The Julius Kühn-Institut (JKI)
Federal Research Centre for Cultivated Plants

Avena Genetic Resources for Quality in Human Consumption (AVEQ)

AGRI GEN RES action 061

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and with financial support from:
Peter Koelln KGaA, Germany²,
Emco spol. s r.o., Czech Republic³, and
Gemeinschaft zur Förderung der privaten deutschen Pflanzenzüchtung e.V. (GFP), Germany⁴

http://aveq.jki.bund.de


² Peter Koelln KGaA is a German company creating, developing and marketing high-quality oat products, breakfast cereals, edible oils and fats, with a tradition of almost 200 years.

³ Emco spol s.r.o. is a Czech production and sale company of cereal products (crunchy müsli, oatmeal, müsli biscuits, oat flakes).

⁴ GFP is the association of German private plant breeding companies.
1. Background

1.1. Oats quality in human consumption

Oat is a crop with an important European history and tradition. Nutritive substances deter-
mine the physiological quality of oats in human nutrition. From a nutritionists point of view oat
is our most valuable cereal, based on the following traits:

- High protein content of oat grain and high biological value of the protein.

- High fat content in oat grain. Oat fat has a high proportion of polyunsaturated fatty acids
  and has a positive impact on the aroma of oat products. However, the oat fat also re-
  duces storage stability of extruded products.

- High contents of dietary fiber. Of special value is the oatmeal gruel, which is chemically
  the soluble and highly viscous mixed linked (1->3)(1->4)-β-D-glucans. It reduces serum
  cholesterol levels mainly by increasing the viscosity in the gut. Thus molecular weight
  distribution of β-glucans is important as well. Oat products can be added to carbohydrate
  containing food for reducing insulin requirements.

Recent research focused on antioxidants as additional health promoting ingredients of oat
products. These are tocols, also known as vitamin E, and avenanthramides, a recently de-
tected family of compounds, which play a role for the plant as substances protecting from
diseases (phytoalexins), and are chemically very similar to Tranilast, an anti-allergenic phar-
macutical.

The unique nutritional value of oats is widely recognized and resulted in health claims for oat
products, initially only in the USA, but since end of 2011 also in the European Union (The
European Commission 2011). Thus, oat has potential for the production and marketing of
premium quality priced products. Beginning in the Nordic countries new products and mar-
kets emerged. A market dedicated to health products will also direct to sustainable agricul-
tural production.

Figure 2 A diversity of oat products is available primarily in health oriented and organic food
markets
1.2. Oats in sustainable agriculture

Oats rank seventh among cereals in world production, following maize, rice, wheat, barley, sorghum and the millets. Oats are intrinsically a low input cereal crop: their nutrient requirements are less when compared to wheat or corn; they are amongst the least demanding in regard to suitable soil; they have low susceptibility for cereal diseases and high competitiveness to weeds. This makes oat a crop highly adapted to sustainable management and, together with its unique nutritional quality in whole grain cereal products, an ideal crop in organic farming systems. Comparable yields and technical quality can be easily achieved with oats in organic farming. Oat is considered valuable for disease reduction in cereal crop rotations, which are dominating throughout European agriculture. Growing oat can lead in the succeeding cereal crops to a reduced need for chemical plant protection.

1.3. The preservation of oats in genebanks

Most oat species can be easily stored as seeds in genebanks. The European oat collection, available through web based information systems, contains approximately 35,000 entries (accessions), stored and made available as seed samples. They comprise four cultivated and about 20 wild species in the genus *Avena*. Figure 3 shows the impact of domestication on the appearance of seeds. Seeds of the wild species (upper row) have hairs and awns, which facilitate their distribution by wind and animals. But they are not suitable for mechanical operations, like sowing and harvesting, or for animal feeding. Cultivated forms in the middle and lower row have mostly lost hairs and awns, although most cultivated oats are still a husked cereal. Nevertheless, free threshing forms (so called naked oats) have already been bred of the sand oat (diploid) as well as of the common (hexaploid) cultivated types (right hand side of the middle and lower row).

**Figure 3** The evolution of seeds during the domestication process from wild *Avena* species to cultivated oats. Seeds of wild species are in the upper row of seeds, cultivated species in the middle and lower rows, with naked oats at the very right.
1.4. Objectives of the project

The main objectives of the AVEQ project were the evaluation of oat genetic resources for traits relevant to the physiological quality of oats in human nutrition: contents of protein, fat, minerals, dietary fibre - especially β-glucan, antioxidants and phenolic compounds. Furthermore, resistance to *Fusarium* infection and the resulting risk for humans of contamination with mycotoxins was evaluated in field experiments by means of artificial inoculation with strains of the most important *Fusarium* species known to occur on oats. Another aspect dealt with cold tolerance in field and growth chamber tests. Cold tolerance is important for oat in several European regions, because oat is sown early or even as a winter crop in order to maximize the yield potential.

All the traits evaluated are of high importance for breeding cultivars needed for the production of premium quality oat raw products to meet an increasing demand for healthy food in Europe, and for the competitiveness of oats as a crop in European agriculture. A further objective was to make all results available with an internet accessible database.

1.5. Results of the project

The working collection

*Avena* species with 14 (diploid), 28 (tetraploid) and 42 chromosomes (hexaploid) have originated from crosses between primitive species with 14 chromosomes. Wild and cultivated species are available at all ploidy levels. More than 600 accessions and cultivars from 25 germplasm collections and 31 breeders in 14 European countries were compiled to a working collection, which was multiplied and managed to serve the project purposes. Biological classification (taxonomy), together with data on geographic origin and the assumed time of use in agriculture have been used to a great extent for selecting a working collection with a maximum of biological diversity. It included current commercial and obsolete cultivars, landraces and wild species, representing 12 different *Avena* species, more than 100 years of breeding history and more than 50 countries of origin.

A) Cultivated hexaploid oats - *A. sativa* and *A. byzantina*

Currently, commercially available oat cultivars belong to the hexaploid species *A. sativa* and *A. byzantina*. *A. byzantina*, also known as red oat, is close to *A. sativa* and not generally accepted as another species. 554 accessions of *A. sativa* and 24 accessions determined by holders as *A. byzantina* have been grown at seven field sites widely distributed over Europe, and were analyzed for protein and fat. All harvests from three of seven participating countries were also analyzed for total β-glucan and 123 of these accessions, grown on the three sites, were additionally analyzed for other carbohydrates and antioxidants.
A. byzantina  
A. sativa var. tristis „Schwarzer Fahnenhafer“  
A. sativa cv. Angus  
A. sativa ssp. nudisativa Naked oat  
A. sativa Modern oat cultivar “Belinda”

**Figure 4** A small set showing the variability in the hexaploid cultivated oats

B) **Marginally cultivated oats – A. strigosa and A. abyssinica**

Forty six accessions of the diploid *A. strigosa* and five accessions of the Ethiopian oat have been grown in the field experiments and analyzed for protein, fat and total β-glucan, 20 respectively two were additionally analyzed for other carbohydrates and antioxidants.

**Figure 5** Marginally cultivated tetraploid and diploid oats
The diploid *A.strigosa* has been grown for feed and fodder already in the old Celtic cultures in west Scotland and the Hebrides, where its tolerance to acid soils, manganese and copper deficiency was crucial. As a result, *A. strigosa* remained the most grown oats in Great Britain and Ireland until the 17th century. It was also cultivated in Romania (Karpaty), Portugal, Poland, and Denmark. It is considered an important genetic resource for oat breeding for earliness and stress tolerance. The tetraploid *A.abyssinica* (Ethiopian oat) has long been grown in Ethiopia in mixture with barley and has been used for the flat national bread, local beer and other products like roasted snacks. It is well adapted to the high elevations, the climatic and soil conditions in Ethiopia.

C. **Wild relatives of Avena**

Wild relatives in the genus *Avena* are ordered into a gene pool concept according to their ability of crossing with the cultivated hexaploid oat. The hexaploid wild species (*A.fatua*, *A.sterilis*, *A.hybrida*) are easily crossed with *A.sativa*. The project used 16 accessions of *A.fatua*, five accessions of *A.sterilis* and one accession of *A.hybrida*. Twelve, four and one of these accessions, respectively, were analyzed for protein, fat and total β-glucan; eight and four and one additionally were analysed for other carbohydrates and antioxidants. The use of tetraploid and diploid species in breeding of hexaploid oats is more difficult. Thirteen accessions of *A.barbata* (tetraploid), *A.canariensis*, *A.damascena*, *A.hirtula*, and *A.wiestii* (diploid) have been included in the evaluation field experiments and most of them were analysed for protein, fat, total β-glucan, carbohydrates and antioxidants.

**Figure 6** Wild relatives of oats from the genus *Avena*
Quality for human nutrition in oat breeding – the potential of genetic resources

Nutritive substances define the physiological quality of oats in human nutrition. However, easily determinable traits of relevance for processing such as grain size, grain weight and husk content dominate the commercial perception of the quality of oat as a raw material. High kernel size is considered of special importance for industrial quality, because it makes mechanical processing easier and more efficient. But high kernel size is likely associated with lower contents of valuable compounds as e.g. fat and vitamin E (tocols).

Figure 7 indicates that selection for high yield and seed weight in oat breeding may not ensure valuable characters regarding health effects and taste. Eleven very popular more or less modern cultivars from different countries were selected as standard cultivars for the project and grown for comparison reasons in both years and in replications.

![Graph showing correlation between seed weight and nutrient content](image)

**Figure 7** Higher seed weight is on average associated with lower contents of fat and antioxidants in seed (samples harvested in Estonia 2008), but considerable variability of nutritive traits is available for breeding on each level of seed weight.

In all genetic resources groups, including the modern cultivars, a high range of variation for protein, fat, total β-glucan, carbohydrates and antioxidants can be exploited. High contents of each compound were also found in different wild relative species. Remarkable is the high content of antioxidants in the diploid bristle or sand oat (*A. strigosa*). This suggests that valuable traits for nutritional quality can be made available also from less developed species.

**Mycotoxins, a danger in oats?**

Mycotoxins contamination of food products is of serious concern to health authorities. Commission Regulation (EC) No 1881/2006 sets up limits for contaminants in cereal foodstuff. Different species of *Fusarium* produce the major target toxins. Thus a mixture of *Fusarium* species had to be inoculated in field experiments with artificial *Fusarium* inoculation to cover all relevant mycotoxins contamination risks. Among the targeted toxins the Trichothecenes...
(T-2 and HT-2 toxin) are of special importance, because they occur primarily on oats and have high toxicity, however, an analysis methodology is not yet readily available.

*Fusarium* infection of oats unlike wheat causes hardly visible symptoms in the field or on the grain. Typical symptoms were found only in Romania in 2008, after extremely wet weather conditions (Fig. 8 a, b). A freezing blotter test, where seeds killed by freezing are incubated on moist filter paper (Fig. 8c), has been found an appropriate method to detect *Fusarium*. Also in germination tests contaminating fungi identifiable as *Fusarium* were frequently found (Fig. 8d). Mycotoxins contents differed significantly already in the standard cultivars. A wheat cultivar included for comparison showed much higher contamination with the mycotoxin deoxinivalenol (DON), while T-2 contamination was generally higher in oats. Naked oats were less contaminated, indicating that most mycotoxins are located in the hulls. Genotypes were identified with consistently low mycotoxins contamination. An old landrace found in Schenkenfelden, Austria was very low for both mycotoxins DON and HT-2.

![Image](image1.png)

Figure 8  Fusarium symptoms in the field (a) and on seeds (b), as observable only after extreme weather conditions, in the freezing blotter (c) and germination tests (d)

**Frost tolerance would allow earlier sowing for higher yields**

Field screening for frost tolerance was done for all working collection in Bulgaria and Romania. The field results were in line with frost injury measured under controlled conditions (growth chamber) with chlorophyll fluorescence in the first leaf stage as an indicator. Even though only spring oats were evaluated in the AVEQ project considerably frost resistant genotypes were found.
2. Communicating value

AVEQ was an initiative out of the Avena Working Group of the European Cooperative Programme for Plant Genetic Resources (ECPGR). Leading working group members, if not participating as partners, were invited to project meetings. The final meeting held at Bucharest (Romania) in October 2010 was a joint meeting of the AVEQ project group with the ECPGR Avena working group. One overlapping day of the meetings was used by the AVEQ partners to present their results and discuss them with experts and stakeholders from the ECPGR Avena working group. A report of these meetings is available at the ECPGR web site.

A publicly accessible website has been set up to communicate the objectives and achievements of the project. The project used expertise available in only one or few EU countries, e.g. for the analysis of avenanthramides, tocols or mycotoxins. The possibility to collaborate with partners in Europe on aspects in genetic resources and quality analysis created synergies, which would not have been possible without funding from the GENRES Programme.

3. The Action and the Partners

3.1. Action details

For the implementation of the action a total budget of 1,037,882 € was available; 490,375 € as co-founding from EU, in addition donations 20,000 €, from Peter Kölln KGaA Germany, 7,000 €, from Emco spol s.r.o., Czech Republic, 2,000 €, from Gemeinschaft zur Förderung der privaten deutschen Pflanzenzüchtung e.V., Germany, as well as 518,507 € as own contribution from the project partners. The project started on 01 March 2007 and ended on 29 February 2011. The Julius Kühn Institute coordinated the action. The project had 10 work packages and was implemented by 15 partners.
### 3.2. Partner details

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<th>Partner</th>
<th>Name and Details</th>
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4. Links

4.1. The AVEQ project portal

The project results and products can be found on the web portal at http://aveq.jki.bund.de. The web site presents the objectives and gives a short introduction into the project. It lists the partners and main sponsors with links to their web representations.
4.2. The AVEQ project database

A project database has been created to support the management of the action and to provide facilities to upload and download project results. It is accessible as a production version (http://aveqprod.jki.bund.de), and a testing version (http://aveqtest.jki.bund.de). The latter will be used to demonstrate and popularize the software modules and concepts developed.

Figure 13 The publicly accessible part of the project database gives access to the working collection, to observation methodology, observation results and pictures
The working collection and observation methodology used, observation results and pictures can be researched, viewed and downloaded by everyone without a login being needed. In addition, field plans, sowing and observation lists, direct data input or downloading Excel templates to input observations, or uploading data and pictures are available to project partners via login and password.

4.3. The European Avena Database

The European Avena database (EADDB) was created by the former Braunschweig Genetic Resources Collection and is now maintained by the Julius Kühn Institute on behalf of the European Cooperative Programme for Crop Genetic Resources (ECPGR) http://www.ecpgr.cgiar.org/ as one of the European Central Crop Databases. It provides an information tool on oat genetic resources for the ECPGR Avena Working Group and for other end users interested in the use of oat genetic resources in agriculture, breeding and research. The developmental focus during the last years was on evaluation and characterization data, which have been generated in AVEQ and a preceding project (GENRES 99-106).

The EADDB web application allows for a combined search of passport (origin), characterization and evaluation (trait observation) data. Various result sets can be displayed and partly also downloaded as lists of passport data, trait observation data, descriptions of observation methodology, field experiment details, photos and some genetic and allelic information. Further information is available at: http://eadb.jki.bund.de

Figure 14 Compound query for passport and trait data and result sets available in the EADB.

![Figure 14 Compound query for passport and trait data and result sets available in the EADB](image-url)
4.4. List of publications

Scientific publications are under preparation. The full list of publications will be published on the project web site at [http://aveq.jki.bund.de](http://aveq.jki.bund.de).

References


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