management of French accessions.

**Material and Methods**

Molecular identification and diversity characterization was carried out on 22 samples (cf table 1).: 11 samples of peasant populations, collected on farm in 2013, 10 samples of accessions from INRA gene bank of Rennes and 2 samples of marketed varieties, "La Harpe" and "Drollet" which originated respectively from 2 French regions, Bretagne and Massif Central.

| | |
|---|---|
| "La Harpe" ; "Drollet" | Certified variety |
| "Brusvily" ; "Langourla" ; "Massif Central" ; "Petit gris de la Gacilly" ; "Saint Méen" ; "Saint Congard" ; "Saint Martin sur Oust" ; "Saint Nicolas du Tertre" ; "Limousin Faux de la Montagne"; "Montredon" | Population (French gene bank) |
| "Petit gris du Morvan" ; "Petit gris du Tarn" ; "Petit gris de Sidobre" ; "Petit gris de Bain de Bretagne"(JPC) ; "Petit gris des Hautes-Pyrénées" ; "Petit Prussien gris" (JPLR) ; "Petit Prussien" (AP) ; "Petit Prussien" (BM) ; "Petit Prussien" (JD) ; "Monédières" ; "Sarrasin Français" | Local population (on-farm conservation) |

Table 3: Origins of the buckwheat samples. The initial letters indicate the name of the farmer owning the population.

The samples were characterized during a trial experiment in summer 2013 in Le Rheu in Brittany. Each sample was sown manually. Ten plants per sample were described according to the list of descriptors currently used for buckwheat and established by IPGRI protocol (1994). Statistical analyses of phenotypic data were carried out with the software R : Analysis of variance (ANOVA) and Tuckey's range test [HSD]).

The populations were genotyped with sixty-four genome-wide SSR markers showing polymorphism in literature (Ma, et al., 2009, Konishi, et al., 2006, Iwata, et al., 2005), using 15 plants per populations. Molecular analysis was performed after a DNA extraction from leaf samples using a standard protocol. The study of genetic diversity was carried out using GENETIX, Darwin and STRUCTURE softwares.

**Results and discussion**

These are preliminary results which have to be deeper analysed in order to confirm the observed trends.

Only three phenotypic quantitative descriptors were discriminating criteria for populations and varieties: number of primary branches per plant, number of internodes per plant and stem diameter. However, these descriptors did not allow a clear differentiation between all the populations neither the comparison between these populations and the variety "La Harpe". Furthermore, a broad intra-variety diversity was observed.

Among the 4 on-farm populations named "Petit Prussien", 2 appeared different from "la Harpe" according to the shape and the color of seeds and to some of the quantitative descriptors."Petit Prussien" is indeed a local population some farmers and transformers are looking for because of its putative qualities. It can be hard to distinguish as some populations are wrongly thought to be "Petit Prussien" because of inbreedings.

Populations named "Petit Gris", from on-farm and gene bank conservations, showed similar characteristics for seeds like the certified variety "La Harpe". This result could be coherent with the putative origin of the variety "La Harpe" which was supposed to be bred from local Breton populations.

Only 9 out of 64 SSR markers were polymorphic. Two to 24 alleles were observed at these 9 loci. The level of polymorphism was studied according to allelic diversity so as to assess a first evaluation of genetic diversity within and among populations taking into account their origin (local/on farm populations or marketed varieties).

"La Harpe", with an average number of 4.3 alleles per locus, ranged under the others. This low allelic diversity could be explained by the effect of selection, although the other marketed variety "Drollet" showed a high value of 6.1 alleles per locus.

Within population and among them, expected heterozygosity (mean = 0.62) is higher than observed heterozygosity (mean = 0.56). For some populations this heterozygote deficit could be explained by the small sample size during regeneration or seed multiplication (bottle neck effect) but as we also observe this deficit for certified varieties, which are cultivated in large fields, we suppose that the heterozygote deficit could be explained by a part of autogamy in buckwheat reproduction.

At a global level, populations showed a high level of inbreeding (average fixation index, FIS = 0,13) whatever the origin. The $F_{ST}$ value (average Fst = 0,04) supported little differentiation among the populations. A higher genetic diversity was detected at intra-population level than at inter-population level whatever the origin of the samples. The large intra-population diversity is coherent with open-pollinated species.

**Conclusion**

Few microsatellite markers, from the panel established by several authors in the world, were polymorphytic for the French populations. This result indicated that only a small portion of the global genetic diversity of the species was represented in the French populations. Moreover, both results from molecular analysis and phenotypic descriptors revealed more diversity within population than among them whatever the origin (on farm, gene banks and on market). Such results suggested that French populations could be managed like a "crop metapopulation" (Louette, 2000). In respect to our breeding objective, the next step will be a comparison of French populations with accessions from other gene banks in the world to broader the working genetic bases. Then, performance and yield stability, pollinators attractiveness and quality will be assessed in order to study the relationship between these criteria and diversity level. Finally breeding strategies will be drawn to improve French populations.

**Acknowledgements**

This study is funding by Fondation de France, project "Sarrasin de pays", n°00038087.

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# Evolution of a barley CCP: an insight gained by morphological & molecular markers

## Evolving crop populations can be useful sources of genes in the actual scenario of climate changes

LORENZO RAGGI[1], SALVATORE CECCARELLI[2], VALERIA NEGRI[1]

[1] Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università degli Studi di Perugia, Italy, http://www.unipg.it/en/, lorenzo.raggi@gmail.com, valeria.negri@unipg.it

[2] ICARDA,Lebanon, http://www.icarda.org/, ceccarelli.salvatore83@gmail.com

**Key words:** *Hordeum vulgare*; Composite Cross Population (CCP); genetic diversity; morphological diversity structure

**Summary:**

Many studies have highlighted the continuously increasing need for agro biodiversity. Evolutionary plant breeding offers the possibility of reconciling agro-biodiversity, higher yields and adaptation to climate changes. In 1997, UNIPG produced a barley CCP by crossing different progenies derived from crosses of cultivars, landraces and promising lines that were good performers under low-input conditions in Central Italy. The SSR analysis of the resulting CCP showed that a high level of diversity exists in the population. According to morphological analysis, both traits related to spike and plant morphology may have played a relevant role in determining the success of the different genotypes in the CCP.

**Background**

The importance of biodiversity and the dangers associated with its decline are frequently emphasized as it is the vulnerability of our crops associated with the continuous decline of diversity in the field. A strategy to cope with such a challenge is evolutionary plant breeding. The simplest and cheapest way to implement evolutionary breeding is to plant and harvest mixtures or Composite Cross Populations (CCP). The expectation is that the frequencies of adapted genotypes increases without creating a uniform population. However, the diversity that can be conserved in heterogeneous populations, its structure and evolution and the potential of the evolutionary breeding approach in the actual scenario of climate change is still a matter of debate. Indeed, the interactions between plants in heterogeneous populations are extremely complex and depend on a number of dynamic environmental factors. In this scenario molecular markers have already been invoked as the decisive tool for understanding population dynamics and the effects of competition in CCP studies.

**Main chapter**

The development of new barley cultivars that tolerate the higher pressure of abiotic stresses, that is expected as a result of climate changes, represent a unique problem for plant breeders because, contrary to most breeding objectives, adaptation to climate changes is a moving target as we do not know what is the exact combination of temperature increase and rainfall decrease expected in any given target environment. This requires a good understanding and management of the genetic diversity existing in both landraces and cultivated barley. With the rapid disappearance of landrace populations, heterogeneous populations might offer a realistic alternative by producing a modern equivalent of landraces or “reconstituted” landraces. Composite Cross derived Populations can be useful materials to exploit genetic diversity in environmentally friendly agricultural systems, to provide experimental material for studying the effects of natural selection and to be used as a source of locally adapted new varieties.

In 1997, a barley CCP was produced by crossing seven different F8 progenies, derived from seven crosses of cultivars, landraces and promising lines, which were good performers under low-input conditions in Central Italy. The population was then multiplied for 13 years under a low input management system and without any conscious human selection. In 2011/2012, 91 seeds from the CCP were randomly chosen and grown as single plants (Figure 1) that were characterized using molecular markers (“neutral” an EST-derived SSR). In 2012/2013 the same lines were sown in a single row 1 m long with 1 m spacing between rows (Figure1) and morphologically characterized together with five check cultivars (namely Nure, Ketos, Cometa, Aliseo and Express). The experimental design was a partially replicated row and column design in which five different genotypes were replicated four, six, four, seven and three times and randomized.

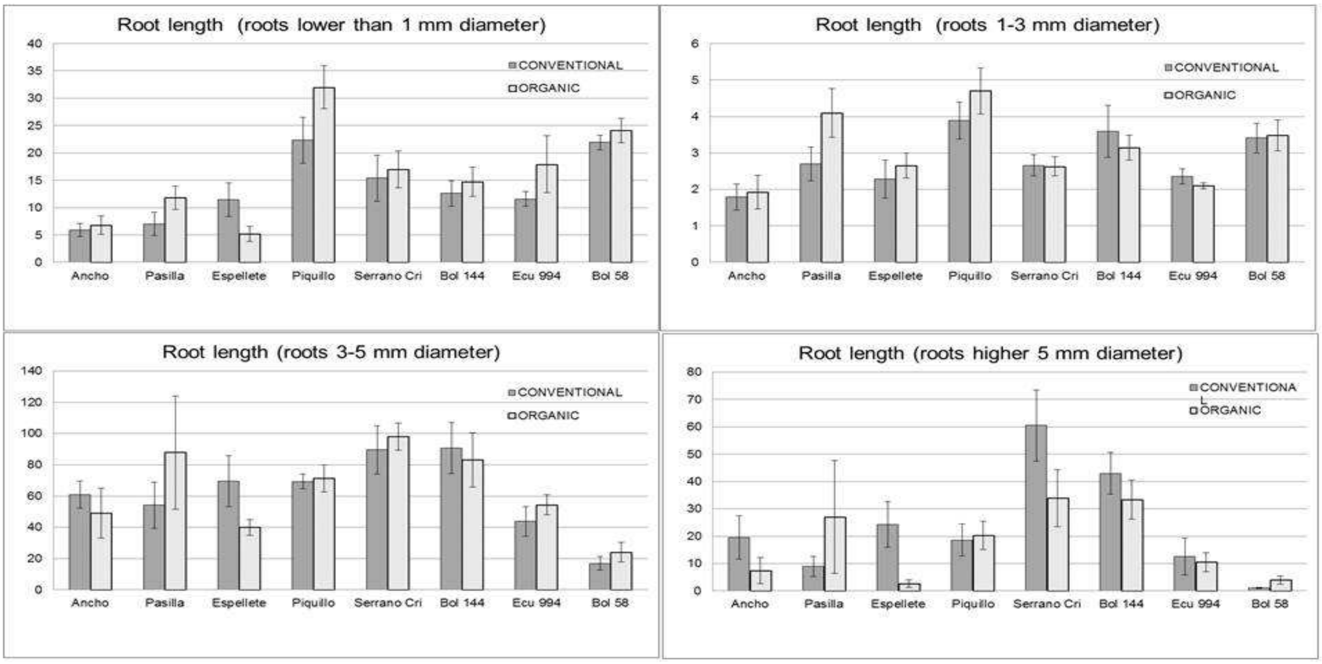


Figure 1. Barley pants grown as single plant (a) and in row (b).

A total of 100 polymorphic alleles were detected in the CCP: 69 were produced by the 13 neutral and 31 by the 9 EST-derived SSR. Allele number ranged from 3 to 8 and from 2 to 5 in neutral and EST-derived SSR, respectively. The high mean level of fixation index (0.98 and 0.99 in neutral and EST-derived, respectively) revealed that the CCP is essentially a mixtures of homozygous lines. A graphic representation of the genetic relationships among individuals of the CCP is shown in Figure 2. According to the different multilocus genotypes identified, the population is composed of a minimum of 60 different genotypes belonging to different clusters.

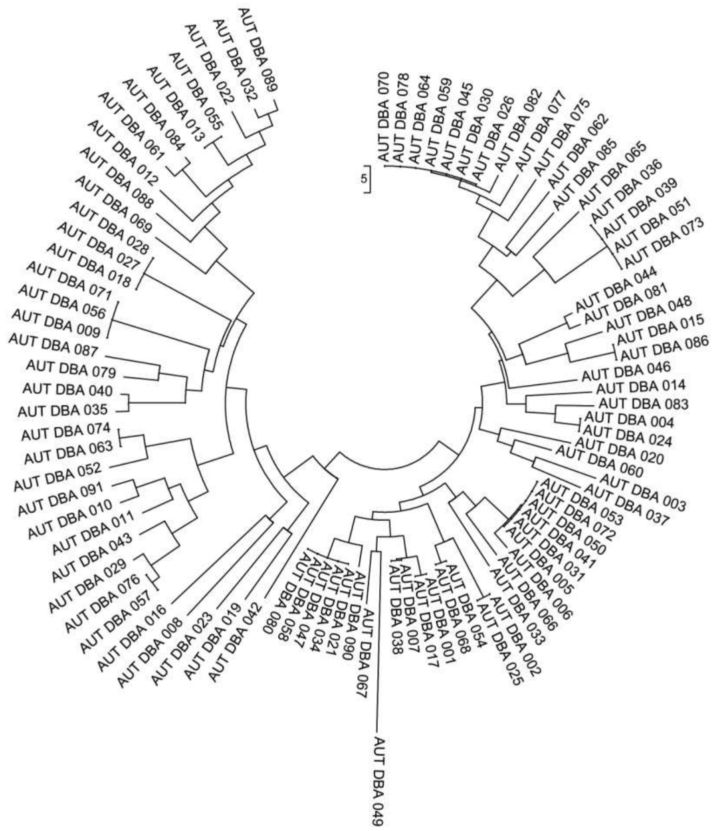


Figure 2. Neighbour-joining tree of genetic distances of the 91 barley genotypes.

According to the morphological data recorded, six-row type were predominant in the CCP and this suggest that they possess superior performances and competitive ability in comparison with two-row type. In comparison with two-row, six-row lines produced heavier spikes, characterized by higher seed number. Six-row clearly overcome two-row lines for plant height. Since we observed a wide range of morphological diversity in population that reflect the diversity of parental lines, the studied CCP can be useful as a gene-pool for selecting lines. In particular, the population contains interesting lines that outperformed the best commercial varieties for traits of agronomic relevance like spike weight, number of seeds per spike and kernel weight.


**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

# Short term response of European wheat populations to contrasting agro-climatic conditions: A genetic diversity analysis

Abdul Rehman Khan[1, 2], Mathieu Thomas[1,3], Nathalie Galic[1], Sophie Jouanne-Pin[1], Isabelle Goldringer[1]

[1] INRA, UMR de Génétique Végétale, Gif-sur-Yvette F-91190, France. http://moulon.inra.fr
[2] Department of Environmental Sciences, COMSATS Institute of Information Technology, Abbottabad, Pakistan. http://ciit-atd.edu.pk. arehman@ciit.edu.pk
[3] Centre d'Écologie Fonctionnelle et Évolutive, Montpellier, FRANCE, mateothom@gmail.com

**Key words:** Wheat, within population diversity, on-farm conservation, ex situ conservation.

**Summary:** Landraces and historic varieties being genetic diverse populations are becoming more desirable to the organic farmers as they have the capability to cope with the diverse environmental conditions through their within-population genetic diversity. Wheat was used as model crop and flowering time being a trait directly affected by environmental variation was studied. Seven Farmers' varieties and one modern variety (after three year cultivation at seven different sites across Europe) were genetically and phenotypically analysed. It was revealed that the level of genetic diversity and population structure strongly depends upon their conservation history. The complexity of genetic structure and level of genetic diversity then in turn influenced the response of these populations to contrasting agro-climatic conditions.

## Background

In agrosystems, genetic diversity especially within-population diversity is very important because it can provide a buffering effect against the year-to-year variation of climatic or biotic pressures. Moreover, it serves as a resource for the population to respond to selective pressures due to specific local conditions (Wolfe et al. 2008), thus allowing for local adaptation, particularly in the case where a population is introduced into a new location. Therefore understanding the role of this within population diversity when populations are introduced to contrasting agro-climatic conditions is crucial especially in the context of organic and low input farming system.

## Main chapter

With the modernization and mechanization of agriculture, the diverse landraces and farmers' varieties were replaced by genetically uniform modern varieties (Dawson and Goldringer 2012). These modern varieties give high yields under favourable environmental conditions and the conditions are made suitable due to heavy inputs like synthetic fertilizers, pesticides etc. But with predicted variability in the global climate (Olesen et al. 2011) and ever increasing costs of these inputs, the need of more sustainable agricultural system is becoming more and more prominent. Organic agriculture is one of the more sustainable systems. In this system, due to the absence of heavy inputs, the performance of modern varieties has been questioned. In this situation the usage of genetically diverse landraces and historic varieties could be a solution. Due to within population genetic diversity, these landraces and historic varieties could have the ability to buffer the climatic or biotic pressures as well as it could lead to local area adaptation. Therefore the objective of this study was to gain insights on the influence of within-population diversity onto the short-term response of populations to contrasting agro-climatic conditions, by studying the genetic and phenotypic variation.

Wheat is one of the most important cereal crops of the world. Its high adaptive potential indicated by its wide geographic distribution and world-wide socio-economic value makes it a good model crop to study the response of crops to contrasting agro-climatic conditions and how within population diversity influences this response. As flowering time is a major adaptive trait directly responsive to climate change, leading to its ability to grow over a wide range of ecological and climatic conditions, this trait has been investigated in this study. European wheat populations coming from a set of seven farmers (they will be called as farmers' varieties here after) and one modern variety, each of which was grown on seven farms (distributed across three countries, France, Italy and The Netherlands in Europe) for three years were selected. These populations were used to study their short term response to contrasting agro-climatic conditions in Europe by analysing their phenotypic and genotypic variations.

Fine genetic structures of these Farmers' varieties were analysed through DAPC (Discriminant Analysis of Principal Components) and haplotypic network analysis. Results revealed that conservation history of the farmers' varieties strongly influenced their genetic diversity and fine genetic structure. As shown by the *Nei* gene diversity in the Table 1, *ex situ* conserved farmers' variety and the modern variety (Haute-Loire and Renan respectively) showed low genetic diversity and simpler structure whereas *in situ* conserved farmer varieties and mixtures (Rouge de Bordeaux, Solina, Redon, Touselles and Zone Hoeve) revealed higher level of genetic diversity and complex genetic structure and their pattern of complexity varied according to the conservation history.

Varying levels and patterns of genetic and phenotypic *spatio-temporal* differentiation were observed depending upon the level of diversity and structural complexity of the farmer variety. The traditional varieties tend to become more differentiated than the modern variety arguing in favour of the use of diverse traditional (farmer) varieties in organic and low input agriculture systems. The traditional varieties which were conserved *ex situ* showed low differentiation whereas the mixtures being more complex and diverse showed higher differentiation.

This study demonstrated strong influence of conservation history on the population structure and the short term response of these populations was dependent upon the genetic structure and level of diversity of these populations. At large this investigation provides useful insight on the evolutionary response of diverse populations which could be helpful in designing of more efficient breeding and conservation approaches.


#### Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM


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# Project Apfel:gut - participatory, organic fruit breeding

MATTHIAS RISTEL, INDE SATTLER

Saatgut e. V., Project Apfel:gut, Kamper Weg 6, 24887 Esperstoftfeld, Germany. matthiasristel@gmx.net

**Keywords**: Participatory, organic fruit breeding for diversity, genetic resources, ancient varieties

Apfel:gut is a participatory project started in 2009 with the aim to develop new ecological table fruit varieties. The project is transparent and charitable under the umbrella of the Saat:gut e. V. since 2011. The first open pollinated seedlings were planted in 1997 on the land of an active project partner. Controlled crosses are performed since 2009.

The modern apple varieties can be traced back to mainly 6 quite disease-susceptible varieties. Breeding with this narrow gene - pool would mean to increase inbreeding and the probability for pathogens to adopt, which seems to result in lower "Vitality" of some modern varieties (Noiton and Alspach 1996, Bannier 2011).

In the worldwide resistance breeding of scab resistant apple varieties the main resistance ( *Rvi6* ) was derived from *Malus floribunda* 821. This monogenic – dominant – resistance is no longer effective through all of Europe (Bus et al. 2011), even though the level of scab susceptibility differs strongly between the varieties (Haug und Karrer 2013). One central question for substantially more ecological fruit growing through more resistant varieties seems to be the durability of disease resistances. Durable resistance depends, aside from resistance genes, strongly on preformed defense mechanisms and susceptibility genes (Pavan et al. 2010, Fan and Doerner 2012). With apples there seems to be no or very little research into preformed defense mechanisms and susceptibility genes. To get reliable information about the durability of a resistance, many years of observation under field conditions are necessary (Johnson 2000).

Considering this background the project Apfel:gut started the participatory and organic fruit breeding work in different environments. In the project modern varieties are chosen maximum as one parent variety. Usually they are crossed with polygenic-resistant or at least less susceptible ancient varieties. This should also bring interesting fruit traits which are lacking in new varieties.

In different localities of various environments the farmers are actively involved in the selection process of the parent varieties and the seedlings. Crossings are performed on organic farms, where the resulting seedlings are planted in the 5th-7th leaf stage. The project focuses its breeding research on pit fruits. Open pollinated seedlings have been used to evaluate breeding values. Selection on fruit quality was focused on open pollinated seedlings sown since 1997. First controlled crossings were done each year since 2009.

The four participating farms are in the northern half of Germany. The project concentrates on the main diseases affecting the plants, which are scab, canker ( *Nectria galligena* ) and mildew ( *Podosphaera leucotricha* ). The project prefers polygenic resistances against these diseases. Polygenic resistances should be found in old varieties, which are not or very seldom used (Laurens et al. 2004). Especially on one farm in Bielefeld, which is part of the German Gene bank for fruits, these "genetic resources" were found and used for breeding purposes. Besides graftings from 15 ancient varieties of West Ireland were done in spring 2014 and will get evaluated on their robustness against scab and cancer. If they should show the expected hardiness, coming from a very wet climate, introgression lines should be build up with this "west Irish gene pool".

In crossings parent varieties are chosen according to their resistance - susceptibility level to scab, canker and with lower priority mildew, to reduce considerably pesticide - use. For reaching a durable resistance some old varieties which resist on a high polygenic level were elected. Besides other agronomic traits, like a general vitality even if diseases should occur, the project is heading for more diversity in taste and look of the fruit. It is planned to aim for a holistic organic process demanded on the table fruit market.

Breeding techniques are transparent. Crossings between polygenic, resistant and usually old varieties are done with the least susceptible of the modern varieties. Seedlings grow on their own roots until they start fruiting on organic farms under field conditions. They are planted in rows with a distance of 30 cm. For three years disease - susceptibility of the seedlings gets evaluated and the most susceptible seedlings of each progenies get pulled out. After three years the healthiest and culture type like growing trees are positively selected and planted in one meter distances. Seedlings with good fruit quality are then grafted and evaluated on all four farms. Grafting for apples is done on M 9 and M 25, for pears on Quince A. The seedlings are not sprayed at all and fertilized with compost.
Before 2020 no varieties will be registered. The health level of some seedlings (which are already bringing well tasting fruits) is good. These observations could be made even in 2013, with a very high scab pressure. In sum there are around 3000 apple seedlings, 100 pear seedlings, a few apricot and cherry seedlings planted on the farms.

Looking at the worldwide fruit breeding programs, the Apfel:gut project goes quite different ways. In conventional fruit breeding time till fruiting is shortened as much as possible. So the breeding goal for high fruit quality gets more important while agronomic traits under field conditions get a lower priority. Apfel:gut has the aim to make the breeding process transparent, public and ecological. It's a matter of concern to stop the loss of genetic diversity in modern variety development, and widen the base of new varieties again. Seedlings on their own roots are usually more vigorous than on the common M 9, so they fit better to a more extensive growing system of the seedlings.

One of the most important factors for the successful development of varieties seems to be the parental selection. The project tries to proof that a selection of old varieties sometimes only has one or two traits which block their cultivation in modern fruit growing. This selection and evaluation of old varieties should be continued. Keeping this in mind there should be a chance to bring together the best of the old and the new world of fruits.

Different environments for the selection should result in different “Genotype x Environment Interaction”. In this project the diversity of different organic farms for the growing process should result in more diverse outcome, resulting in a wider genepool to have higher chances of getting vital trees and fruits for farmers and consumers.

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# BleguPoitou: a participative project for co-breeding of wheat and legumes

## Cultivated diversity for farmers' empowerment and on farm research

ESTELLE SERPOLAY-BESSON[1], ANTONIN LERET[2]

[1] ITAB, Domaine de la Motte, BP 35327, 35653 Le Rheu, France, http://www.itab.asso.fr, estelle.serpolay-besson@itab.asso.fr
[2] INRA SAD, Le Rheu, France

**Key words:** participative research, co-breeding, wheat, legumes, farmers' empowerment

**Summary:** Blégu Poitou is a participative project of co-breeding of wheat and legumes. Farmers from Poitou-Charentes Region (West of France) are looking for cultivated diversity from specific and genetic points of view and set up experiments in their farms. This project allows empowerment of those farmers (they experiment by themselves, increase seed autonomy) as well as developing on farm research through focuses on certain questions. In 2014, the focus chosen is AMF and we show that they are more present on wheat when it is cultivated together with a legume. Such a project also reveals the importance of the symbiosis of the 3 types of stakeholders: farmers, animator and scientist.

### Background

Considering that diversity at specific and genetic levels will bring crop efficiency, and also looking for seed autonomy, a group of organic and low input farmers from Poitou-Charentes Region in France asked research institute to build a participatory co-breeding project of wheat and legumes intercropping. Collaboration between 10 farmers of the association Cultivons la Biodiversité en Poitou-Charentes (CBD), the animator of the association and an engineer from the research team INRA-ITAB of Le Rheu started in 2010 in the framework of the European Research project SOLIBAM. This local project is called BléguPoitou and is based on a network of on farm trials. A challenge of this project is to manage a collective work with a great diversity of situations of farms systems and objectives.

### Main chapter

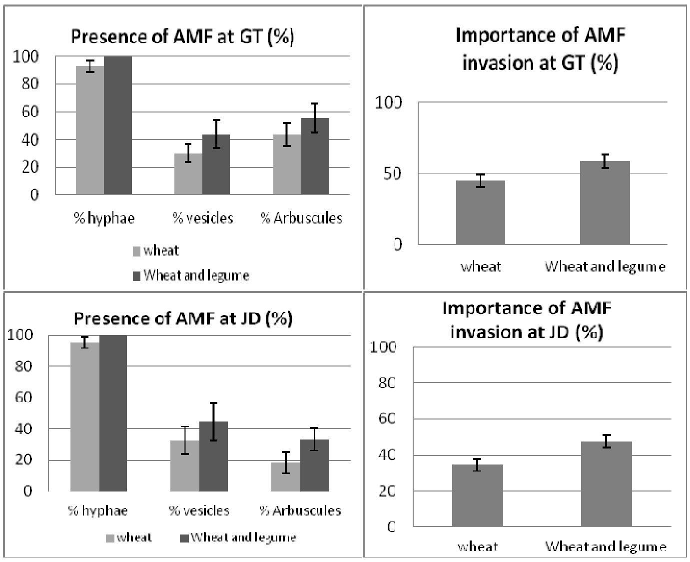
Introduction: The farmers participating in the project Blégu Poitou are looking for genetically diversified wheat varieties (populations, dynamic populations…) adapted to co-cropping with legumes. They cultivate wheat and legumes for different uses (cash crop or animal feeding for example) and have different practices for co-cropping as well (sowing together wheat and legumes, sowing in the legume or sowing legume in the wheat). After a first year of common observations on a platform with different varieties, all the farmers started trials in their farms, building up a network of trials. The project is going on through collective moments of reflection and exchanges, managed by the animator of the association. The farm trials network allows the farmers' empowerment on different aspects as well as it gives the possibility for focusing on punctual research questions of the farmers, as the impact of co-cropping on AMF in 2014.

Material and method: The project started by a platform of observation where about 30 genetically diversified varieties (populations, old varieties, dynamic populations and CCP) were cultivated in 2010. The farmers tried observations in order to be able to observe their future trials by themselves. At the end of this first year of observations, they chose some varieties to observe in their farms. Since then, they started multiplying and experimenting the varieties chosen with legumes according to their practices or whishes of experimentation. The network of trials is today much diversified in terms of varieties tested, legumes and practices. The table 1 below summarizes the continuity of the project.

Table 1: run of the BléguPoitou project

| | Trial design | Realisations |
|---|---|---|
| Harvest 2011 | Platform of diversity<br>- one place<br>- 30 varieties<br>- 2 replicates | Collective observations at different stages (learning process of observation)<br>Choice of different varieties per farmer in order to experiment in its farm |
| Harvest 2012 | Several varieties in each farm<br>Very small plots | Seed multiplication<br>Field observations (farmers and animator) |
| Harvest 2013 | Several varieties in each farm<br>Larger plots than 2012 (and small plots for new varieties) | Seed multiplication and sometime selection<br>Field observations (farmers and student)<br>Management experimentation (different legumes) |
| Harvest 2014 | Several varieties in each farm<br>Larger plots than 2013 (and small plots for new varieties)<br>Common control population | Seed multiplication and sometime selection<br>Field observations (farmers and student)<br>Management experimentation (different legumes, different soil management)<br>Research focus on AMF |

This year (2014), a research focus on AMF was done thanks to the common control sown in all the trials (decision of the farmers). Different modalities on different farms were chosen in order to answer various questions. In this paper, we will focus on the question: “does co-cropping with legumes increase AMF rate on wheat and thus its collaboration with soil”? We present here the results for 2 farmers (GT and JD). 10 root systems were harvested at the end of April on 2 modalities at each farmer: control (population called Carré de Crète) without co-cropping and control with legume (faba bean for GT and alfalfa for JD). The root systems were colored and 10 roots per root system were observed in 2 points each in order to determine the importance of AMF colonization. Presence or absence of hyphae, vesicles and arbuscules was observed and a global note of colonization of the AMF was given too (from 1=very scarce to 5=very important). The results of the observations are presented as percentages (of presence of the different AMF structures and % of global colonization).




Results:

***AMF 2014 first results:*** The graphs close by present the rates of presence of the AMF structures as well as the importance of AMF “invasion” at 2 farmers. Despite the difference of legume species of co-cropping, we clearly see in the 2 cases that the wheat cultivated with a legume is more colonized by AMF (more hyphae, vesicles, arbuscules and global note of invasion). We will then correlate these results with yield and quality aspects and would also like to explore the effect of co-breeding on the long term (do the plants “used” to be cultivated with legumes develop specific ability to interact with them through AMF, consequences for yield and quality?).

***Farmers’ empowerment:*** Since the beginning of this participative project, we see a clear empowerment of the farmers on different aspects. First of all, they have learnt how to experiment in their own farms. Some of them have built elaborated trials and they realize some observations by themselves, allowing them to give an elaborated opinion on the varieties observed (all the observations already available have been compiled in a report addressed to the farmers for sharing experiences). They have started adapting genetically diversified varieties to their systems and some farmers are already cultivating some hectares of them. They also breed the varieties, creating their own mixtures according to the different varieties they observe in their fields. All this work contributes to increase their seed autonomy. When farmers develop such varieties as cash crops, commercialization might be a problem because of the different qualities of these varieties (different protein and technological characteristics). This aspect, related to the economy of the farm, will enlarge the dimension of the project.

*Discussion-perspectives*

This participatory project is going-on on diverse aspects and has different types of outputs: empowerment of farmers as well as scientific studies thanks to the trials network built. This enables on farm research and development. One of the challenges of this project is to manage a collective project with individual trials. The participative organization set up with this purpose principally consists in 2 annual meetings with farmers, animator and engineer. One field meeting in June to discuss of the plants during the cycle and one “room meeting” in September to realize an assessment of the past cycle and to orientate collectively the new cycle. For example, adjustment of the observations, pointing out a specific research question we will focus on… These moments are important to keep the coherence of the group as well as for creating a space for farmers to exchange their experiences. But they are not sufficient. The role of the animator of the association is crucial because he/she will contribute to make the link between the meetings, by visiting the farmers from time to time, reminding them for the observations… This makes another kind of result emerge: the importance of the symbiosis of the different competences of the 3 types of partners in such a participative project: farmers, animator and engineer.

# Farmer to farmer exchanges: a new way to foster local innovation. The case of garlic and lentil in Lazio Region

MASSIMO TANCA[1], PAOLA TAVIANI[2], RICCARDO BOCCI[3], RICCARDO FRANCIOLINI[4], MARIATERESA CONSTANZA[5]

[1] ARSIAL
[2] ARSIAL
[3] Rural Seed Network
[4] Rural Seed Network
[5] ARSIAL

**Key words:** garlic, lentil, landraces, participatory, social capital, local and traditional knowledge, Lazio Region

**Summary**

The Regional Agency for Development and Innovation of Agriculture in Lazio (ARSIAL), pursuant to Regional Law no. 15/2000 “Protection of indigenous genetic resources of agricultural interest”, manages the Network for Conservation and Safety” by sponsoring in situ/on farm conservation of local varieties and breeds from Lazio. ARSIAL and the Rural Seed Network propose local actions to encourage collective approaches that, starting with the dynamic conservation of crop diversity, foster exchanges of knowledge among peers as an agricultural training tool, organizing meetings between growers of local varieties of the same species.

**Background**

The globalization of the international economy, the post-Fordist inter-organizational models and the *knowledge society* as an intangible development resource, have repercussions at the level of local *governance* and management innovation.
Innovation is changing from a linear *top-down* use of science and technology, through new forms of collaborative action in social-interactive innovation that actively involves stakeholders such as designers, developers and users of innovation that draw on its benefits.
The new programming for the EU structural funds (ESF, ERDF, EAFRD), involving rural areas, through the Lisbon strategy, “Europe 2020”, the new CAP and Horizon 2020, acts as an interface between the world of Rural development and research. It is based on an interactive innovation model of the *bottom-up* type.
This approach is evident in the establishment of the European Innovation Partnership (EIP) “Agricultural Productivity and Sustainability”. The goal is to promote innovative investments capable of producing immediately applicable results on the farms, based on the actual needs of farmers, especially with regard to agro-biodiversity, which would offer huge potential for development if it were to be used.
The “participatory” method (Community Led Local Development, CLLD) is a new paradigm that involves scientific research and local planning aimed at maintaining and developing biodiversity. The belief is that a local community that regains the ability to design its own future, and has acquired perception of the scientific, economic and cultural value of the territory, is definitely less vulnerable in finding an approach to sustainable land management in the commons.
In the Lazio Region, the agricultural systems that grow and breed varied indigenous genetic resources protected by the Regional Law 15/2000, both animal and vegetable, represent a widespread intangible cultural heritage of “know how” deposits, whether they are oriented toward transforming local products or enhancing intangible assets. For the most part, these farms are located in hilly or mountainous areas, are small in size, and if they are involved in agriculture, it is often not the main activity.
In order to maintain high levels of diversity in the agricultural and semi-natural regional ecosystems by creating more resilient systems that are also capable of mitigating the impact of climate change, Arsial in its role of implementing agency for the Regional Law on protection of agricultural biodiversity, proposes local measures to encourage collective approaches. The approaches, starting with the dynamic conservation of crop diversity, promote exchanges of knowledge among peers as an agricultural training tool. The technical experts are entrusted with the role of facilitators and, flanked and supported by such professionals as anthropologists, sociologists and historians, promote local revival and encourage grassroots participation.

**Main Chapter**

In the Lazio Region Conservation and Safety Network (provided for by the Regional Law 15/2000) there are currently 496 farmers and 661 breeders who respectively grow/raise 186 varieties and 24 local protected breeds. In the Voluntary Regional Register, there are 48 varieties of field crops listed, mainly belonging to horticultural species whose reproduction is based on a largely informal seed production system. Through a technical-scientific and historical-anthropological approach, ARSIAL and the Rural Seed Network are promoting “networking” actions between local communities that are custodians of agricultural biodiversity and the knowledge related to it. In particular, “*focus groups*” have been organized among those who have local varieties of the same species: “Red Proceno Garlic” and “Red Castelliri garlic; “Ventotene Lentil”, “Rascino Lentil” and “Onano Lentil.”

The meetings are organized by the members from the Lazio Network for Conservation and Safety who grow local varieties of the same species of garlic (*Allium sativum* L.) and lentil (*Lens culinaris* Med). The methodology used was the "focus group" with a moderator. The meeting was also attended by a grower of the local variety of "Santo Stefano Sassanio Lentil", originating in the Abruzzo region.

The first meeting was held in Fiamignano (RI, 900 m asl) March 1, 2014, where the community of growers of the 3 local varieties of lentil met. The following issues emerged during the meeting:

- varietal control of the seed and cleaning;
- cultivation techniques (mechanization difficulties, manual labour, rotation);
- environmental sustainability (environments located in protected areas and the Natura 2000 Network);
- associations (participation and enthusiasm);
- product communication and sales.

The second meeting was held on April 29, 2014, in Proceno (VT, 400 m asl) with growers of the two local varieties of garlic. Starting with the visit to the fields of "Red Proceno Garlic", the meeting was an opportunity to exchange information on the following issues:

- propagation system of cloves, choices made both on the farm and in the community;
- identification of specific growing practices to solve plant protection and production problems;
- various uses of the product in terms of processing, from harvesting to the different food preparations;
- enhancement of the local variety in different types of markets from on-the-farm selling to selling at local fairs/markets (0 Km), and medium/large-scale distribution.

The communities of growers involved in the meetings talked about the various methods for growing local varieties of garlic and lentil, the size of the farm and its growing system. Data is recorded in the farm information file for all the growers of the same local variety, in such a way as to obtain a synthesis of information on the varieties (the file proposed by the guidelines drawn up by the Ministry of Agriculture and Food), containing all possible information on the local variety: the morphological, agronomic and historical characteristics, and tracking of the individual farms growing the varieties in situ/on farm.

The meetings include socializing - lunch and dinner - between the farmers in the community. Strengthening the links between the different nodes of a social network is essential to its maintenance over time. The Network for Conservation and Safety is a social network made up of players and institutions spread over a vast territory. Opportunities for different players to exchange direct knowledge improve the ability to transfer knowledge and consequently the resilience of the individual local systems.

With the community, an investigation into the knowledge and "know how" of farmers has been started, using the ethnographic method that makes it possible to document ways of life from within the farm, and identify the skills, knowledge and opinions of the farmers themselves in regard to their actions. It will also be possible to develop an interpretative framework centred on "social capital" that may be used for detecting untapped potential, risks and fragility in a local farm that is a keeper of knowledge related to biodiversity.

Figure 1. Meeting of growers of "Red Proceno Garlic" and "Red Castelliri Garlic" at the Proceno farm (VT), April 29, 2014.

# Breeding common bean for organic farming system

Carlo Tissi[1], Renzo Torricelli[1], Lorenzo Raggi[1], Sally A. Howlett[2], Frédéric Rey[3], Valeria Negri[1]

[1] Dipartimento di Scienze Agrarie Alimentari e Ambientali, Università degli Studi di Perugia (IT)
[2] The Organic Research Centre (UK)
[3] Institut Technique de l'Agriculture Biologique (FR)

**Keywords:** Common bean; organic agriculture; landrace germplasm; multi-environmental field trials; GGE biplot; SSR markers.

Poorly adapted cultivars may be partially responsible for the yield gap between organic and conventional farming systems, as most commercial varieties are bred for the latter conditions. At present, cultivars specifically bred for organic agriculture do not exist for the majority of the crop species, including the common bean ( *Phaseolus vulgaris* L.).

The main aim of this study was to check the suitability in organic agriculture of 17 common bean lines obtained from a breeding program carried out under organic farming conditions following an evolutionary breeding approach. The yield performances of the lines were assessed in comparison with cultivars of the same commercial class phenotype. At this purpose a GGE biplot analysis was carried out on data recorded from 11 multi-environment field trials at five location for three consecutive growing seasons. Furthermore, a genetic characterization of the plant material was carried out using 25 Simple Sequence Repeats (SSRs) molecular markers.

Overall, our results highlight how common bean lines bred against a background of organic conditions are able to overcome the yield performance of traditionally bred cultivars in organic farming systems. The GGE biplot identified a line adapted to a broad spectrum of organic agriculture conditions as well as two lines better adapted to specific environments. Molecular analysis showed that landrace germplasm played an important role in the adaptation to the organic farming conditions.

**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

# Session D

# Sustainable food supply systems from diversity

# What is efficiency in sustainable food systems and how could it be measured?

JOHANNA BJORKLUND

[1]Associate professor, School of Science and Technology, Örebro University, Sweden, +46 19 30 39 76, E-mail: johanna.bjorklund@oru.se

Key words: multifunctionality, ecosystem services, perennial intercropping, agroforestry, assessment methods

Summary: Large-scale monocultures are not enough efficient to feed an increasing global population and in the same time cope with depletion of non-renewable resources, climate change and ecosystem degradation. Ecological intensification is needed. Low input systems based on agroecology, using our knowledge about processes and function of natural ecosystems as models is one feasible option. To develop methods to assess multifunctionality, and to find ways to include these assessments when evaluating systems performance are urgent. “Bundles of ecosystem services” is a new pedagogic tool which lend it self to considerations of trade-offs between different different aspects of multifunctionality.

A sustainable food system not only has to fulfil the human needs of food, fuels and fibres, it also has to contribute to the generation of ecosystem services which is fundamental for the well-being of our society (IAASTD, 2009, DeSchütter, 2011, Foley, et al. 2011). For example, it will be crucial that agricultural land use:

• *Contributes to the mitigation of global warming* – Presently agricultural land is a significant source of greenhouse gases, but a growing body of research provides evidence of the large potential for such land use to sequester carbon dioxide (Soussana, 2007, Nair et al. 2010). To break the trend of rising carbon dioxide emissions this potential has to be taken care of. Furthermore the dependence on fossil energy in the whole food system has to be reduced significantly. Agricultural production needs to be based on local ecosystem services for e.g. nutrient supply, biologic regulation and water supply.

• *Adapts to the effects of global warming* – As global warming continues the presence of extreme weather and climate events are anticipated (IPCC 2014). More powerful and unpredictable weather such as extreme temperatures, droughts, floods and strong winds, together with expected new pests, will be a major threat to food security. Increasing the resilience within food production systems is therefor an urgent and important object.

• *Accommodates biodiversity* – The Intergovernmental Panel on Climate Change (IPCC) anticipates a 20-30% reduction of the number of species to be expected when we reach 2 -3 degree of temperature rise globally (IPCC, 2007). Continuing the present rate of carbon dioxide emissions the temperature will, in a 100 years time span, rise far higher than this (Potsdam Institute for Climate Impact Research and Climate Analytics, 2012, IPCC 2014). Maintaining and harbouring diversity per se, and vital populations of important carriers as well as passengers species, will therefore be of increasing importance in all kinds of ecosystems (Millennium Ecosystem Assessment, 2005).

• *Generates fertility and efficiently recirculates nutrients* – A reduction as large as perhaps 75% of the inout of new nitrogen (N) and a ten times reduction of phosphorus (P) fertilizers has been suggested as a mean to adjust global biogeochemcial flows of N and P to levels that are within safe limits regarding the complex web of negative environmental effects of the use of these nutrients, e.g. contribution to eutrophication, global warming and acidification, reduction of stratospheric ozone (Rockström et al. 2009).

An increasing number of studies show that large-scale monocultures are not enough efficient to feed an increasing global population and in the same time cope with depletion of non-renewable resources, climate change and ecosystem degradation. Instead international research indicates that systems with perennial intercropping for example, agroforestry systems; a) give a higher total production per area than monocultures because they use resources such as sunlight, nutrients and water more efficiently, b) can accumulate carbon in biomass, i.e. can act as sinks for carbon dioxide, c) harbour a higher diversity and more natural enemies to pests, reducing the need for chemical control, d) gives less nutrient runoff and more efficient recycling, because crop residues and manure may be recycled in the system, e) decreases the need of fossil energy through provision of biofuel and less need of fossil-based inputs, providing means to decreasing emissions of greenhouse gases. (Ewel, 1999, Garcia-Barrios and Ong 2004, Goncalves 2007, Jose 2009, Tscharntke et al., 2011, Kremen 2012)

This gives strong arguments for the necessity to change from the input intensive industrial mode production prevalent in our part of the world to a more ecologically intensive one, which means low input systems based on agroecology, using processes and function of natural ecosystems as models (Izac & Sanches, 2001, Francis et al., 2003, Gliessman, 2007, Scherr & Mc Neely, 2008). Ecological intensification combines production and conservation, resulting in an exchange from fossil fuels to wise use of local ecosystem services. This requires an increase in diversity at all scales in time and space, e.g. in habitats, among wild species and within these species, as well as of domestic crops and animals and varieties of these, and in management solutions. Conscious design of production systems are important to build useful interactions. Awareness of appropriate scales for maximizing the generation of certain ecosystems is found to be crucial, as well as evolutionary breeding of animals and crops to increase genetic variation, enhancing the ability for adaptation and for utilizing varying local conditions (Dalgaard et al. 2003, Björklund & Helmfrid, 2012).

To develop methods to assess multifunctionality, and to find ways to include these assessments when evaluating systems performance are urgent. Efficiency will not any longer simply be a question of the highest economic yields. It will concern high production of a combination of desirable outcomes, including ecosystem services and resilience, and in the same time minimizing the use non-renewable resources.

The definition by Daily (1997) that ecosystem services are "…conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" as well as the classification in provisioning, supporting, regulating and cultural services developed within the Millennium Ecosystem Assessment (MA) (2005) are appropriate as a starting point for assessments. However, food systems are different to natural systems, for example in that they would not be there without humans. They are socio-ecological systems, and the human activities are crucial for the generation of ecosystem services, in kind and amount.

Methods for assessing and valuating a variety ecosystem services in large scale in food production systems is lacking and research in this area needs to be prioritized (SOU, 2013). Studies performed indicate that measuring the actual service in consideration often is time consuming, expensive, or impossible due to lack of appropriate methods. Instead inventories of presence and richness of species performing services are done (e.g. presence of pollinators in the case of pollination), with the presumption that if the species are present the services will be performed (Björklund et al. 1999, Bommarco et al. 2012). Furthermore, variables of concern may be dependent on slow processes (e.g. soil carbon storages, species compositions, mycorrhiza development) and to be statistically reliable, many repetitions are needed when systems are complex and variables are plenty. Relevant references points also needs to be defined.

Within a participatory learning and action research project concerning Swedish agroforestry systems a tentative list of ecosystem services and methods useful for their assessments has been developed (Björklund et al. 2014). These assessments, which may add to the assessments of eco-efficiency within food supply system in the SOLIBAM project, includes; a) Assessing Land Equivalent Ratio (LER) in harvestable yields as well as in standing biomass, b) Carbon accounting in standing biomass and measurement of total soil carbon, c) Assessment of biodiversity and biotic regulation by focusing on indicator species and key measurements, d) Assessment of soil fertility by measuring biologic activity and e) Using ranking methods and sensory panels to evaluate natural, cultural, culinary and nutritional values. (Meed & Willey, 1980, Östman, 2001, Belfrage et al., 2005, Pearson et al. 2007, Björklund & Johansson, 2012, Nair 2012, Albinsson et al. 2013).

In the end, to assess efficiency for the development of sustainable food production systems, the different aspects of multifunctionality that are measured also need to be valuated. "Bundles of ecosystem services" is a new pedagogic tool to described the result of assessments of ecosystem services, which lend it self to considerations of trade-offs between different services and to weight their individual importance within a certain context (see e.g. (Foley et al. 2005, Björklund & Johansson, 2010). More examples needs to be preformed and common agreements on how to use the tool needs be established. It is also important to recognize pitfalls when using a tool, which aggregates an immense amount of aspects with greatly distinct and diverse qualities.

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# Sustainable food supply systems from diversity

## Integrated assessment of environmental and economic sustainability applied on case farms

HANNE ØSTERGÅRD[1], THOMAS NEMECEK[2], MORTEN GYLLING[3]

[1] Department of Chemical and Biochemical Engineering, Technical University of Denmark, Denmark, www.bioeng.kt.dtu.dk, haqs@kt.dtu.dk
[2] Agroscope, Institute for Sustainability Sciences, Zurich, Switzerland, www.agroscope.ch, Thomas.nemecek@agroscope.admin.ch
[3] University of Copenhagen, Denmark, http://www.ifro.ku.dk/english/, gylling@ifro.ku.dk

**Key words:** Life cycle assessment, emergy assessment, micro-economic analysis, case farms, participatory innovation, renewability

**Summary:** Sustainability assessments of food supply systems have to identify hotspots for reducing use of non-renewable resources and potentials for substitution of these with renewable resources as well as hotspots for reducing emissions to the environment. We have used a number of indicators based on LCA, emergy and economy to evaluate central phenomena in innovative food supply systems based on interviews and statistical data. The indicators chosen point to where systems need to be changed to better support a sustainable development according to SOLIBAM strategies. Examples are given from innovative farms and food supply systems studied in different countries.

**Background**

Current agricultural practice is under pressure and there is a need to develop and implement new practices with a high degree of renewability and reliance of local resources. In SOLIBAM we focus on organic and low-input practices. A central concept for food supply systems is that they should support a sustainable development. Strictly speaking this would imply that we 1) use resources at a rate that allows their re-formation and 2) produces waste at a rate which allows the environment to absorb it. Sustainable development, therefore, implies making use of renewable resources to a larger extent. Thus a sustainability assessment has to identify hotspots for reducing use of non-renewable resources and potentials for substitution of these with renewable resources. Further, it should address the production of wastes and the potentials for using them as resources within the system.

If the environmental impacts of food systems are to be significantly reduced, then it is necessary to view the production and distribution of food together. Direct marketing and local selling of products offers a way for farms to by-pass the energy intensive mass distribution system. The development in food supply systems has resulted in a push towards producers being more specialized and production in larger, uniform units. These changes tend to imply reductions in crop diversity at the farm level which in the long run may cause problems for our society. For example, the biodiversity loss associated with these systems has been shown to result in decreased productivity and stability of ecosystems due to loss of ecosystem services (Cardinale et al., 2012). Specifically, biodiversity at the farm level has been shown often to have many ecological benefits (ecosystem services) like supporting pollination, pest and disease control. A driving force for increasing on-farm biodiversity has been shown to be local selling in a Swedish study (Bjørklund et al., 2009).

LCA (Life Cycle Assessment) as well as emergy assessment provide tools for such analyses. Emergy is defined as the total available energy directly or indirectly required to make a given product or service and is measured in solar equivalent Joules (seJ). The two methodologies are to a large extent based on the same type of inventory of energy and material flows, but rely on different theories of values and system boundaries. LCA draws system boundaries around the studied system as supported by human dominated processes (resource extraction, refining, transportation etc.) whereas emergy accounting considers systems as embedded in the larger natural system and thus also includes all direct and indirect flows of freely available resources such as sun, rain, wind and geothermal heat. Another difference is that emergy accounting includes labour in order to take into account the indirect resources from society, e.g. infrastructure, needed to support a system. LCA on the other hand considers emissions to the environment in addition to resources. However, the emergy method lacks some of the standardization and robustness of LCA. In SOLIBAM we have combined the advantages of both methods. Further, we have included economic analyses to understand better the outcomes of innovative food supply systems.

Combining different assessment tools is a requirement for addressing the complexity of today's society to end up with a more comprehensive description of each system as well as a discussion of how to progress towards systems applying the SOLIBAM strategies, i.e., innovative sustainable strategies where products and processes for the food supply system are based on PPBM and diversity at all levels. The purpose is to learn about central phenomena in innovative food supply systems based on interviews and statistical data and to point out the complexities of these systems which make each of them unique. The indicators chosen should be able to point to where the systems need to be changed to better fulfil the expectations to systems working according to the SOLIBAM strategies. New tools have been developed and combined with well-known tools to perform this task.

**Selected food supply systems**

In SOLIBAM we have considered eight cases of a food supply system, mainly based on innovative farms aiming at reducing inputs and applying large diversity of crops and varieties and thus being candidates for stepping stones towards SOLIBAM strategies. We designate these systems as paradigmatic cases since they represent a fundamentally different way of producing and distributing food compared to the dominating practices which are conventional agricultural production and supermarket mass distribution of the produce.

We analyse the environmental impacts, the resource use efficiency and the economic feasibility of these cases. We have benchmarked them against 'normal practice' as well as made scenarios for how to increase their contribution to a sustainable development of the European agriculture.

We define a food supply system as consisting of the production at the farm, processing and distribution to the customer. Our cases are defined based on the main output from the farms considered as either vegetable systems or bread systems:

1. Vegetable systems: two farms in UK, one in Italy and one in Portugal
2. Grain and bread systems: two farms in France, one in Italy and one in Portugal

Some farms also have animals. Further, the farms can be classified into their degree of input as well as their scale (farm area compared to average national farm size). Also, the crop diversity differs between the farms. Finally, each food supply distribution system is either direct to consumers or indirect via supermarket. The selected cases also include different stages of establishing low input farms.

The study was mainly based on primary data representing the actual situation in 2008, 2009 and 2010. Data were collected directly from 8 producers through direct semi-structured interviews on farm and further contact via post, e-mails and telephone.

**Selected indicators for integrated assessment**

Data consist of inputs and emissions from total annual food production at farm gate and of food provision at consumers door or table. The indicators chosen are:

- Extended eco-efficiency = 'impact'/'functional unit'

  impact = global warming potential, non-renewable energy use, eutrophication, acidification, ecotoxicity, emergy use, emergy footprint, revenue, costs, etc

  functional unit = 1 kg bread, food energy in total production of vegetables, 1 EUR, 1 hectare, 1 seJ (solar equivalent Joule), etc
- Origin of inputs

  % renewable inputs at different scales

  % inputs from farm, from local community, and globally

**Example of integrated results from two French systems**

FR1 is a well-established organic farm of more than 70 ha that besides from its cereals and flour production also produces and distributes milk and a variety of cheeses. It cultivates more than 300 varieties, of which more than 100 are grown each year. FR2 is a 10 years young farm of only 5 ha. The main product for the farm is own produced bread, based on grain grown and milled on the farm. The bread is also distributed by the farm. A large variability of eco-efficiency calculated in different ways was found between farms and even among the years 2008-2010 within individual farms. This 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 calculated as emissions per kg bread produced with a proper organisation, ii) that it is possible to improve eco-efficiency of such systems without compromising their distinctive properties like local production and diversity and iii) that large improvement potentials suggest that a lack of knowledge on eco-efficient cropping system management can be a key limiting factor for environmental sustainability (Kulak et al, this congress).

The origin of inputs were analysed by emergy assessment. 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 (Wright et al, this congress).

Economic analysis showed that the analysed food supply systems were socio-economic sustainable in the sense that they were able to tackle changes in the external economic environment such as the economic crisis and shifting consumer behavior, selling products at premium prices, and enhancing the economic performance at system level. (Tavella and Gylling, this congress).

**Example of integrated results from UK food supply system**

We have evaluated the advantages and disadvantages of a paradigmatic case, UK1, which is a small-scale low-input organic vegetable farm in UK with high crop diversity and a related box scheme food supply system. By combining emergy evaluation and life cycle assessment (LCA), we have benchmarked the resource use and environmental impacts from UK1 against two modelled organic systems, UK2Low and UK2High (Markussen et al 2014). The UK2-systems produce the same amount of vegetables (accounted for in terms of food energy) as UK1, however, they have a much reduced crop diversity and either low or high inputs and yields. Together they represent a range of standard practices for organic vegetable production. In addition, the UK2-systems are embedded in a supermarket-led mass distribution food supply system. The UK1 distribution system is at least three times as resource efficient as UK2 when assessed by emergy analysis. The results of the LCA for the cultivation phase were less conclusive as the case had neither consistently more nor consistently less environmental impacts compared to the model systems. However, for the distribution phase, both the emergy assessment and LCA evaluated the case to perform substantially better than model systems. However, UK1 uses still very many services from the society (89% of emergy flow).

We have compared the economic performance of UK1 for 2008, 2009 and 2010, and explained how the farm developed economically within these three years in order to adapt to external changes and enhance socioeconomic sustainability. Based on this analysis, we have argued that UK1 needs to continuously cultivate different crops, diversify its distribution strategies, create different tasks to carry out at the farm, and generate income and year round work for full-time employees in order to enhance its socio-economic sustainability. To this end we have illustrated a future strategy implying a delivery of vegetables (additional 20% of bag sales) to a restaurant. This strategy has shown that delivering vegetables to a restaurant leads to a decrease of labour costs (due to reduced requirements for packaging) and an increase in annual total return. This increase will contribute to enhancing the socioeconomic sustainability of UK1. (Tavella and Gylling, this congress)

**Conclusion**

The indicators chosen have demonstrated that even for innovative farms and food supply systems there are large potentials for improvement of environmental sustainability, resource use and economic outcome.

**Acknowledgement**

Data collection by Michal Kulak, Mads Markussen, Carolina Passeira, Livia Ortolani in collaboration with the farmers and local SOLIBAM researchers are acknowledged as well as the support by EU.

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# The role of learning networks in co-producing sustainability.
## The case of Crisoperla Association

ADANELLA ROSSI[1], ELENA FAVILLI[2], GIANLUCA BRUNORI[3]

[1] Dept. Agriculture, Food and Environment, University of Pisa, Italy; adanella.rossi@unipi.it
[2] Dept. Agriculture, Food and Environment, University of Pisa, Italy; efavilli@gmail.com
[3] Dept. Agriculture, Food and Environment, University of Pisa, Italy; gianluca.brunori@unipi.it

**Key words:** learning networks, social innovation, sustainable food systems, transition

**Summary:** The transition of food systems towards sustainability entails complex changes, involving multiple actors and fields of action. The paper draws on the analyses conducted during the EU project SOLINSA, concerning the role of learning and innovation networks as drivers of transition in agriculture and rural development. Within the conceptual framework provided by transition theories, it proposes the case study of a hybrid network developed around organic farming and, more generally, sustainability issues, in Tuscany (Italy). It focuses on the social learning processes and governance mechanisms underlying the development and spread of innovation, highlighting potentials and challenges.**On processes of innovation towards sustainable food systems**

The need for a transition towards more sustainable food systems is widely acknowledged. This process is complex and sees the co-presence and interrelation of multiple dimensions, from technological and organizational to cultural, institutional and juridical aspects, at all the levels of the system. According to transition theories (Geels 2004), it requires a redefinition of the whole socio-technical system underlying food production and consumption practices, that is a re-organization of systems of knowledge, rules and norms of behaviour, and a re-design of the organisational and material infrastructures involved from production to consumption practices. A multiplicity of actors are increasingly involved in promoting and driving this process of innovation: farmers and other rural entrepreneurs, chain actors, end users, researchers and advisors, policy makers and public administrators, NGOs and civil society organizations. As multi-dimensional and multi-actors process the transition to sustainability thus appears to involve multiple fields of action, types of knowledge, perspectives and interests, including the pursuit both of public and private goods.

To tackle this complexity researchers and practitioners have increasingly adopted a systemic perspective, focusing on the dynamics of interaction between the diverse actors and the diverse forms of learning, with reference to a contextualised dimension (Knickel et al., 2009). Among the others, the EU research project SOLINSA (7FP, ended in January 2014) focused on the potential of these hybrid networks (*Learning and Innovation Networks for Sustainable Agriculture – LINSA*), considered as innovative forms of relationship and learning, that can meet the challenge of sustainability (Brunori et al. 2013). In the context of the new EU policies for innovation, the project proposed this concept as policy device to support farmers and rural actors in generating innovations for transition (Moschitz et al. 2014).

Interactions and social learning processes developing within multi-actor relational environments are thus central to innovation for sustainability. The new frames of common understanding that result from them generate shared knowledge that, translated into new attitudes and practices, allows a coherent re-configuration of all the components of the system.

The effectiveness of learning processes in giving rise to innovative ways of thinking and practices as well as the potential of the networks to spread their innovation, so as to have some influence on the mainstream system, are strongly conditioned by the quality of the interactions inside and outside these networks, that is by the governance modes (Rossi et al., 2014). The role of governance is particularly significant into a perspective of pursuit of public goods. To meet the new demands of environmental and social sustainability, the co-ordination of interests, institutional cultures, and often conflicting perspectives within the multi-actor and multi-dimensional environments of innovation appears crucial. They become the spaces where shared knowledge and competences can lead to collective vision, coherent practices and new collaborative arrangements amongst the different societal and institutional actors involved.

From the perspective of transition theories, the ‘cross-boundary interactions’ which develop amongst these different actors / fields of activity and the related learning processes are important in the re-configuration of socio-technical systems. In this regard, both within the network relational dynamics and in their interaction with the ‘outside’, the presence of boundary and intermediary actors play a key role (Howells 2006). The SOLINSA project called these actors ‘transition partners’ (Moschitz et al., 2014).

**The experience of a learning and innovation network: the *Crisoperla Association***

Drawing on the theoretical reflections and the research conducted within the project SOLINSA, this paper aims to contribute to the understanding of these processes through the insights derived from one of the two case studies carried out by the Italian team. It analyses the experience of the Association *Crisoperla,* located between Tuscany and Liguria, in Italy. Born around the common desire to enhance organic farming, it has gradually embraced broader goals of promoting social and environmental sustainability in lifestyles and development patterns. Over this process Its network has grown in number and types of actors and in fields of activity. The members include organic farmers, social farming and fishermen cooperatives, consumers’ groups (Solidarity - based Purchase groups, GAS) other consumers’ associations, technicians. It does not include public actors, but it is increasingly interacting with some local administrations. The Association has moreover begun to interact with other local organizations as well as outside the two regions of origin, by establishing relationships with organisations for organic farming, at national and international level, and with organizations engaged in the area of ‘solidarity economy’ in Italy.

The case study aimed at deepening the social learning and governance mechanisms underlying the development of new attitudes and practices within this network and its effort to spread this innovation in the local context. The main goal was the identification of strengths/weaknesses and of the most suitable forms of support. The following are the main findings.

The growth of the network, its articulation with relation to the various fields of interest developed (farming, marketing, education, cultural animation, political activism), its hybridization through the gradual opening up to new relationships and, thus, to new attitudes, knowledge and practices are read as an integral part of the development of the innovation process. Social learning takes place in these relational spaces: the collaboration among farmers and between these and technicians; the interaction between producers and concerned consumers and, more generally, civil society; the encounter between food practices and other areas of social mobilization and citizenship; the new forms of interaction between new food networks and public institutions. Within them, peer-to-peer exchanges of knowledge and integration of different sources lead to the creation of new shared knowledge. The reframing process is central in this regard. By adhering to new frames of reference the actors develop common visions, define priorities and shared goals, fine-tune languages and modes of action to meet them (Brunori et al., 2012). The 'boundary work' around specific objects proves to be crucial to these processes. Starting from cooperating on organic farming, actors have developed interaction and cohesion around other issues, such as food quality, GMOs, land consumption and access to land, consumers' education, sustainability of patterns of socio-economic development.

The network thus develops the co-learning processes inside, through the interaction amongst the members of the Association, as well as by interacting with the outside, at territorial level, where the Association wants to put pressure on public institutions, other organizations and public opinion to promote changes. As important are the relationships established at broader level (regional, national), where the Association finds new spurs to learn and opportunities for action. To analyze the role of the mechanisms of governance that regulate the interactions internally and externally we take into consideration aspects that characterize the internal organization, such as quality of social relations, sense of community, inclusiveness, leadership balance, level of formalization, decision-making mechanisms, kind of management, infrastructures and forms of communication, presence of intermediary functions (Rossi et al., 2014). The last aspects prove to be extremely significant to allow an effective interaction between the internal different systems of knowledge, resources and practices, but appear also critical in the interaction with the outside, in the socio-cultural and political environments in which the network tries to induce changes.

The case study, together with the whole SOLINSA research activity, thus provides useful information on the mechanisms, the potentials and the challenges that characterize the processes of innovation towards sustainability driven by hybrid networks. This appears important to fine-tune effective forms of support. It emerges in that regard as the main needs concern the improvement of the network building capacity and of the internal management, through suitable governance mechanisms; the enhancement of the related learning processes, strongly based on peer-to-peers exchange and on boundary works; the development of collective strategic and planning capacities; the possibility to realize exchanges with other similar experiences; the presence of favourable external governance environment where the networks can express their potential. In the new context of EU policy for innovation these indications appear particularly significant.

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# Is cultivated diversity a guarantee of stability?
## An example with bread wheat

ESTELLE SERPOLAY-BESSON[1], LISE CLÉLIA BLANCHET[2], CAMILLE VINDRAS[3], VÉRONIQUE CHABLE[4]

[1] ITAB, Domaine de la Motte, BP 35327, 35653 Le Rheu, France, http://www.itab.asso.fr, estelle.serpolay-besson@itab.asso.fr
[2] INRA SAD, Le Rheu, France
[3] ITAB-INRA SAD, Etoile sur Rhône, France
[4] INRA SAD, Le Rheu, France

**Key words:** organic, wheat, diversity, coefficient of variation, stability

**Summary:** Three varietal types were compared for performances and stability "from soil to fork" through an on farm trials network lasting for three years. The first results of this methodological study suggest that the genetically diversified varieties show better and more stable performances for agronomic and technological traits, while their transformation and taste qualities seem very sensible to the differences of environments. On the contrary, the pure line tested tends to be unstable for agronomic and technological traits, but has always the same taste. These results need to be confirmed by further studies but highlight the objective of selection of the different varietal types.

### Background

Availability of adapted bread wheat varieties is a key for the development of organic agriculture in France. Because of their selection in fields with high inputs levels, commercial varieties are not always suitable for organic farms, where conditions cannot be standardized with chemical inputs. Instead of maximizing quantitative performances, organic farmers look for stability of performances in contrasted conditions. They often associate stability with genetic diversity through the use of genetically diversified "varieties" (populations). Yield stability and genetic diversity are two of the SOLIBAM key concepts that we studied "from soil to fork" for bread wheat. Stability, which is a recent concept, needs accurate tools to be assessed and we propose here a specific approach of it.

### Main chapter

*Introduction*

This study explored the relationships between genetic diversity and stability of performances, with the hypothesis that more diversified are the cultivated populations, more stable are the performances (this is generally observed by the farmers). Three varietal types of bread wheat were tested, through a methodological approach, across an on farm trials network in the West of France, lasting for three years. Their performances and stability were studied "from soil to fork" (agronomic, flour quality, bread-making process and organoleptic characteristics were assessed and tested).

*Material & Methods:*

The three varieties tested were representing different varietal types and were chosen in order to maximise the differences of genetic diversity levels: a pure line, with a very low level of diversity (commercial variety = Renan); a population, with higher level of diversify than the pure line (Sixt sur Aff, called Sixt); and a dynamic population, with very high level of diversity (Dynamic population, called Dyn, including 11 populations evolving through generation on farm).

These varieties were cultivated in a network of on farm trials during a total of 3 years (from 2011 to 2013). In each trial, each variety was replicated twice. The trials were included in a wheat production field and the practices were the usual ones of the farmers.

Data was collected from soil to fork: during the culture (agronomic traits), on flour (technological traits), during bread-making process and across organoleptic tests.

Assuming that a good variety for organic farming is a variety with good and stable performances, for each characteristic observed, we determined which variety was the most efficient (significant highest mean for yield, significant lowest weed cover...) and which one was the most stable (lowest CV, taking CV as the indicator of varieties stability, as it has already be done for some participatory programs: Ceccarelli, 1994; Le Buanec, 1997; Lecompte, 2005). Then we correlated these two results in order to determine which one was "the best variety" for each characteristic (best performance with the lowest CV). For the taste characteristics, we only looked at stability (taste is a subjective notion).

Analyses (means, CV, ANOVA, Tuckey tests) were performed through R and the correlation was done with LibreOffice-Calc.

*Results:*

Table 1 below presents the results of the analysis (number of characteristics for which the variety corresponds to the objective). They are presented per variety and per step of the food chain (field, milling, bread-making and taste).

Table 1: number of variables per performance and step of the food chain

| | Renan | Sixt | Dyn |
|---|---|---|---|
| Best performances (mean) : | 20 | 31 | 31 |
| - agronomic criteria | 15 | 22 | 29 |
| - flour technological quality | 4 | 8 | 2 |
| - bread-making process | 1 | 1 | 0 |
| Best stability (CV) | 42 | 42 | 50 |
| - agronomic criteria | 9 | 15 | 19 |
| - flour technological quality | 15 | 16 | 21 |
| - bread-making process | 3 | 1 | 1 |
| - taste | 15 | 10 | 9 |
| “Best variety” for organic farming | 38 | 48 | 50 |
| - agronomic criteria | 7 | 18 | 24 |
| - flour technological quality | 14 | 18 | 16 |
| - bread-making process | 2 | 2 | 1 |
| - taste | 15 | 10 | 9 |

Sixt and Dyn, the two varieties with the highest genetic diversity, have the best performances at a global level. The most stable variety is Dyn. So in our trial, we can say that Sixt and Dyn are the varieties the most adapted to organic farming because they often combine high performances and good stability.

However, the results are quite different according to the different types of variables: if Sixt and Dyn are good and stable from agronomic and flour technological quality points of view, Renan is the most stable in terms for bread-making and taste. The graphs below synthesize the results:

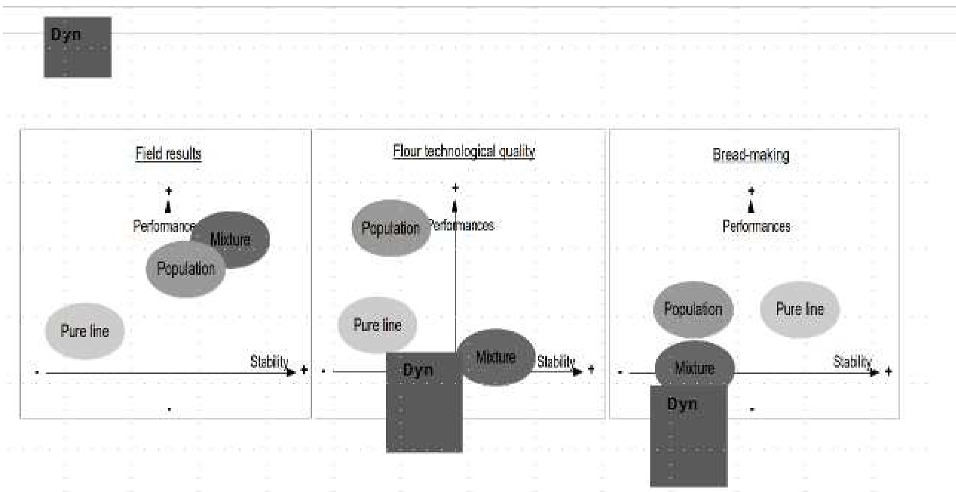


Figure 1: Performances and stability of the three varietal types, for three types of variables (from left to right): agronomic variables, bread-making variables and flour technological quality variables.

*Discussion*

According to these preliminary results, Renan has unstable results in the fields, but tastes always the same, and Sixt and Dyn have better and more stable results in the fields, but their taste is different according to the environment. So, in our trial network, it seems that increasing genetic diversity allows stability of field performances and flour technological quality. However, for bread-making process and taste of the final product, the results suggest that the stability is reached with the lowest genetically diversified variety.

Dyn and Sixt are composed of different genotypes, and their proportions probably change from one environment to another, which could explain their agronomic and flour technological quality stability (diversity would allow buffering the environment), which is not the case of Renan, pure line, which is composed of one genotype only. Taste is very linked to the genotype, and this would explain that Renan, with only one genotype, is more stable than Sixt and Dyn ; genetic diversity of the two populations would allow them expressing the environmental conditions, the *"terroir"*, as for wine.

Our experiment tested only 3 varieties and was firstly a methodological approach; so those results need to be confirm by further investigations (it is starting to be confirmed by Knapp et al., 2014). However, they confirm the saying of the farmers that genetic diversity would buffer contrasted environmental conditions. They also highlight the different breeding objectives of the varietal types and the agricultural systems for which they are created: the pure line is rather bred for industrial agriculture and the populations are rather bred for local and low inputs farming and processing. So a farmer will choose a varietal type according to its objective and farming system.

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# Economic sustainability of SOLIBAM food supply systems.
## A comparative analysis

ELENA TAVELLA, MORTEN GYLLING

University of Copenhagen, Department of Food and Resource Economics, Rolighedsvej 25, 1958 Frederiksberg, Denmark

**Key words: socio-economic sustainability, organic, low-input, economic performance**

**Summary :** Selected SOLIBAM food supply systems are described and their economic performance and socio-economic sustainability are assessed and compared with each other. Based on this assessment and comparison strategies to maintain and enhance economic performance and socio-economic sustainability within the food supply systems are formulated.

### Background

Up to five organic and low-input food supply systems, comprised in the SOLIBAM project, will be selected for economic analysis. The selected food supply systems include commodity production at the farm, as well as storage, processing and distribution to the customer. Identifying and understanding the development of local, organic and low input food supply systems from an economic perspective is important, because it provides valuable insight into (i) how the systems perform economically depending on changes within the external environment, e.g. changes caused by the financial crisis and shifting consumer behaviours; and (ii) how actors deal with those external changes in order to ensure the survival and prosperity of the systems. This insight is useful because it supports researchers in formulating strategies to maintain and enhance economic performance and socio-economic sustainability within the food supply systems.

### Comparative economic analysis of selected organic and low input food supply systems

The aim of this paper is to provide insight into the economic performance and socio-economic sustainability of SOLIBAM food supply systems by quantitatively analysing (i.e. calculation of gross margins and total returns) and comparing six selected systems. We analyse and compare the economic performance of each food supply system for 2008, 2009 and 2010, explain how each system has economically developed within these three years, and formulate strategies for maintaining and enhancing economic performance and socio-economic sustainability of SOLIBAM food supply systems.
SOLIBAM food supply systems are selected based on the outputs produced - examples:

1. Vegetable supply systems: two systems in the UK, and one system in Italy.
2. Flour and bread supply systems: two systems in France (also producing livestock and dairy products), and one system in Italy.

The economic analysis is carried out in a stepwise approach. Adopting this approach enables the illustration of actors‘ opportunities to react and adapt to internal and external changes in the short- and medium run. The analytical approach considers the cost structure for the years 2008, 2009 and 2010, for which the economic analysis is carried out.

Overview of analytical approach

| | |
|---|---|
| Revenue - variable costs | = gross margin 1 |
| Gross margin 1 - semi-fixed costs | = gross margin 2 |
| Gross margin 2 - fixed costs | = total return |

The gross margins and total returns in 2008, 2009 and 2010 are calculated for each food supply system and the development within the systems is compared. This approach allows for assessment of how the systems have economically performed and developed within the three years. Performance and development are assessed from a system specific perspective, as well as in comparison among the six selected systems. Based on this assessment strategies for maintaining and enhancing economic performance and socio-economic sustainability of the systems are formulated, which have generalizable implications for SOLIBAM food supply systems.

### Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

# Integrative design. Resolving the conflict between diversity and efficiency.

MICHAL KULAK [1,2], THOMAS NEMECEK [1], HANNE ØSTERGÅRD[3], EMMANUEL FROSSARD [2], GÉRARD GAILLARD[1]

[1] Institute of Sustainability Sciences, Agroscope, Switzerland, www.agroscope.ch, michal.kulak@agroscope.admin.ch

[2] Institute of Agricultural Sciences, ETH Zurich, Switzerland, www.plantnutrition.ethz.ch

[3] Technical University of Denmark DTU, Denmark, www.kt.dtu.dk Key words: **diverse cropping systems, environmental efficiency, life cycle assessment, sustainability**

**Summary:** Increasing diversity and reducing external inputs leads to the reduction of environmental impacts per area, but is not necessarily the case when productivity is taken into account. In this study, we used the methodology of integrative design to assess and improve the environmental efficiency of two cropping systems from France without compromising their diversity. In the method, breeding and management innovations are generated in a multi-stakeholder design process and Life Cycle Assessment (LCA) is used as a decision support tool. Results revealed that diversity and efficiency can but do not necessarily have to be in conflict and that diverse, low-input cropping systems can also be environmentally efficient with their proper organisation.**Background**

LCA studies using product-based functional units are often favouring cropping systems based on high levels of material throughput (high-input high-output). These tend to be more productive but also more homogenous than low-input cropping systems due to simplified management and the uniformity of products. Cropping systems with high genetic diversity, on the other hand, might be better adapted to future environmental shocks and may provide a range of important ecosystem services that are not incorporated in most LCA models. This includes the in-situ conservation of rare varieties, increasing the farmer autonomy or providing social benefits from direct interaction between the producer and the consumer. In this study, we have developed and applied a methodology that allows improving environmental efficiency of low-input cropping systems without compromising diversity and all of its associated potential benefits.

**Main chapter**

The study was based on a detailed analysis of a case study – bread from alternative food network in France. Fig. 1 illustrates the methodological framework applied. Primary data were collected from two farmers who cultivate mixtures of cultivars of cereals under the condition of low-input farming, process grains on farm and sell products directly to the consumer. Farmers were given results of their product LCA for feedback and an interdisciplinary workshop was organised to map out opportunities for improvements. Participants included breeders, agronomists, representatives of seed companies and farmer's associations. Results of the workshop were consulted with producers. To increase the probability of adoption, only solutions that were approved by farmers were considered in further LCA simulations. Improved systems were compared to normative references (initial situation) as well as to a generic reference - a bread made of conventional wheat from the region, processed in an industrial bakery and sold in a large-scale supermarket in France.

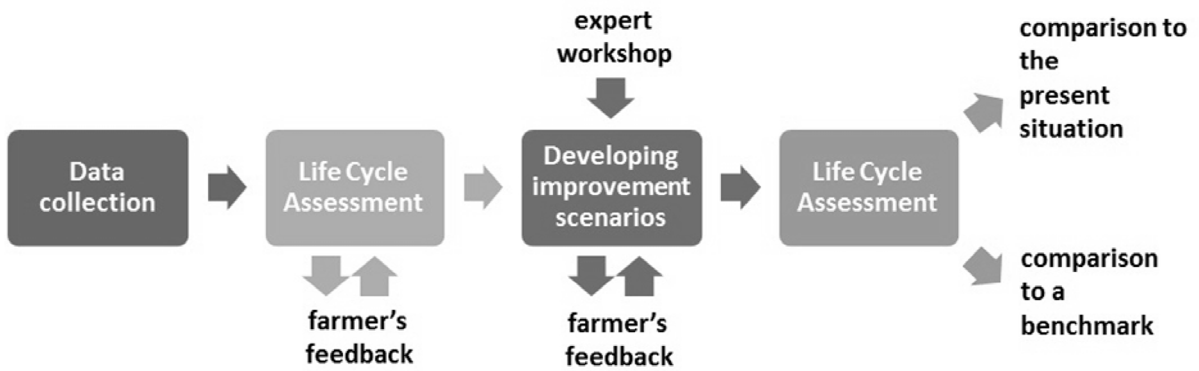



**Figure 1. Methodological framework**

The workshop gave rise to a range of improvement options. Management suggestions included switching varieties, optimising rotations or installing anaerobic digestion units. Farmers rejected some but were able to develop other solutions, such as increasing the proportion of rye in the bread recipe. Fig 2. shows the results of LCA for 12 impact categories. Conservative modelling of improved systems demonstrated potential reduction of 47% in the global warming potential at one farm and 40% for aquatic eutrophication at the other one. Overall, improved bread from one farm was characterised by lower energy use, global warming potential, ozone formation, acidification and eco-toxicity than the conventional reference. The bread from the improved second farm had lower energy use, terrestrial eutrophication and eco-toxicity than the conventional reference.

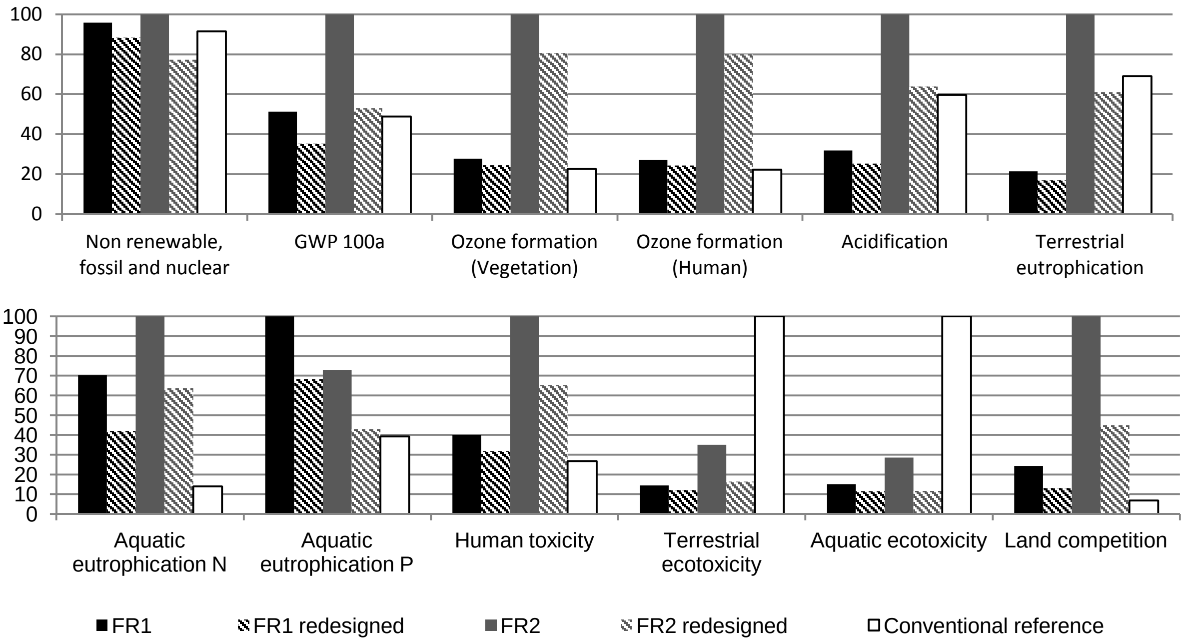



**Figure 2. Relative environmental impacts two cases of bread from low-input cropping systems in France, their improvement scenarios and a generic reference (bread made of grains from conventional agriculture, processed in an industrial mill, industrial bakery and distributed through a French supermarket).**

Results of the study suggest, that diverse, low-input cropping systems can have similar or even better environmental efficiency to high-input agriculture and centralised processing and distribution channels, provided that they are properly organised. Environmental efficiency can often be in conflict with diversity and resilience as homogenous cropping systems are productive. Environmental efficiency of low-input cropping systems can be limited by the lack of innovation, suboptimal management and farmer's knowledge. Environmentally efficient management of diverse systems is knowledge-intensive. Results of the study suggest that there is a scope for large improvements in the environmental efficiency of European low-input cropping systems.


### Acknowledgements

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM

# Does crop genetic diversity pair with production systems diversity?

## A preliminary typology for the cases of wheat and maize in the French Regions of Brittany and Loire

Anaïs Cramm[1], Estelle Serpolay-besson[2], Veronique Chable[3]

[1] Montpellier Supagro Institut des Régions Chaudes, France, http://www.supagro.fr, cramm@supagro.inra.fr
[2] INRA SAD/ITAB, Le Rheu, France, estelle.serpolay-besson@itab.asso.fr
[3] INRA SAD/ITAB, Le Rheu, France, veronique.chable@rennes.inra.frKey words: agro-economy, farmers' varieties, typology

**Summary:** The last two decades have witnessed a movement of re-appropriation of farmers' varieties and landraces. The development of these breeding practices and their viability are currently among the arising concerns. In this work, a typological work grounded in a system approach of farm functioning is being prepared in order to **1**) assess the diversity of the farms involving maize and wheat farm seeds in the French Regions of Brittany and Loire and **2**) understand the technical, organisational and socio-economic changes linked to these adoptions. The first results show a dichotomy between wheat and maize situations, and different types can be distinguished in the wheat "branch".

**Background**

The last two decades have witnessed a movement of re-appropriation of farmers' varieties and landraces, notably in France. Mostly in organic or low-input farming systems, an increasing number of farmers opt for crop diversity by breeding their own farm varieties. The reasons for the choices of those farmers are as diverse as well as their production systems.

Today this movement has reached a crucial stage. While the pioneering on-farm breeding initiatives are getting mature enough to be evaluated, it seems that an increasing number of farmers is looking for introducing farmers' varieties into their farming systems. The development of these breeding practices and their viability in particular from an economic point of view is among arising concerns.

The review of existing literature reveals a lack of references in this field. There is thus a need for getting a better knowledge of these farms, their diversity and their systems of production in order to document this movement with data.

**Main chapter**

Material & Methods

In order to tackle these questions, we propose a systemic approach in two steps: i) building a typology and ii) analysing the technico-economic aspects of some type situations. Only the first step is presented is this paper.

The proposed typology is based on the concept of "production systems", and built by giving the primacy to the understanding of farm functioning and trajectory.

This typology has been designed for two species (wheat and maize) in a relatively homogeneous geographical unit (Brittany and Loire Regions). We have chosen these two crops because they have a wider development in these two regions and concern many active farmers groups. Moreover, their uses and breeding patterns differ.

Participating farmers have been chosen in collaboration with the local associations which confederate farmers' initiatives on "Farmer Seeds and varieties" (Triptolème, GABB Anjou, Civam PROVERB, CIVAM 44, FRAB).

The number of interviews is based on the principle of "data saturation" and amounts to about twenty semi-directive individual talks of two hours average duration. Then, typology is built in an iterative process between field – office – experts. It is validated individually and at the time of a collective workshop, both by the actors and the researchers.

First results

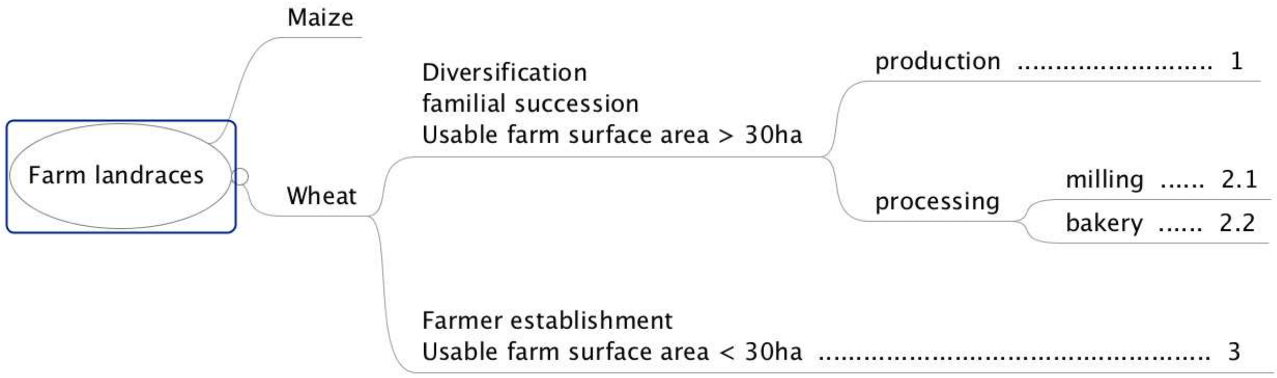
1. "Wheat-Maize" dichotomy

The first results confirm that the adoption of farm varieties falls under two logics that can be clearly differentiated for the cases of wheat and maize in terms of goals and objectives. These different logics entail specific structural and organisational changes at the farm production system level.

To a large extent, this can be explained by the function of the two crops within the production system. In the region studied, maize is mainly cultivated as forage for dairy cows. The agronomic results of the adopted maize populations differ little from hybrid maize and even sometimes tend to be superior. As a matter of fact, the production target of "open-pollinated" maize populations is the "on-farm feed autonomy of cow farming". This intermediate consumption in the production system does not imply important structural changes – aside from the seed breeding work.

On the contrary, wheat is grown to be traded. Farm varieties differ more significantly from the commercial varieties: both from quality point of view (different organoleptic properties, health aspects, etc) and in quantitative terms (yield losses). To counterbalance these quantitative losses, the farmers who adopt farm varieties must differentiate their products on the market and/or increase their added-value. They often significantly modify the production system. It entails not only seed breeding work, but also the creation of new on-farm workshops – in particular processing units – to integrate the wheat>flour>bread chain and to market the products in short food supply chains (SFSCs).

2. Focus on wheat




In the case of wheat, the first results show three main dynamics. The two first types are cases of inherited family farms, generally dairy cow farming. In the first type (1) the farmers choose to focus on grain production and create links with traditional bakers in order to promote their farmers' varieties as grain products.

The second type shows production systems with dynamics of increasing diversification and progressive integration of bread-making: adoption of farm varieties, progressive development of flour-milling (2.1), then bakery activities (2.2). The later stage generally consists in introducing a new business associate.

Finally, type 3 represents the "farmers-bakers". It is typical of first generation farmers without farmer family tradition but who have designed from the beginning a system allowing them to develop a small farm area at best with a minimal capital. This is possible thanks to labor intensification, diversification of acquired skills, and collaborative networks.

Conclusion

These examples illustrate three cases at odds with the model prevailing in French farms specialized in production *sensu stricto* with other activities left to industry. The farmers who adopt farmers' varieties and landraces go against this specialization associated with labor division and ensuing loss of knowledge, not only "upstream" of the sector (seed selection and production) but also "downstream" (transformation and marketing). The return of these activities to rural areas is associated to the development of local supply chains and transformation units bringing back added-value to the local level. It can offer new employment opportunities and mitigate the constraints related to breeding and possible lower yields of farmers varieties.

To pursue this work we will extend the typological approach to maize and, in a second research phase, will detail the technico-economic analysis for certain types previously identified according to the issues newly emerged from the results.

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# Network analysis for sustainability assessment of innovative farms*

## A description of farm structure based on farmers' relationships

LIVIA ORTOLANI[1], RICCARDO BOCCI[2] MORTEN GYLLING[3], GIANLUCA BRUNORI[4]

[1] University of Pisa – CIRAA, www.avanzi.unipi.it, lortolani.aiab@gmail.com
[2] Italian Association for Organic Agriculture, AIAB, www.aiab.it, r.bocci@aiab.it
[3] Institute of Food and Resource Economics - University of Copenhagen, gylling@ifro.ku.dk
[4] University of Pisa –www.unipi.it, gianluca.brunori@unipi.it

**Key words**: farm autonomy, sustainability, innovation, network analysis

**Summary:** The potential relationships that the farmers can develop with the society, the environment and the local and global economy have an important role in defining individual capacity of innovation for sustainability. The aim of this study is to create a socio economic model of farms with a focus on these relationships. Network analysis is tested as a methodology to describe farm structure and to include human and social capital in a comprehensive sustainability assessment of individual farms. A case study of a french farm will be presented as an example.

### Background

Using a transition theory approach to innovation (Geels and Schot, 2007), it is possible to state that the present landscape at EU level characterized by economic crisis, increasing unemployment and volatility of energy prices (Woodhouse, 2010) could offer an opportunity for a change in farm structure and an application of low input strategies by a larger typology of farms. The need to reduce the dependency on fuel and energy exists, however it need to be compensated by innovation that increase the farm autonomy (Van der Ploeg, 2008) through the use of on-farm input (eg. Seeds), innovative distribution models and non agricultural activites that help increasing the added value of food production.

Shifting the attention from the goal of productivity and the use of yield as unique indicator of farm efficiency to a combination of goals such as productivity, sustainability and quality, a diversity of possible combination of resources at farm level exists. This asks for innovative methods of farm structure analysis. The potential relationships that farmers can develop with the society, the environment and the local and global economy have an important role in defining individual capacity of innovation. Human and social capital strongly influence the definition of the best solution at local level, a specific attention to the farmer should be considered in micro economic assessment.

### An application of network analysis for sustainability assessment

Starting from the concept of farm autonomy introduced by van der Ploeg (Van der Ploeg, 2008), the general aim of the individual farmer become the reduction of dependency from input producers and market prices and the increase dependency and investment in social connection and interaction with nature. Considering sustainability as a moving target, depending on decision making and governance (Funtowicz and Ravetz, 1990, Tillman et al. 1994 Steyaert and Jiggins, 2007), the "new peasant" (Van der Ploeg, 2008) can increase sustainability, with his economic activity, through his contribution to local development and regional policies on health, education, tourism, local promotion etc.

The individual capacity of proposing innovative solutions at local level is an important aspect to be considered in a comprehensive sustainability assessment of individual farms. A network approach to innovation (Leeuwis 2004, Knickel, 2009, Roling, 2009) can be used to describe the interactions of the farming systems with the system as a whole and the synergies that organic and low input systems can create at environmental, social and economic level.

The aim of this study is to test the possibility to use network analysis in the assessment of individual capacity of innovate for sustainability. The methods has been tested in innovative farms (SOLIBAM case studies) looking at organic and low input strategies as a key for economic viability.

A participatory mapping approach (Pahl-Wostl, 2002, Newig et al. 2008) has been used to draw the farm structure network (fig.1) with the farmer or with someone that have a good knowledge of the specific farm. The analysis of the relationships of the farmer, described by the map, allows an interesting qualitative description of the farms that can integrate other sustainability assessment methodologies. Qualitative data has been collected talking to the farmers about the relations they consider relevant for their economic activity. The farmers have been asked to describe the type of relationship they have with different actors, choosing among exchange of information, materials and money. As an example this paper will present the case of a french farm involved in PPB (Participatory Plant Breeding) programme within the SOLIBAM project.

The map can give interesting input for a descriptive analysis of the farm. The main components of the map that can be observed are the nodes and the fluxes. The nodes represent the actors that the farmer consider relevant for his economic activity and the fluxes represent the type of interaction with them and among them that the farmer percive. The circle line has been drawn by the farmer to distinguish the internal system from the external one. It is interesting to see the complexity of the internal system of this farm due to the number of family member and workers directly involved in the economic activity.

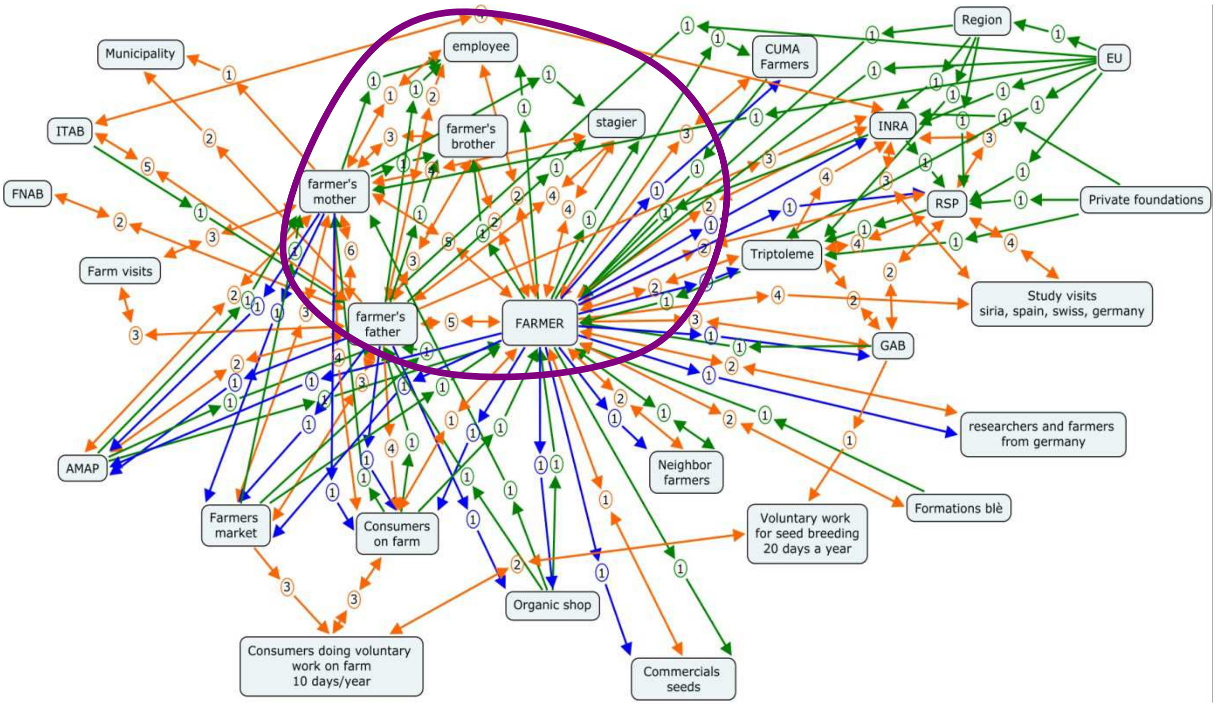


**Fig. 1 Network map of a french farm.**

An interesting result is to observe that the main relevant actors for this farmer are other farmers and farmers'associations togehter with consumers or citizens. No role is given to the extension services, that often are considered as the key for innovation transfer. Another interesting point is to see the perception that the farmer have of EU funding schemes. Most of the relevant actors involved in the EU project are listed by the farmer as relevant actors and the fluxes of money among them are well described.

Looking at knowledge fluxes, the exchange among farmers and with farmers'associations is the more relevant, together with the knowledge exchange in the market, associated to material exchange of final products. Material fluxes includes both final products and input produced on farm. In this case the farm is directly producing old varieties seeds and most of the material exchange with other farmers, also in different countries are related to seeds. Seeds' exchanges are often associated also to knowledge exchages. Money fluxes are of 3 types: wages, paid by the farmers to the actors of the internal system; payments of final products by consumers, fundings coming from EU and associations.

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# Resource use efficiency and renewability
## Assessment of low-input agricultural production in Western France

CHRISTINA WRIGHT[1], MICHAL KULAK[2], HANNE ØSTERGÅRD[3]

[1] Department of Chemical and Biochemical Engineering, Technical University of Denmark, Denmark, www.bioeng.kt.dtu.dk/, chriw@kt.dtu.dk
[2] Institute of Sustainability Sciences, Agroscope, Switzerland, www.agroscope.ch, michal.kulak@agroscope.admin.ch
[3] Department of Chemical and Biochemical Engineering, Technical University of Denmark, Denmark, www.bioeng.kt.dtu.dk/, haqs@kt.dtu.dk

**Key words:** Renewability, emergy assessment, diversity, local production

**Summary:** We have analysed two farms from Western France that regenerate resources in addition to the production of goods and services. Result shows that the large farm (75 ha) had an input of renewable resources of 27% while the small (6 ha) had a renewable fraction of 20%. This is based on assuming that the firewood used is 50% renewable. If this percentage is increased to 100% then both farms have a renewable fraction of resource use of about 27%. Further, the study showed that the smaller farm had a higher input of machinery, fossil fuels and labour per Joule of food output compared to the larger which may indicate an economy-of-scale effect.

### Background

Global food demand is projected to increase by up to 70% within the next 50 years . Until now the demand for food has been met by the use of abundant and cheap fossil fuels; however we need to reconsider our modes of production to avoid a global environmental crisis. It is important to develop and manage food production systems that sparingly utilise the scarce resources of energy, water and nutrients, while preserving natural resources and diversity without reducing yields. Food production systems should, therefore, increasingly rely on renewable inputs and increase their stability by reducing dependency on external input and volatile markets and increasing their interactions with nature, i.e. increased autonomy. The broader research community (reviewed in  has realised that small-scale diverse farms might be able to achieve this goal, and there are numerous examples that organic management is beneficial on a large range of environmental indicators. Autonomous farmers rely on a self-managed resource base and regenerate resources in addition to the production of goods and services, thus contributing to the sustainability of their systems. Locally managed agricultural systems reduce the global nutrient flow, increase the visibility of negative externalities to the consumers and use fewer resources associated with transportation. Additionally, there is a need to consider land area as a limited resource with increasing competition from various utilisations.

### Materials & methodology

Two case farms with a low external input and a high degree of autonomy have been chosen to evaluate their efficiency and use of renewable resources. We apply a multi-criteria approach where we include efficiency in resource use while distinguishing between use of renewable and non-renewable resources as well as on-site, local and non-local resources. In this way we also assess the direct and indirect land requirements if farms were to be supported solely on annual renewable flows from the sun, rain, wind and geothermal heat.
The case farms are situated in Western France, and data have been collected by interviewing the farmers. FR1 is a farm of 75 ha producing flour, meat (beef and pork) and a wide variety of dairy products having a total food Joule output of 6.8 GJ per year. FR2 is a smaller farm of 6 ha producing bread and also selling buckwheat pancakes and rabbits in total 0.6 GJ per year. The resource use was assessed by emergy (spelled with an "m") accounting. Emergy is defined as 'the available energy (exergy) used up directly and indirectly to make a product or service . The emergy support required to provide a product or service is calculated by adding up all forms of available energy used after converting them to the same unit of solar equivalent Joules (seJ). Emergy assessment is particularly useful for studying agricultural systems as it accounts for non-commercialized natural resource inputs (e.g. solar radiation, rain, soil etc.) as well as inputs from human-dominated systems (refined fossil fuels, goods, labour). From an emergy perspective, agricultural systems capture and transform renewable available energy flows into products that are useful to society. As each case farm provides different composition of food output, we recalculate all products into food Joules in order to compare farms equally. Our main indicator is the renewable fraction of the amount of seJs used to produce one food Joule on the on-site, local and non-local scale. The Overall renewability of the farms is a sum of the three. We define on-site inputs as from within the boundaries of the farm, local inputs as coming from the neighbouring area outside the farm and non-local inputs coming from the wider national and global economy, meaning resources which are not accessible within the local area or managed outside the local area. Renewability is defined as the fraction of the annual renewable flows (sun, rain, wind and geothermal heat) of the total emergy use of the farms.

### Results and discussion

Labour, fuels & electricity represent the largest resource input per gram of output (food Joules) for both farms, but especially for the smaller farm FR2 (Figure 1). The low fraction of renewable input to labour, fuels & electricity is determinant for the overall renewability of the farms. The higher fuels and electricity input to FR2 is mainly because of the high input of fuel wood for baking bread.

The on-site renewability is 14% for FR1 while only 5% for FR2. The on-site renewable fraction is determined by the annual renewable flows (sun, rain, wind, geothermal heat) to the farm area. On the local scale, being annual renewable flows to the neighbouring land area, the renewability of FR1 increase to 27% and to 20% for FR2. The annual renewable flows from areas outside the neighbouring area are insignificant why the overall renewable fraction to FR1 and FR2 remain on 27% and 20% respectively. Especially the higher input of wood both for buildings and as a fuel increases the renewability of FR2. Therefore the renewable fraction of wood is very relevant for the overall renewability of this farm. For the value presented above, wood is considered 50% renewable however, if reduced to 0% or increased to 100% the range of renewable fraction for FR2 is between 15% and 26%. For FR1 the values are unchanged.

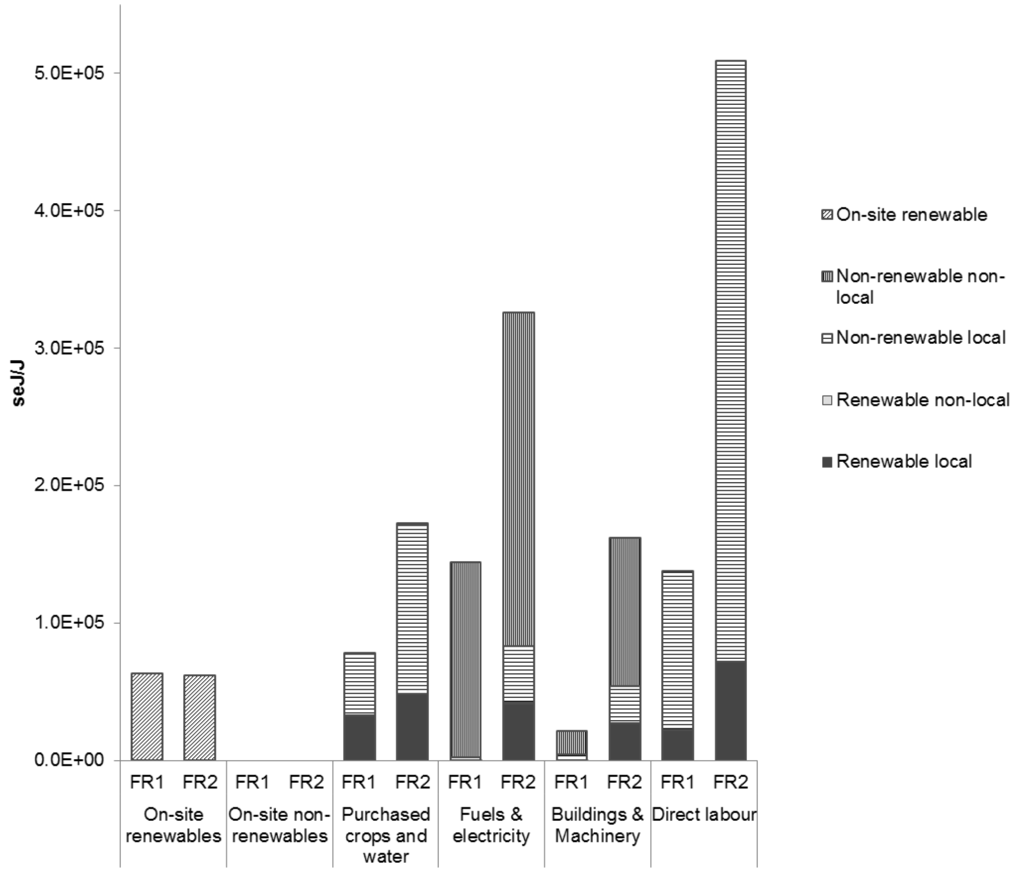


**Figure 1. The emergy profile for FR1 and FR2 in groups of: renewable, non-renewable, on-site, local and non-local flows.**

**Conclusion**

In conclusion, especially fuels and machinery are subject for management improvements as these represent a large fraction of the total emergy use. Further, they are characterized by being mainly non-renewable. The larger resource inputs per food Joule to FR2 compared to FR1 may be due to the small size of the farm compared to FR1 where more crops can be grown on-site reducing the external inputs and increase renewability. Also the larger farm area and field size may reduce the input of machinery per ha of processed area, reducing this part of the total use per food Joule produced. Buildings and machinery are generally more fixed inputs, independent of farm area, why they represent a large resource input to small farms.


**Acknowledgements**

This research received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement n°245058-SOLIBAM


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# Plenary

# for future : Agriculture for a future society: challenging paradigms

# Agriculture for a future society: challenging paradigms

RICCARDO BOCCI[1], LIVIA ORTOLANI[1], BRUCE PEARCE[2] AND VERONIQUE CHABLE[3]

[1] AIAB, Associazione Italiana Agricoltura Biologica, Italy, www.aiab.it, r.bocci@aiab.it
[2] The Organic Research Centre, Wakelyns Agroforestry, Metfield Lane, Fressingfield, Eye, Suffolk IP21 5SD, UK,
[3] INRA, Sciences for Action and Development, Rennes- Le Rheu, France, chable@rennes.inra.fr

**Key words:** agriculture, autonomy, family farming, farmers, agricultural policies, seed policies

**Summary:** "Food policy is made, not given. It is a social construct, not ordained by a pre-programmed, perpetual or externally affirmed human order" (Lang et al., 2008). Therefore, its definition must be the result of negotiation among several different actors, taking into consideration their various interests and relative power relations. In the actual food crisis new forms of agriculture are emerging as a response to the crisis, as highlighted by the SOLIBAM case studies. These new experiences aim at acquiring fresh niches of autonomy, within an economic context, which is characterized by dependence and marginalizing. A novel methodological approach will have to study and understand how this autonomy is attained, how relations emerge between endogenous and exogenous resources of a farm; all of this knowledge must then be applied to the remodelling of agricultural policies.

**"Leaving the fate of soil and people to the market would be tantamount to annihilating them"**

Polanyi (1957)

**Introduction**

As Lang et al. (2008) points out "food policy is made, not given. It is a social construct, not ordained by a pre-programmed, perpetual or externally affirmed human order". Therefore, its definition must be the result of negotiation among several different actors, taking into consideration their various interests and relative power relations. It is essential to understand the importance of suitable agricultural and seed policies, implemented at the local, national, regional or sub-regional level, as indispensable tools to promote, protect and sustain diversified agricultural systems, which are socially and ecologically sustainable. The above consideration is of great importance, particularly when we take into account the on-going tendency to let the market deal with agricultural issues, and the ever-increasing weight of international organizations in this field, to the detriment of national sovereignty.

In order to meet this challenge, however, we need to redefine the categories and concepts around which policies are built; indeed, the ones we have today are often devoid of significance, or else they provide only a partial representation of reality. Otherwise, we risk making the same old mistake: leaving into oblivion some of the social practices, particularly those weakened by the current neo-liberal policies. For example, it makes no sense to make legitimate, through agricultural policies, only large industrial farm businesses, while several other farm structures exist – farmers, full-time or part-time agricultural workers or peasants, and significantly contribute to the development of rural agro-systems. Also, it is detrimental to consider agricultural work as a sign-mark of backwardness in a country. In this particular case, as Colin Tudge writes: "we need again to see farming as a major employer [...]. Yet modern policies are designed expressly to cut farm labour to the bone and then cut it again" (2004).

Indeed, after having determined that a new approach is necessary to finally overcome the concept of industrial agriculture as a theoretical and practical reference model for agricultural policies, the issue becomes just how to construct this new approach, by coupling science with practice in a reciprocal and fruitful exchange. SOLIBAM tried to do exactly this: setting the foundations from which to start changing the current methodological model, by interfacing science with knowledge.

We saw that in many cases experiences already implemented in several countries are often much more advanced than any theory. By analyzing them we can highlight the innovations ensuing from interactions among the several different actors and factors at a local level (social, environmental, economic, cultural...). This is the so-called "art de la localité" which gets reinvented each time according to local specificities. In facing the current crisis of agriculture, these experiences implement resistance practices – not just subsistence or survival practices – that can form the base from which to build future actions.

**How to define the new actors?**

If we place the interest of society and its citizens at the core of agricultural policies, the arena where the future of agriculture is played is no more a battlefield of the northern countries of the world versus the southern ones. On the contrary, the core of the issue becomes the existence of different agricultural models facing each other on the global market, with family or peasant agriculture and industrialised farming business at opposite ends. In this perspective, it is possible to establish alliances in different countries and regions, among people who share the same agricultural models and difficulties in their daily activities. But who are these people? Are they peasants, agricultural workers, farming entrepreneurs? What bonds them together and what do they share? In order to answer these questions, it is necessary to delineate some boundaries: "peasants should be defined according to what they are, not as a negation of what they definitely are not. Likewise, characterizing the peasant as not yet possessing the traits of an entrepreneur or as disappearing category is clearly deficient" (Van der Ploeg, 2008).

In the actual food crisis new forms of agriculture are emerging as a response to the crisis, as highlighted by the SOLIBAM case studies. These new experiences aim at acquiring fresh niches of autonomy, within an economic context, which is characterized by dependence and marginalizing. A novel methodological approach will have to study and understand how this autonomy is attained, how relations emerge between endogenous and exogenous resources of a farm; all of this knowledge must then be applied to the remodelling of agricultural policies.

**New agricultural and seed policies**

If agricultural and seed policies cease to be sectorial and become central to a whole new series of objectives, from the environment to public health, the right to food, the preservation of the territory (Lang, 2004), deciding what, how and when we eat and sow is a choice that must involve the whole of society and can no longer be delegated to bureaucrats or farmers' unions. In fact, seed policies were conceived to promote only formal seed systems, in an ideal progression from backward system (the so-called informal ones) to one that was progressive and modern. This linear approach theorised by Douglas in 1980 and called the Seed System Development Paradigm, has, over time, been the ideal that every State, included the European Union, and International Organisations has drawn from, in pursuit the ultimate goal of creating a commercial seed system in every country (Louwaars, de Boeuf, 2012).

The hard part is to understand how to define policies and how to mediate among the various actors at play. Also in this case, food sovereignty comes into play, implying a revision of the current system of food democracy; it is gradually becoming more and more important, and it will be the challenge which agro-food governance will have to face in the third millennium. From the international to the local level, small farmers organizations and civil society as a whole must conquer new spaces in defining agro-food policies, and this implies a novel capacity to listen on the part of Governments.

SOLIBAM has been concerned to regain within-crop diversity, also through development of Composite Cross Populations based on inter-crossing many parents. Because of their diversity, such populations proved, as expected, to be more stable and resilient in performance under varying abiotic and biotic conditions. Such crops are likely to be particularly useful for small-scale and organic farmers with their lower dependence on crop inputs. Given the increasing problems of climate change, they are also likely to be of wider value in agriculture generally.

However, the practical problem for farmers is that trading such populations for seed is currently illegal. SOLIBAM partners proposed to seed officials in the EU that a legal exception needs to be made for cultivation of known, registered populations. As the next step in this process, it has now been formally agreed that a 'temporary experiment' can run from 2014 to 2018. This will determine whether an agreed provisional protocol fulfils various needs for farmers and the seeds industry, so that further development and use of composite cross populations and line mixtures can go ahead.

**Conclusion**

Agricultural and seed policies must meet their challenge in the field of regional integration, rather than struggling with international competition. Protecting one's agriculture – a concept banned from the speech of any politician or expert – is the keyword, with a special attention to attaining coherence among local, national and regional levels.

In conclusion, we can affirm that the world of family agriculture should launch a challenge to humanity. The disappearance of farmers, the destruction of rural culture and agriculture landscape, its most visible fruit, have been systematically perpetrated by the current agricultural policies in the name of modernization. These negative facts do not affect just a few people at the fringes of modernity; they concern everybody, our society at large. But how are we to address the issue, starting from a totalizing modernity that tends to homogenize all territories and cultures? How are we to create a democratic space in which to discuss and define the right food choices to make for the future? Undoubtedly the various ideas coming from this Congress and the SOLIBAM project provide interesting thought lines and analyses, of crucial importance to comprehend the vastness of the challenge we are facing.

However we have to recover the full meaning of the term "agriculture" by bringing it back to the very essence of our culture, in the sense exemplified by Hannah Arendt: "the word Culture derives from the Latin term *colere* – to cultivate, to plant, to take care of, to maintain and to preserve – and relates to the activities of man with nature, in the sense of cultivating and handling nature with the scope of making it fit for man".

Only in this way, through a cultural revolution, the art of cultivating may be redesigned and rebuilt.

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The SOLIBAM project is supported by the European Commission through the Seventh Framework Programme (FP7) for Research and Technological Development under the Grant Agreement n°245058

Graphic creation : Lilou B. - Internal layout : Plume & Sciences - Printing : Tirex