

## Project 3: Barley Improvement

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### Rationale

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ICARDA has the global responsibility for the improvement of barley, which is grown annually on 56 million hectares globally in a wide range of environments. In several developing countries, most barley is grown by resource poor farmers in marginal environments, often at the fringes of deserts and steppes, or at high elevations in the tropics, receiving modest or no inputs. Barley grain is used as feed for animals, malt and human food. Barley straw is used as animal feed, for animal bedding and as cover material for hut roofs. After combine harvesting barley stubbles are grazed in many developing countries. Malt is the second largest use of barley, and malting barley is grown as a cash crop in a number of developing countries. The most popular use of malt is the production of alcoholic beverages, but malt and malt extracts are increasingly becoming very important in the bakery and baby food industry. Globally, the demand for beer is rapidly growing, particularly in many developing countries. This makes malting barley an important cash crop for resource-poor farmers in areas where options are very limited, and barley is often the only possible crop. This is the case in the highlands of Ethiopia, Eritrea, and the Andean region. It is an important food source in North Africa, highlands of Tibet, Nepal, Ethiopia, Eritrea, Yemen, and the Andean countries. These regions are characterized by harsh living conditions and are home to some of the poorest farmers in the world who depend on low production systems. Improvement in the production of barley through germplasm enhancement will contribute substantially to food security in developing countries.

Project 3 on barley improvement develops facilitating methodologies and technologies, enhanced germplasm and associated knowledge which improve the lives of people in the developing world. The MTP 2008-2010 emphasizes the role of impact-oriented outputs in creating barley technology that fosters both poverty reduction and food security while contributing to biodiversity conservation, environmental protection, and sustainable development. These are built around a set of international public goods, relying on a decentralized approach for delivery of impacts. The outputs will catalyze research operations across locations where ICARDA and partners operate, while partnerships are used to leverage capacity and help accelerate results and inputs. Each output represents a research operational unit that is shaped by clearly defined objectives. Targeted research areas and priority traits aiming at reducing poverty and ensuring global food supplies are defined.

Within the context of the CGIAR System Priorities and the Millennium Development Goals, ICARDA's impact pathways lead from our most valuable resource, genetic diversity and enhanced germplasm of barley to poverty reduction for poor rural households. Along the way, priority setting and targeting focuses crop improvement and other technology development activities on problems to produce maximum impact. Permanent feedback and participation is sought from our partners throughout the innovation pathways to fine-tune the targeting and priority setting and add to our knowledge base on barley, on its cropping systems and on commodity and value chains.

The activities of the barley improvement project align with System Priority (SP) 2, producing more and better food at lower cost through genetic improvement: sub-priority 2A, producing improved barley germplasm with high and stable yield; sub-priority 2B, producing barley germplasm with resistance/tolerance to abiotic stress, with particular attention to drought and salinity; sub-priority 2C, selecting barley germplasm with superior end-use and nutritional. The project is fully engaged in the CGIAR Challenge Programs on *Water and Food, Generation and HarvestPlus*.

Large barley areas are under high stress from pests and diseases and other unfavorable growing conditions. ICARDA has engaged in focused partnerships both to develop and to deliver improved genetic material and technologies to resource-poor farm families. These networks have strengthened partners' capabilities in addressing farmers' needs. They have also resulted in new genetic advancement, seed delivery and crop management approaches that are more effective and relevant in resource-constrained environments.

The barley improvement project has focused its agenda for 2008-2010 around three Outputs. These represent genetically enhanced, seed-embedded technologies developed by multidisciplinary teams (germplasm enhancement, integrated pest management, biotechnology, genetic resources) charged with the generation of products reflecting integrated solutions for target end users.

These products listed below form an exciting portfolio developed through consultation with and analysis of the needs of our clients:

- Stress tolerant (drought, salinity, and cold) germplasm for food security and crop diversification (Output 1, SP 2B);
- Barley germplasm with superior end-use (malt) and nutritional quality (biofortified barley, HarvestPlus Challenge Program) for improved nutrition, health, and farm income (Output 1, SP 2C);
- New traits through gene discovery for crop diversity (Generation Challenge Program) (Output 1, SP 2A);
- Improved methodologies and tools for genetic improvement (i.e. participatory plant breeding and doubled haploids) (Output 1, SP 2A);
- Integrated pest management (IPM) options for the control of barley diseases and insect pests (Output 2, SP 2A);
- Capacity building in NARS programs (Output 3, SP 2A).

Within ICARDA, the barley project links with the Biodiversity and Seed System projects within Biodiversity and Integrated Gene Management Program, with the Integrated Water and Land Management Project through genetic research on drought tolerance. Research on malt and nutritional grain quality contributes to the research in the Diversification and Sustainable Intensification of Production Systems Project. The project links with the MTP Project on Poverty and Livelihood Analysis and Impact Assessment in Dry Areas in the targeting of research and the assessment of adoption and impacts of the project's outputs.

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## **Project Outputs**

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The project goal, purpose, outputs, output targets and associated expected outcomes and impacts are provided in the attached Project Logframe. Where an Output Target contributes to a Challenge Program or a Systemwide/Ecoregional Program, this is indicated in the Project Logframe. Below, we describe for each Output: (a) the relation to system priority goals, (b) the impact pathway, (c) the research approach to developing international public goods (IPG), and (d) the role of partner organizations.

### **Output 1: Improved genetic stocks of barley developed through conventional, biotechnological and participatory plant breeding methods and distributed globally through different mechanisms including International Nursery Network**

#### ***1.5 Relation to SP goals***

Output 1 meets specific Goals 1 and 2 of SP2A, by developing and promoting conventional and novel breeding technologies (including molecular breeding and participatory plant breeding), promoting the use an exploitation of genetic resources, and prioritizing areas where barley is grown by resource-poor farmers; general goal of SP2B, by producing stress tolerant (drought, salinity, and cold) germplasm, and allele mining for drought tolerance in reference germplasm collection; and specific goal 1 of SP2C by producing barley germplasm with enhanced concentration of iron and zinc.

#### ***1.6 Description of Impact Pathways***

The intended users of the outcomes are farmers, NARS, and barley researchers worldwide. Through Participatory Plant Breeding (PPB) participating farmers will select improved barley varieties that in turn, will be demonstrated and disseminated to other farmers and communities. The successful adoption of improved varieties will contribute to a more stable production of barley in the targeted areas. The livelihoods of farmers, especially resource-poor farmers in very dry areas, will improve by adopting these varieties specifically adapted to their conditions. The poor consumers will benefit from improved nutritional quality of biofortified varieties. Farmers, researchers, and other NARS partners will acquire increased skills to use participatory methodologies for crop improvement. The barley researchers will utilize the lines with resistance/tolerance to biotic and/or abiotic stresses in their breeding program, to develop improved barley varieties. The adoption of those varieties will stabilize production of barley in the targeted areas.

#### ***1.7 Research Approach to Develop International Public Goods***

The improved barley germplasm and knowledge generated with it will be made freely available to NARS, Advanced Research Institutions (ARI), and barley researchers worldwide. The methodologies developed (Participatory Breeding and Breeding for stress prone environments) are being applied in barley and other crop improvement programs by ICARDA, NARS, ARI, and other CGIAR centers.

## 1.8 Partners' Roles

### **CGIAR Centers and Systemwide Programs:**

- **PRGA** (Systemwide Program on Participatory Research and Gender Analysis): research partner in baseline surveys and participatory monitoring and evaluation within CPWF project on *Improving Water Productivity of Cereals and Food Legumes in the Atbara River Basin of Eritrea*, led by ICARDA

### **Challenge Programs:**

- **CP Water and Food** funds the project *Improving Water Productivity of Cereals and Food Legumes in the Atbara River Basin of Eritrea*.
- **CP HarvestPlus** funds biofortification of barley.
- **CP Generation** funds barley genotyping and phenotyping; allele mining based on non-coding regulatory SNPs in barley germplasm; genomic dissection of tolerance to drought stress in wild barley.

### **Other International Partners:**

- **ACSAD** (Arab Center for the Studies of Arid Zones and Dry Lands): Joint development of barley germplasm. ACSAD contributes germplasm to the barley PPB program in Syria.
- **CIHEAM** (International Center for Advanced Mediterranean Agronomic Studies), IAMZ (Mediterranean Agronomic Institute of Zaragoza): Cooperation in mapping adaptation of barley to drought environments, and dissemination of methodologies in PPB.
- **ICBA** (International Center for Biosaline Agriculture): Evaluation and selection of barley germplasm for saline conditions.

### **Advanced Research Institutions:**

#### **Australia**

- **University of Adelaide, Waite Institute and CRC for Molecular Plant Breeding:** Joint evaluation of barley germplasm for low rainfall environments, and for salt stressed environments; University of Adelaide is responsible for hydroponic screening of germplasm, identification of molecular markers associated with tolerance to salt stress, development of mapping populations, and genotyping; joint publications.
- **University of Adelaide, Waite Analytical Services:** Development of micronutrient-dense barley germplasm, and micronutrient analysis within CP HarvestPlus.
- **Southern Cross University, Grain Food CRC:** Identification of novel germplasm for food and malt through joint PhD student.
- **Plant Breeding Institute, University of Sydney:** Joint evaluation of barley germplasm for resistance to barley stripe (yellow) rust at Cobbity.

#### **Canada:**

- **Alberta Agriculture, Food and Rural Development:** Joint evaluation and selection of germplasm for disease resistance and agronomic types

#### **France**

- **Université de Paris-Sud, Labo Morphogenese Vegetale Experimentale:** Production of doubled haploids in barley.
- **CIRAD, Montpellier:** Development of a dataset on allele diversity at orthologous candidate genes in CP Generation.

#### **Germany**

- **IPK-Gatersleben:** Association mapping and microarray analysis in barley.
- **University of Bonn:** QTL analysis in barley.

#### **Italy**

- **Istituto Sperimentale per la Cerealicoltura, Sezione di Fiorenzuola d'Arda:** Mapping adaptation of barley to drought environments: evaluation of germplasm, including mapping populations; evaluation of *Arta/H. spontaneum* 41-1 mapping population for net blotch.
- **University of Udine:** Allelic imbalance and gene expression in barley

## Spain

- **University of Barcelona:** Mapping adaptation of barley to drought environments, and stress physiology
- **UdL-IRTA (University of Lleida and Institut de Recerca i Tecnologia Agroalimentaria – IRTA):** Mapping adaptation of barley to drought environments.

## United Kingdom

- **NIAB** (National Institute of Agricultural Botany): Allelic imbalance assay and gene expression analysis in barley supported by CP Generation.
- **SCRI** (Scottish Crop Research Institute): Mapping adaptation of barley to drought environments and genotyping.

## USA

- **Busch Agricultural Resources Inc.** (Anheuser-Busch): Development of barley germplasm with multiple disease resistance and enhanced malting quality.
- **Oregon State University:** Molecular mapping of barley within the North America Barley Genome Mapping project and identification of molecular markers associated with resistance to diseases of barley.
- **USDA:** Funding for Fusarium Head Blight testing.

## NARS Partners:

**Algeria:** **ITGC** (Institut Technique des Grandes Cultures) and **INRAA** (Institut National de Recherche Agronomique d'Algérie): Collaboration on PPB at six locations.

## China

- Fusarium Head Blight testing of nurseries in Hangzhou and Shanghai
- Genotyping a set of barley accessions with SSR markers at **Chinese Academy of Agricultural Science** within CP Generation

**Egypt:** Matrouh Resource Management Project): Joint participatory barley improvement.

## Eritrea

- **NARI** (National Agricultural Research Institute), Ministry of Agriculture: Joint project Improving Water Productivity of Cereals and Food Legumes in the Atbara River Basin of Eritrea, within CP Water & Food.
- **Hamelmallo College of Agriculture.** Research on *hanfetse*, barley agronomy conducted within above project of Water and Food Challenge Program

## Iran:

- **SPII:** Joint selection of special barley germplasm for terminal drought suitable for cold areas.
- **DARI:** Joint selection of barley germplasm adapted to dry and cold areas.

**Jordan:** **NCARTT** (National Center for Agricultural Research and Technology Transfer): Joint participatory barley breeding project.

## Mexico

- **ICAMEX:** Generation of barley lines and varieties adapted to the agro-ecological conditions and industrial needs of the State of Mexico.
- **Guanajuato Foundation:** Generation and promotion of forage barley with high productivity and tolerant to drought conditions at the State of Guanajuato.

## Syria

- **GCSAR** (General Commission for Agricultural Research): joint participatory barley breeding.
- **Tishreen University.** Collaboration in genotyping diverse gene pools and study of allelic imbalance in barley supported by Generation Challenge Program.
- **Al Shark Malting Company.** Selection and testing of new malting barley varieties.

## **Output 2: Integrated pest management (IPM) control options including resistance sources, pathogenicity spectrum, and biological control mechanism against barley diseases and insects**

### **2.1 Relation to SP goals**

Output 2 meets specific Goal 1 of SP2A, by characterizing the variability and pathogenicity of major diseases and insect pests, identifying sources of resistance/tolerance to major diseases and insect pests, and deploying resistance gene(s) to produce barley germplasm with enhanced resistance to major diseases and insect pests.

### **2.2 Description of Impact Pathways**

The IPM research at ICARDA involves basic and applied research on fungal pathogens, viral diseases, and insect pest of barley and integrates both strategic research (e.g. the characterization of pathogenic variability) and applied adaptive research (IPM components for diseases and insect managements) through use of pilot sites and farmer field schools (FFS) conducted with NARS. IPM research outputs are technologies that have direct application in breeding programs of ICARDA and NARS. The technologies are being tested in farmers' fields through direct collaboration with NARS researchers, universities, extension specialists, farmers groups, and NGOs. The IPM outputs are of immediate impact on productivity and sustainability of production. The ultimate beneficiaries of IPM products are resource-poor farmers.

### **2.3 Research Approach to Develop International Public Goods**

Effective resistance sources are published and germplasm are made available to NARS and ICARDA breeders. All technological packages developed are distributed to NARS research groups and extension, and to farmers' groups, and these are applied in many countries. The knowledge and practices to combat diseases and pests are published internationally.

### **2.4 Partners' Roles**

#### **CGIAR Centers and Systemwide Programs**

- **IITA:** Exchange of information on cereal cyst nematodes (CCN).
- **CIMMYT:** Collaboration on CCN and root rots in Turkey.
- **Systemwide IPM program:** exchange of information and methodology on IPM related issues.

#### **Advanced Research Institutions:**

- **University of Adelaide and South Australian Research and Development Industry (SARDI):** collaboration in the management of scald and net blotch in barley.
- **Danish Institute of Agricultural Sciences (DIAS):** characterization of barley yellow rust and its population dynamics, and integrated disease control in barley.

#### **NARS Partners:**

- Eritrea: Collaboration on net blotch screening
- Ethiopia: Screening for net blotch, scald, powdery mildew, and stem rust
- Tunisia: Screening for scald and BYDV
- Morocco: Screening for barley stem gall midge
- Mexico: Screening for Fusarium head blight, yellow rust and scald
- Ecuador and Peru: Screening for yellow rust

## **Output 3: Enhanced research capacity of NARS through training, workshops and conferences**

### **3.1 Relation to SP goals**

Output 3 meets specific Goal 1 of SP2A, by enhancing the research capability of NARS in the utilizing the conventional and novel breeding technologies developed by the project.

### **3.2 Description of Impact Pathways**

Training courses and student degree programs are designed to meet the needs of our NARS partners and other stakeholders. Training is based on the needs of individual scientists or a group of scientists

interested in specialized subjects. This trend of individual catering is client-driven and has evolved over many years.

The project influences human capacity in disciplines of plant breeding, IPM and biotechnology. Several scientists and technicians who have participated ICARDA's training courses are active in the core activities in NARS. In the degree program the graduate students not only contribute to ICARDA's research, but also become the future leaders of research in NARS. Trained people become the backbone of the national research systems and ensure the sustainability of the systems.

### **3.3 *Research Approach to Develop International Public Goods***

The original research results and methodologies developed through this output are published in international scientific journals and other media and are made available worldwide. The knowledge generated is formatted into forms for advancing development projects where food security is most needed. The trainees and students participating in the courses become future ambassadors for disseminating this knowledge to others in their environments.

### **3.4 *Partners' Roles***

The following Universities are collaborating in MSc/PhD degree programs:

**Aleppo University, Syria:** Developing of marker assisted selection for disease resistance genes; Genotype by Environment interaction in barley; Water requirement and physiological traits analysis for drought tolerance in barley; Developing of a TILLING system in barley.

**Southern Cross University, Australia:** Novel germplasm for food and malt.

**University of Jordan, Jordan:** QTLs for drought tolerance in barley.

**National Institute of Agronomy of Tunisia Supervisor, Tunisia:** Association mapping in barley; Genetic diversity and associative traits analysis of barley germplasm by simple sequence repeats.

<b>Project 3</b>	<b>Barley Improvement</b>
<b>Goal</b>	Sustainable conservation and use of barley diversity to increase agricultural production in developing countries
<b>Purpose</b>	Improved livelihoods of resource poor farmers from the conservation, improvement and sustainable use of barley diversity and the adoption of improved barley varieties and associated technologies

Output Targets		Intended Users	Outcomes	Impact
<b>Output 1: Improved genetic stocks of barley developed through conventional, biotechnological and participatory plant breeding methods and distributed globally through different mechanisms including International Nursery Network</b>				
<b>2008</b>	At least 500 doubled haploid lines of barley produced and evaluated in Syria for yield and quality	Plant breeders and farmers	Rapid availability of homozygous lines of barley	Farm incomes improved and risks reduced through fast turnover of varieties
	At least two improved drought tolerant varieties of barley selected and tested in partnership with farmers, and which have proven farmer acceptability in Eritrea ( <i>CP Water and Food</i> )	Farmers and NARS in Eritrea	Improved drought tolerant varieties of barley used by farmers in Eritrea	More stable production of barley in Eritrea Adoption of improved varieties will contribute to improved livelihood of farmers in Eritrea Improved farmers access to new knowledge and germplasm
	QTLs analysis for iron and zinc content in the grain initiated ( <i>CP HarvestPlus</i> )	Barley breeders and biotechnologists worldwide	Knowledge on trait genetics and efficiency of varietal development enhanced	Barley varieties with better nutritional quality delivered faster to farmers
<b>2009</b>	At least 50 barley lines with resistance/tolerance to salinity identified and distributed to NARS	ICARDA, NARS, ARIs, barley researchers worldwide	Barley lines with resistance/tolerance to salinity used by barley breeding programs worldwide	Production of barley in saline prone areas stabilized
	Barley germplasm stocks with single and multiple disease (scald, net blotch, yellow rust, and Fusarium head blight) resistance developed and distributed worldwide	ICARDA, NARS, ARIs, barley researchers worldwide	Barley lines resistant to one or more diseases used by barley breeding programs worldwide	Adoption of improved varieties will contribute to improved livelihood of farmers
	Participatory Barley Breeding institutionalized in Jordan	Farmers and NARS in Jordan	New varieties of barley with higher yield, better adapted to local conditions	Adoption of improved varieties will contribute to improved livelihood of farmers Improved farmers access to new knowledge and germplasm

Output Targets		Intended Users	Outcomes	Impact
2010	At least 50 new barley lines with enhanced malting quality identified and distributed to NARS	ICARDA, NARS, ARIs, Industry, barley researchers worldwide	Barley lines with enhanced malting quality used by barley breeding programs worldwide and by farmers	Adoption of barley varieties with enhanced malting quality will contribute to improved livelihoods of farmers
	Marker assisted selection for scald (3H), Yd2, Yd3, and for other biotic stresses initiated	Barley breeders and researchers worldwide	New varieties of barley with resistance to scald and BYDV	Increased barley productivity
	QTLs identified for traits related to drought tolerance (mapping populations)	Barley breeders and biotechnologists worldwide	Knowledge on trait genetics and efficiency of varietal development enhanced	Barley varieties better adapted to drought stress delivered faster to farmers
	Allele mining for drought tolerance in reference barley collection ( <i>CP Generation</i> )	Barley breeders and biotechnologists worldwide	Knowledge on trait genetics and efficiency of varietal development enhanced	Barley varieties better adapted to drought stress delivered faster to farmers
<b>Output 2: Integrated pest management (IPM) control options including resistance sources, pathogenicity spectrum, and biological control mechanism against barley diseases and insects</b>				
2008	Wide array of barley germplasm, including wild relatives, evaluated for new sources of resistance to diseases (barley yellow dwarf virus, scald, and net blotch) and insect pests (Russian wheat aphid and barley gall midge).	Breeders, geneticists	Sources of resistance identified and used	Broader gene pool for resistance to biotic stresses available to breeding programs for germplasm improvement
	Virulence surveys and pathogenicity spectrum investigated. Variability of scald fungal disease and Russian wheat aphid insect pest characterized	Breeders and plant protection scientists	Pest variability elucidated and exploited in breeding for resistance	Better deployment of resistance sources
2009	Wide array of barley germplasm, including wild relatives, landraces and breeding lines evaluated for new sources of resistance to diseases (Barley yellow dwarf virus, scald, and net blotch of barley) and insect pests (Russian wheat aphid and barley gall midge)	Breeders, geneticists	Sources of resistance identified and used	Broader gene pool for resistance to biotic stresses available to breeding programs for germplasm improvement
	Virulence surveys and pathogenicity spectrum investigated. Variability net blotch, one virus, and one insect pest characterized	Breeders and plant protection scientists	Pest variability elucidated and exploited in breeding for resistance	Better deployment of resistance sources

Output Targets		Intended Users	Outcomes	Impact
2010	Wide array of barley germplasm, including wild relatives, landraces, and breeding lines evaluated for new sources of resistance to diseases (Barley yellow dwarf virus, net blotch, and CCN) and insect pests (Russian wheat aphid and barley gall midge)	Breeders, geneticists	Sources of resistance identified and used	Broader gene pool for resistance to biotic stresses available to breeding programs for germplasm improvement
	Virulence surveys and pathogenicity spectrum investigated. Variability of one virus, two additional fungal diseases, and one insect pest characterized	Breeders and plant protection scientists	Pest variability elucidated and exploited in breeding for resistance	Better deployment of resistance sources
	Effect of IPM components targeting control of major diseases and insect pests of barley tested in hot spots, and IPM pilot sites established	NARS plant protectionists, extension services, farmers	IPM pilot sites out-scaled, and IPM options for different cropping systems and agro-ecological zones developed and used.	Sustainable increase in crop production and farmers' income
<b>Output 3: Enhanced research capacity of human resources through training, workshops and conferences</b>				
Annually	At least one specialized training courses in theme related to barley improvement organized each year	NARS Scientists	Increased capability of NARS scientists in new technique leading to enhanced efficiency and effectiveness	Improved farm production and income
	At least one MSc/PhD graduate student complete degree program under ICARDA's co-supervision per year	NARS Researchers	Increased availability of specialists in different disciplines	Increased farm production and income
	Individual non-degree specialized short training program organized annually	NARS Specialists	Increased capability of NARS scientists	Increased farm production and income