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Guidebook to Participatory Plant Breeding for organic wheat in the EU

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TABLE OF CONTENTS

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Introduction

This guidebook is designed as a foundational resource for farmers, agricultural enthusiasts and anyone interested in sustainable agriculture. Whether you are a seasoned farmer or new to the field of organic farming, this guide aims to provide you with valuable insights into the practice of PPB and how it can be effectively implemented in growing wheat organically, in line with EU standards.

What is Participatory Plant Breeding (PPB)?

PPB is an innovative approach to plant breeding that actively involves farmers in the selection and breeding of crop cultivars (meaning not only pure varieties but also adapted heterogeneous material). Unlike conventional breeding programmes that are often conducted in research stations, PPB takes place in the field where the crops will be grown. This approach ensures that the developed cultivars are well-suited to the specific conditions and needs of local farming systems. In PPB, farmers' knowledge and experience are valued and combined with scientific methods to create robust, resilient, and productive crop cultivars.

Why focus on wheat?

Wheat (*Triticum aestivum* L.) is an ultimate source of staple food and is one of the most important arable crops for the organic sector giving considerable income to many farmers. Despite its high importance, very few organic varieties are available for farmers, who have to grow conventionally bred varieties not totally adapted to their growing conditions and needs. In addition, organic farming not always needs pure varieties, but heterogeneous material could be also effectively utilised under organic growing conditions to mitigate the effect of the more variable pedo-climatic, nutritional and plant protection conditions. These materials could be developed and improved most efficiently in targeted organic fields providing highly stable and resilient growing material to farmers.

Organic farming and EU standards

Organic agriculture is a holistic approach to agriculture that emphasises the use of natural processes and materials, avoiding synthetic chemicals and promoting biodiversity. In the EU, organic agriculture is governed by strict regulations that ensure the environmental and health standards are maintained. This guidebook will help you navigate these standards, ensuring that your PPB practices for wheat are compliant and contribute positively to the environment and society.

Empowering farmers through PPB

This guidebook is more than just a manual; it's a tool to empower you, the farmer, in playing a crucial role in shaping the future of organic agriculture. By participating in

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breeding programmes, you are not only enhancing your own farming practices but also contributing to a broader movement towards sustainable, resilient and diverse agricultural systems.

References:

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Principles of PPB in Organic Agriculture

Introduction to Participatory Plant Breeding (PPB)

Participatory Plant Breeding (PPB) represents a collaborative approach to crop development where farmers, breeders and scientists work together. It contrasts with traditional breeding methods, where breeders make decisions often removed from the actual farming environment. PPB is particularly effective in organic farming systems where local adaptability and resilience are key. The approach is grounded in the principles of genetic diversity, local adaptation and farmer empowerment (Ceccarelli, 2015). There are two types of participatory programmes, depending on when the participation starts: participatory variety selection (PVS) and participatory plant breeding (PPB). Farmers used to be involved in PVS to know which (mostly conventional) already registered varieties are best adapted to their conditions, while during PPB the selection work continues but also involves the farmer in the process.

Nowadays, there are many methods that are used to create new varieties in agriculture. However, as shown in Annex 1 of the Position paper of IFOAM on 'Compatibility breeding techniques in organic systems' (IFOAM, 2017), not all available methods and practices are acceptable for organic farming conditions. Organic breeders mostly deal with crossbreeding. However, not only the actual breeding method is important, but also the principle. In some European countries, the method of participatory plant breeding (PPB) has started to be used in breeding. This method emerged in the early 1980s as part of a movement promoting the concept of participatory research in response to criticism of the failure of research conducted at experimental stations to address the needs of poor farmers in developing countries. PPB has gained recognition as an activity that is mostly supported by social scientists and agronomists working with non-governmental organisations (NGOs). As a result, PPB was seen from the beginning as the opposite of conventional breeding, instead of being seen as an additional option in the breeding

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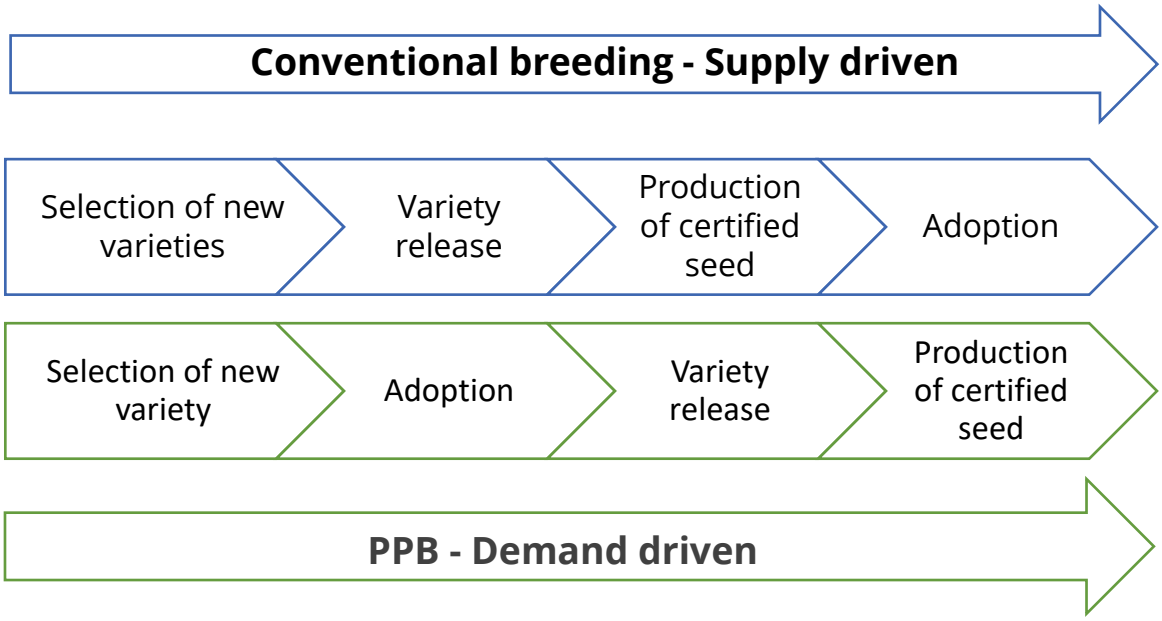
system. Even now, more than thirty years later, this view is still common (Ceccarelli et al., 2009).

Differences between conventional breeding and PPB

The principle of conventional breeding is a closed system where all decisions are made at the breeding station. The principle of PPB, on the other hand, is that from the crossing of the parents; farmers, processors and other PPB participants are involved in selecting and deciding which materials from the cross they consider most suitable for their cultivation/processing method.

The differences between conventional breeding and PPB are shown below (Ceccarelli & Grando, 2007). Conventional plant breeding often follows a supply-driven approach, where new varieties are developed and released without first determining farmers' preferences or acceptance. In contrast, participatory plant breeding operates on a demand-driven model. In this approach, the final phase of introducing new varieties is guided by their initial adoption by farmers, which occurs after a complete cycle of selection.



Relevance of PPB in organic agriculture

For organic farming, PPB is especially relevant. Organic farming systems, being diverse and variable, benefit from crops that are specifically adapted to local conditions. PPB can address specific challenges such as pest resistance, soil adaptability and climatic resilience, which are crucial for organic farmers (Desclaux et al., 2008). As wheat is a staple crop, and its breeding is less complicated compared to outcrossing species, a vast amount of knowledge had been already gained on its participatory selection in European and American farmers' fields (Wolfe et al., 2008; Murphy et al. 2008).

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Key principles of PPB

Farmers play a central role in PPB. Their knowledge of local conditions and needs is invaluable in selecting traits and lines/populations that are most suitable for their specific contexts. This involvement also ensures that the developed cultivars align with their practical and market requirements (Morris & Bellon, 2004).

The cornerstone of PPB is genetic diversity. By incorporating a wide range of genetic traits, PPB enhances the crop's ability to adapt to different environmental conditions and challenges. This diversity is particularly beneficial in organic agriculture, where reliance on synthetic inputs is prohibited (Wolfe et al., 2008). Local adaptation involves selecting and breeding crops that perform well under local environmental, climatic and soil conditions. This principle is critical in organic agriculture, where the focus is on utilising natural ecological processes (Dawson et al., 2008).

Benefits of PPB in organic agriculture

PPB offers several benefits in organic agriculture:

- **Enhanced crop resilience:** Cultivars developed through PPB are often more resilient to local pests, diseases and climatic stress.
- **Sustainability:** PPB supports the broader goals of organic agriculture, such as biodiversity, soil health and reduced dependence on external inputs.
- **Economic viability:** By developing cultivars that perform better and meet market demands, PPB can enhance the economic viability of organic farms.

Implementing PPB in organic agriculture

Implementing PPB in organic agriculture involves several steps:

- **Initial assessment:** Understanding local environmental conditions and farmer needs.
- **Variety selection and breeding:** Collaboratively selecting and breeding wheat varieties and populations with desired traits.
- **Field trials and evaluation:** Conducting field trials on organic farms and gathering data for informed selection decisions.

Challenges and solutions

While PPB offers numerous benefits, it also presents challenges such as resource limitations, the need for continuous farmer engagement and balancing scientific rigor with practicality. Addressing these challenges requires strong collaboration, capacity building and support systems for farmers participating in PPB programs.

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Getting started with PPB

Introduction to starting with PPB

Before diving into PPB, it's crucial to understand your local farming environment. This includes soil type, climate, common pests and diseases and specific challenges or advantages of your region. Gathering this information will guide your decisions throughout the PPB process.

Selecting initial cultivars

The choice of initial wheat varieties or populations to include in your PPB programme is a critical step. Consider the following:

- **Local adaptation:** Choose varieties that are known to perform well in conditions similar to yours.
- **Diversity:** Include a diverse range of varieties to maximise genetic diversity and potential for adaptation.
- **Organic suitability:** Ensure that the chosen varieties align with organic agriculture principles, such as non-GMO status and natural resilience to pests.

Conducting field trials

Field trials are at the heart of PPB. Here's how to get started:

- **Trial design:** Set up small plots for each wheat variety, ensuring they are representative of your farming conditions.
- **Documentation:** Keep detailed records of planting, growth and any observations throughout the season e.g. disease levels.
- **Evaluation criteria:** Decide on the traits you're focusing on, such as yield, disease resistance, or grain quality.

Data collection and analysis

Accurate data collection is crucial. Use simple yet effective methods to record data on plant performance. Analyse this data to identify the best-performing varieties and traits.

Be prepared to navigate challenges such as variable weather conditions, pest outbreaks, or unexpected results. Flexibility and adaptability are key in PPB.

Moving forward

After the initial trials and evaluations, the next steps involve selecting the best performers for further breeding and trials. This iterative process is the essence of PPB, where each cycle brings you closer to developing varieties that are ideally suited to your organic agriculture needs.

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Selecting and breeding wheat varieties

Introduction to selection and breeding

In Participatory Plant Breeding (PPB) programmes for wheat, a crucial aspect is the selection and breeding of varieties. Suitable wheat varieties for breeding can be obtained by purchasing standard organic certified seed, from genebanks (although very small quantities available) from breeding pools of the cooperating breeder and other sources of seed material.

Criteria for selection

Identifying desirable traits

Key traits for wheat variety selection might include:

- **Yield:** Grain production efficiency.
- **Disease and pest resistance:** Inherent resistance to local biotic stressors.
- **Drought tolerance:** Resilience in water-limited conditions.
- **Technological quality:** Level and structure of gluten and rheological properties of the dough.
- **Nutritional quality:** Structure and level of proteins, minerals, bioactive compounds.
- **Adaptation to soil and climatic conditions:** Suitability to local environmental factors with enhanced nutrient use efficiency.

Field observations and farmer knowledge

Farmers' observations are invaluable in identifying plants that exhibit desirable traits. This hands-on approach helps in pinpointing varieties that perform well under specific organic conditions.

Breeding techniques for wheat

Managing cross-pollination

Given wheat's self-pollinating nature, breeders can manage pollination to combine desirable traits through the following:

- emasculation and cutting-back of the florets on the whole spike followed by 3-6 days of isolation (the spike is covered by foil or paper bag), and afterwards, manually transferring pollen from one plant to this target plant to encourage specific trait combinations. The pollinated spike is re-isolated to ensure the development of F_1 seeds in a more humid and safer environment.

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Seed selection and multiplication

Selecting seeds from the best-performing plants within the first hybrid generation after crossing. These seeds are then multiplied during following seasons for further trials and eventual distribution.

Maintaining genetic diversity

Ensuring genetic diversity is a fundamental aspect of PPB:

- **Diverse genetic base:** Start with genetically diverse varieties/breeding materials to ensure a broad range of traits. This means, for example, obtaining wheat seeds from different sources, countries, etc.
- **Regular introduction of new genetics:** Continuously introduce new genetic material to maintain and enhance diversity. In order not to reduce the quality of the varieties, it is necessary to continuously work on obtaining new sources of original material.

The participatory approach

Continuous engagement between farmers and breeders is vital:

- **Feedback mechanisms:** Regular feedback helps align breeding efforts with the actual needs and conditions of organic farmers producing wheat as well as with millers or other processors.
- **Joint decision-making:** Collaborative decisions in the selection and breeding process ensure the development of varieties/populations that are practical and beneficial for farmers as well as processors.

Documentation and record-keeping

Keeping detailed records of breeding activities, plant performance and observations is essential for tracking progress and making informed decisions in future breeding cycles.

Creating a data collection plan

Begin by establishing what data you need to collect. This typically includes information on growth patterns, yield, disease resistance and other relevant agronomic traits. Define clear criteria and scales for measurement to ensure consistency.

Tools and equipment

Simple tools like measuring tapes, scales and notebooks are essential. Additionally, digital tools like smartphones or tablets can be used for recording and storing data electronically. For quality measurement, NIR rapid seed analyser is suggested to be used, and for more complicated measurements (e.g. rheological parameters), discuss with the cooperating professional breeder.

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What to observe

- **Growth and development**: Monitor the growth stages of wheat, from germination to flowering and seed maturation. Note the timing of each stage and any deviations from expected patterns. Growth form is also essential to be recorded, because an erect plant type would less cover the soil resulting in weaker weed suppression, especially during the early growth stages.
- **Yield measurements**: Record yield data by measuring the weight of harvested grain from a standard plot size. This provides a direct assessment of productivity.
- **Disease and pest resistance**: Keep an eye out for signs of disease or pest infestation. Document the severity and impact on the plants, noting any resistance observed in particular cultivars. Assessing weed suppression-ability is important in wheat, which can be indirectly monitored by measuring soil coverage during early vegetative growth (using Canopeo smartphone app.).
- **Environmental and soil conditions**: Record environmental conditions like rainfall, temperature and any specific soil characteristics. This data helps in understanding how different varieties perform under various conditions.

Data analysis and interpretation

Analysing the collected data helps in identifying the best-performing varieties/populations and understanding their characteristics. Look for trends, correlations and significant differences among the examined genotypes. In PPB, sharing data with other participants, such as fellow farmers, breeders and researchers, is crucial. Collaborative analysis can provide deeper insights and foster collective learning.

Anticipate challenges like inconsistent data recording or environmental variables affecting the data. Address these by standardising procedures and training all involved in the data collection process.

Use the insights gained from data analysis to continuously improve your PPB practices. Adapt your breeding strategies based on what the data tells you about the performance of different wheat cultivars.

The records might contain the following information:

- **Breeding**
  - Date and location of breeding activities.
  - Description of parent varieties used.
  - Methods of selection techniques employed.
  - Environmental conditions during breeding.
  - Any challenges or deviations from the planned process.

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Grant agreement No 771367

- **Plant growth and development monitoring**
  - Weekly or bi-weekly entries detailing plant growth stages.
  - Photographic records for visual tracking.
  - Notes on weather conditions and their potential impact on growth.
  - Observations on plant vigour, disease resistance, weed suppression and other notable traits.
- **Yield and performance record**
  - Sowing and harvest dates (number of cropping days) and yield data (weight of grains harvested).
  - Assessment of grain quality attributes (rapid test and/or laboratory test).
  - Resistance to pests and diseases.
  - Weed suppression assessment
  - Adaptability to specific soil and climatic conditions.

Progressing post-breeding

Successful varieties undergo:

- **Wider field testing:** Testing in different conditions and at various scales to ensure stability and performance.
- **Community engagement:** Sharing seeds and knowledge about new varieties within the farming community for broader benefit.

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Harvesting and seed saving

Harvesting wheat

In Participatory Plant Breeding (PPB) for organic wheat, the final stages of the cycle - harvesting and seed saving - are crucial.

Timing of harvest

Harvest timing is critical in determining the quality and quantity of your wheat yield, practically if the moisture content of the fully matured seeds is below 14% (a hand-held moisture meter is recommended). Before harvest be aware of any possible bunt infestation of the plants (checking for black bunt balls full of spores instead of the seeds in the spikes), which could contaminate all your material at harvest.

Harvesting methods

Depending on the scale of your operation, harvesting can be done manually or with machinery. For small-scale farms:

- **Manual harvesting:** for a small number of plants, collect all the spikes by hand and thresh them afterwards, either individually (line-selection) or into a bulk (mass-selection).
- **Mechanical harvesting:** If available, a combine harvester can be used, especially for larger plots (consult with your co-operating professional breeder).

Threshing and cleaning

Threshing separates the seeds from the hull and other spike residues. This can be done by beating the spikes or bundle of spikes on a foil lying on a flat large surface or using mechanical threshers. After threshing, winnowing helps to clean the seeds by removing chaff and debris.

Seed saving for PPB

Selecting seeds for saving

Choose seeds from the healthiest, most robust plants that best exhibit the desired traits is integral to PPB, as it directs the future course of your breeding programme.

Seed quality and viability

Ensure that the seeds are fully mature and dry before storing. Test a sample for germination rate to assess seed viability. High-quality, viable seeds are critical for successful future planting.

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Seed drying and storage

Dry the seeds thoroughly to prevent mould and store them in a cool, dry and dark place. Use airtight containers to protect them from moisture and pests. Label the containers with the variety name and date of harvest.

Documenting seed information

Maintain detailed records of the seed-saving process, including parent plant characteristics, harvest date and any observations relevant to PPB. This information is invaluable for future breeding efforts.

Legal considerations and seed sharing

Be aware of any legal regulations regarding seed saving and sharing in your region, especially under EU organic agricultural policies. Sharing seeds with other farmers can help spread resilient, locally adapted varieties and foster community resilience.

Challenges in harvesting and seed saving

Address challenges such as variable seed maturity, weather conditions during harvest, and pest infestations during storage. Develop strategies to mitigate these risks, such as staggered planting for a more uniform harvest and secure storage solutions.

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EU organic standards and compliance

Key aspects of EU organic standards

In Participatory Plant Breeding (PPB) for organic wheat, adherence to EU organic standards is essential. Regulation (EU) 848/2018 effective from January 1, 2022, lays down the rules for organic production and labelling, emphasising environmental protection, preservation of natural resources and animal welfare. For organic farmers, it means adhering to specific practices that avoid synthetic chemicals, promote biodiversity and ensure ecological balance.

Prohibition of GMOs

The use of genetically modified organisms (GMOs) is strictly prohibited in organic agriculture. This includes the use of GMO seeds or any GMO-derived inputs in the breeding and cultivation processes.

Use of Organic Seeds

Organic farmers are encouraged to use organic seeds. However, under certain conditions, non-organic seeds may be used (under a derogation) if organic varieties are not available but this will cease in the EU from 2036. This is particularly relevant in PPB, where developing new organic varieties is a core objective.

Organic Heterogeneous Material (OHM) in PPB

Definition and importance

OHM refers to plant reproductive material, such as seeds, not fulfilling the definition of a variety in the conventional sense. OHM is crucial in PPB as it allows for greater genetic diversity and adaptability to local conditions, which are key in organic agriculture. In addition to adapting OHM to the interested farmer's field, OHM could be also used by farmers as the starting material for pure line selection.

Compliance with OHM standards

When using OHM in PPB, it's important to ensure that it complies with organic agriculture standards. This includes maintaining biodiversity, ensuring the material is GMO-free, and adhering to organic cultivation practices.

Record-keeping and traceability

Maintain detailed records of all farming activities, including seed sources, breeding methods and cultivation practices. This traceability is crucial for compliance with EU organic standards and for potential inspections or certification.

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Challenges and solutions

Organic certification can present challenges, especially for small-scale farmers engaged in PPB. Solutions include seeking guidance from local agricultural bodies, joining organic agriculture associations and participating in training programmes on organic standards and compliance.

PPB plays a vital role in advancing organic agriculture in the EU. By developing locally adapted, resilient wheat varieties through organic methods, PPB contributes to the broader goals of sustainability, biodiversity and ecological balance as outlined in the EU organic regulations.

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Sharing and learning

Participatory Plant Breeding (PPB) for organic wheat is not just about developing new varieties; it's also about building a community of knowledge and practice. Sharing success stories and case studies with the farming community. Highlighting achievements and lessons learned can inspire and guide others in their PPB endeavours.

Building a PPB community

Networking with other farmers

Connect with other farmers engaged in PPB and organic farming. This can be done through local agricultural co-operatives, on-line forums, or PPB-focused groups. Sharing experiences and techniques can lead to mutual learning and support.

Collaborating with researchers and breeders

Establish partnerships with agricultural researchers and professional breeders. Their scientific expertise can provide valuable insights into the PPB process and help address complex challenges. Moreover, the professional breeding infrastructure could increase the efficiency and productivity of the PPB work, thus cooperation with breeders and scientists is well suggested.

Forums and social media

Use on-line forums and social media platforms to connect with a broader PPB community. These platforms offer opportunities for sharing experiences, asking questions, and staying informed about the latest developments in organic wheat farming.

Webinars and online training

Attend or host webinars and on-line training sessions focusing on PPB and organic agriculture topics. These digital resources make learning accessible to a wider audience and facilitate the exchange of knowledge across different regions.

Participatory workshops and field days

Organise or participate in workshops and field days where farmers, researchers and breeders come together to share knowledge, demonstrate techniques and discuss advancements in PPB and organic farming practices.

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Conclusion

PPB as a tool in organic wheat breeding is ongoing and continuously developing thanks to several EU research projects in this topic. The continuous learning, adaptation, and innovation inherent in this approach will guide farmers in meeting future challenges.

In conclusion, the empowerment of farmers through PPB is a transformative force in agriculture. It leads to more resilient, sustainable and productive farming systems, benefiting not just the farmers themselves but also their communities and the broader environment. The future of agriculture is bright, with farmers leading the way in creating a more sustainable and food-secure world.

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Appendix

Glossary

A

Agronomy: The science and technology of producing and using plants for food, fuel, fibre, and land reclamation.

B

Biodiversity: The variety of life in the world or in a particular habitat or ecosystem.

Bioactive compounds: Chemical compounds present in small quantities in plants and certain foods that have actions in the body and can promote good health.

D

Decentralised field trials: Agricultural experiments conducted in various locations under different environmental conditions to test the adaptability of plant varieties.

E

Emasculation: As a first step in crossing of self-pollinated species, all anthers have to be removed from the florets of the female parent to ensure the successful pollination with the pollen of the male parent.

EU Regulation 848/2018: The European Union regulation that sets the standards for organic production and labelling, emphasising sustainable practices.

G

Genetic diversity: The total number of genetic characteristics in the genetic makeup of a species. It is important for the survival and adaptability of a species.

Genetic resources: The genetic material of plants, animals, or other organisms that have actual or potential value for breeding, scientific and preservation purposes. In agriculture, this refers to the diversity of genetic material within crop species, including different varieties, which are crucial for breeding programs like PPB.

L

Local adaptation: The process through which plant varieties become better suited to the local environmental conditions in which they are grown.

O

OHM (Organic Heterogeneous Material): Plant reproductive material, such as seeds, that does not conform to the typical definition of a variety but is used in organic farming for its biodiversity and adaptability.

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Grant agreement No 771367

Organic Farming: A farming method that involves growing and nurturing crops without the use of synthetic based fertilisers and pesticides.

P

Participatory Plant Breeding (PPB): A collaborative approach to plant breeding where farmers, researchers and breeders work together to develop varieties suited to specific conditions.

Pest resistance: The inherent ability of a plant variety to resist damage caused by pests.

S

Seed saving: The practice of saving seeds from vegetables, grain, herbs and flowers for use in subsequent years.

T

Threshing: The process of separating edible grain from the chaff, or the inedible parts of the plant.

Y

Yield: The amount of crop produced on a given amount of land.

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Additional Resources: List of resources for further reading and support.

Organic Eprints**.** URL: http://www.orgprints.org/

FAO Plant Breeding and Farmers Participation. URL: https://www.fao.org/3/i1070e/i1070e.pdf

URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018R0848

Willer H, Trávníček J, Meier C, Schlatter B (eds.) (2021) The World of Organic Agriculture. Statistics and Emerging Trends 2021. Research Institute of Organic Agriculture FiBL, Frick, and IFOAM – Organics International, Bonn (v20210301). URL: https://www.fibl.org/fileadmin/documents/shop/1150-organic-world-2021.pdf

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