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Guidebook to Participatory Plant Breeding for organic potato in the Slovenia

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Introduction

This guidebook is designed for farmers, extension services providers and other stakeholders interested in organic agriculture and in participatory plant breeding (PPB) of potato. This guide aims to provide you with insights into the practice of PPB of potato in Slovenia and how it can be effectively implemented in growing of organic potato, in line with EU standards.

Organic farming is a holistic method of farming that prioritises the use of natural resources and processes, avoiding synthetic chemicals and encourages biodiversity. Strict rules that guarantee the preservation of environmental and health standards apply to organic agriculture in the EU.

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What is Participatory Plant Breeding (PPB)?

PPB is an innovative approach to plant breeding that actively involves farmers in the selection and breeding of different plant species. PPB takes place in the field where the crops are grown and ensures that developed varieties are well-suited to the specific pedo–climatic conditions and needs of local farming systems.

Why focus on potato?

Potato used to be one of the most important crops in Slovenian agriculture. In the early 1980s, it was estimated to cover more than 30,000 ha throughout Slovenia, which represented more than 10% of the total area under cultivation. Slovenian varieties were grown on more than 80% of Slovenian fields. Yields were rather low due to less intensive low input cultivation techniques and the use of older Slovenian varieties with low yield potential. After an outbreak of the PVYNTN virus, the variety assortment changed very rapidly within a few years and modern Western European varieties, some of which are suitable for low-input and organic farming, became dominant. Since organic farming became more widespread in Slovenia after 1990, potatoes are grown on many organic farms either for subsistence or as a cash crop, making it a very important crop.

Potato breeding has a long tradition at the Agricultural Institute of Slovenia. Due to high virus and late blight infection pressure, breeding for extreme PVY and late blight resistance was an obvious choice for the new breeding programme started at the Agricultural Institute of Slovenia in 1993. The main focus of the programme is to breed varieties suitable also for low input and organic conditions, adapted to Slovenian growing conditions and customer requirements.

Additional references:

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- Ceccarelli S, Guimarães EP, Weltzien E (2009) Plant breeding and farmer participation. FAO. Rome. pp 671.
- IFOAM (2017) Compatibility breeding techniques in organic systems. Available on https://www.ifoam.bio/compatibility-breeding-techniques-organic-systems
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Potato

Potato is one of the world's most important staple crops, producing more dry matter and protein per hectare than the other major cereal crops. The crop is grown on a significant scale in 130 countries. Today, potatoes are the fourth most important crop in the world after rice, maize and wheat, with a gross production value of US$63.6 billion in 2016. With annual potato production of 368 million tonnes in 2018 and accounting for more than half of the gross production value of root crops, potatoes are the world's most important root crop, followed by cassava, yams, sweet potatoes and taro.

Statistically, Europe remained the second largest potato producing region in the world, with the most important countries in Western Europe being Germany, France, Poland, the Netherlands and the United Kingdom, with average yields between 35 and 40 t/ha, except for Poland with lower yields.

Potato is grown for food, animal feed, industrial uses and seed production, depending on the region, country development, historical reasons, etc. Food production is both for fresh markets and for processing into crisps, chips, tinned potatoes, flakes, etc.

The main use of potatoes is still as direct fresh food, but an increasing proportion is processed as snacks. In developed countries, consumers demand high quality, uniform tubers with a nice skin finish, with additional specific requirements for certain purposes and uses.

Potatoes provide significant amounts of carbohydrates, protein, vitamin C and iron. Their content varies from variety to variety. Carbohydrates, which make up about 75% of the total dry matter, are the main source of energy. An average consumption of 240 g of potatoes per day provides about 5% of the daily energy requirement. It is also an important source of fibre, providing up to 15% of the daily requirement. Estimates of protein content range from 1.6 to 2.1 g per 100 g of fresh weight. Potatoes are a very good source of lysine, with lower concentrations of sulphur-containing amino acids (methionine, cysteine). Vitamin C is the main vitamin found in potatoes, with levels ranging from 15 to 25 mg per 100 g of fresh weight, providing up to 30% of the daily requirement.

Additional references:

- Peter Dolničar (2020) Importance of potato as a crop and practical approaches to potato breeding. In Solanum tuberosum: Methods and Protocols (Dobnik D., Coll A., Ramšak Ž., Gruden K. – eds), Springer
- EU Commission (2018) Organic Farming in the EU. *European Commission.*

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Principles of PPB in Organic Agriculture

Introduction to Participatory Plant Breeding (PPB)

PPB is a cutting-edge method of plant breeding that actively includes farmers in the breeding and selection of various plant species. It has been used routinely in potato breeding in the Netherlands in the past, using farmers as hobby breeders.

Key principles of PPB

- **Genetic diversity**: Genetic diversity is the cornerstone of PPB. It is necessary for new potato varieties to be resistant to some major potato diseases (PVY and late blight) and more tolerant to different abiotic and biotic stressors. For that purpose, breeders need to create more tolerant genotypes capable to overcome the negative effects of high temperature and lack of precipitation.
- **Local adaptation**: Selecting and breeding crops that perform well under local environmental, climatic and soil conditions are of key importance.
- **Farmer involvement**: Farmers play a central role essential to PPB. When choosing varieties that are best suited for their particular local contexts, their understanding of the requirements and conditions in the area is valuable.

Benefits of PPB in organic agriculture

- **Local:** Varieties developed through PPB are often more resilient to local pests, diseases and climatic stresses. Varieties are tailored for specific pedo-climatic conditions.
- **Local/global:** By developing varieties that perform better and meet market demands, PPB can enhance the economic viability of organic farms.
- **Global:** PPB supports the broader goals of organic agriculture, such as biodiversity, soil health and reduced dependence on external inputs.

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Selection and breeding of potato varieties at the KIS in Slovenia

Potato breeding at KIS is a time-consuming process, taking between 10 and 15 years from crossing to approval of a new variety. The breeding process involves several parallel methods of selection, depending on the purpose and objectives of the new variety: selection of parent plants, selection of clones in the field, selection of virus-resistant clones, monitoring and susceptibility testing for *Phytophthora infestans* (which causes potato blight) and *Synchytrium endobioticum* (which causes potato canker), the determination of resistance to yellow and white potato cyst nematodes and, where appropriate, to other pathogens, methods for characterisation of varieties, determination of edible quality and glycoalkaloids in tubers, and methods to speed up and shorten the process of in vitro production of basic seed. Molecular methods for determining resistance using genetic markers are also increasingly used in selection procedure.

A specific feature of the long-term programme of agricultural plant breeding is that all of these stages of selection and selection methods are carried out each year.

Key traits for potato variety selection might include:

- **Yield:** Tuber production.
- **Disease and pest resistance:** Resistance to local biotic stressors.
- **Drought tolerance:** Resilience in local abiotic stressors.
- **Consumption quality:** Canning, baking, french-fry, chips.
- **Nutritional quality:** Level of dry matter, reducing sugars, protein and ascorbic acid.

Choice of the parents

Based on the results of several years of specific variety trials to date, we will select the parent varieties. To this end, we are monitoring their fertility, yield characteristics, morphological characteristics, particularly those of the tubers, their edible quality and their resistance to diseases and pests.

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Crosses and the first year of raising seedlings in a plastic pot

The selected parent varieties will be planted in March using the brick planting method in a plastic pot at IC Jablje. Bricks are placed on the substrate in pots and the tubers are placed on top of them, covered with a layer of soil or sand. When the plants are 30 cm tall, the soil is removed with a water jet. The tubers and stolons are then visible and any new tubers are removed as they emerge. The assimilates are therefore mainly used for the growth and development of the above-ground parts of the plant and the roots. A sufficient supply of assimilates prevents flower and berry drop. Thus, varieties which do not flower in the field because of a lack of assimilates can also be used for crosses. This method results in plants flowering continuously for up to two months.

Crossing is done by first removing the stamens on the newly opened flowers and then manually applying the pollen of the other variety to the pistil furrow. For successful fertilisation, the pollen must be sufficiently vigorous, which is achieved by maturing the stamens properly. If necessary, store the pollen in a refrigerator at 4 °C for up to 2 months. One week after pollination, the success of the pollination can already be determined. The berries ripen by the end of August. After maceration at room temperature, the true seed is extracted from the strawberries, dried and sown the following year.

The seeds are sown in the greenhouse in March and April in sowing boxes. After emergence, the seedlings are mechanically infected with Potato virus Y (PVY) at the cotyledon stage. The suspension is prepared by homogenising infected 'Igor' potato plants. The plant juice is diluted 2 to 5 times and then 12 g of carborundum 400 per 100 ml of diluted juice is added just before use. After one month, the plants will be transplanted into pots and placed in a plastic pot. During the growing season, we will cull the plants susceptible to Y virus several times. In the autumn, we dig up the plants and keep one tuber per plant (genotype), which we plant in the field and start the in-field selection.

Field selection of clones

In the first year of selection, one tuber of each genotype (clone) is planted in the field. In this year, negative selection is carried out during the growing season and all virus-infected plants are eliminated. All plants showing various physiological disturbances are also removed. In July, each plant is dug up separately and a positive selection is made. Four tubers of each genotype are selected and planted the following year after examination in storage to eliminate genotypes with too short dormancy and genotypes susceptible to storage diseases. In the second year, 4 tubers of each genotype are planted and again screened for the traits listed above. In addition to these, we also monitor their maturity and, to some extent, the height of the crop. Select 10 tubers of each genotype and plant them in the third year. The remaining crop is used to assess the edible quality. In storage, genotypes that are too short dormancy, susceptible to disease or have a lower edible quality are again eliminated.

In the third year, the height and structure of the crop, susceptibility to disease, edible quality and storage are tested, and the harvesting is carried out again. All the tubers of 5 plants are dug up and used for planting the following year, the remaining 5 plants are dug up and harvested in the autumn. The harvest is used to determine the edible quality.

In the third year, tubers are also harvested in the field to produce healthy seed sources, which are planted each year in a screenhouse until they are introduced into in vitro conditions in the eighth year.

In the fourth and subsequent years, we select for yield and structure, edible quality and disease susceptibility. From the third year of selection, the genotypes are compared in the field with standard varieties. In the eighth year of selection, promising crosses are planted in a block field micro-trial. This is followed by trials in variety registration micro-trials and DUS trials (abroad).

Potato leaf and tuber blight resistance testing shall be carried out in the field in accordance with the British Mycological Society 1947 Pathology Section guidelines. Exposure of the experimental plantation to natural infection as recommended by the European Association for Potato Research (EAPR) is used. In addition, the fertility of the clones in the selection, their early maturity and other morphological characteristics are monitored. The edible quality is assessed using the method recommended by the European Association for Potato Research (EAPR).

Data collection and analysis

Accurate data collection is crucial. Keep detailed records of planting, growth, and any observations throughout the season (e.g. pest, diseases). Analyse this data to identify the traits and best-performing varieties. Consult with breeders or experts on analysis or tools that can evaluate variety performances.

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Selecting for resistance to pest and diseases

Introduction of genes for resistance to diseases and pests

The following resistance genes were introduced in the potato breeding programme:

Potato virus Y: For resistance to potato virus Y, we use *R* genes from *Solanum stoloniferum* - *Rysto* gene and *Solanum chacoense* - *Rychc* gene. Both genes confer complete resistance to the virus and have been introduced into the modern varieties we use as parents.

Resistance to potato cyst nematodes: Contamination of the soil with yellow and white potato cyst nematodes (*Globodera rostochiensis* and *Globodera pallida*) is a growing problem in Europe. Yellow cyst nematodes have already been found in our country. Several sources of resistance are known, some of which have already been introduced into commercial varieties that can be used in crosses. Resistance to some races of yellow potato cyst nematodes (*Globodera rostochiensis* - races Ro1-Ro5) and white potato cyst nematodes (*Globodera pallida* - races Pa2, Pa3) is being introduced into the programme. The carriers of resistance are already established varieties.

Resistance to potato wart disease: Resistance to potato wart disease (*Synchytrium endobioticum* (Schilberszky) Percival - race D1) is also being introduced from existing varieties.

Potato late blight resistance: The use of *R* genes has therefore emerged as the only possible source of resistance to potato blight. Combining different R genes is essential for resistance to be durable. The following resistance genes from the genus Solanum have been used in the breeding programme in recent years:

- *R* genes from *S. demissum*,
- In recent years, the *R* genes *R8, Rpi-Blb2, Rpi-Smira2/R8, Rpi-chc, Rpi-vnt1.1, Rpi-vnt1.3* from *S. bulbocastanum, S. chacoense, S. phureja* and *S. venturii* have become increasingly important and are being introduced into new heirlooms. These genes are found in Sarpo Mira, Carolus, Alouette and many other newer varieties (we have about 20 in the programme) which are highly resistant to potato blight. We are already using some interesting genotypes in which we have introduced a large number of *R* genes.

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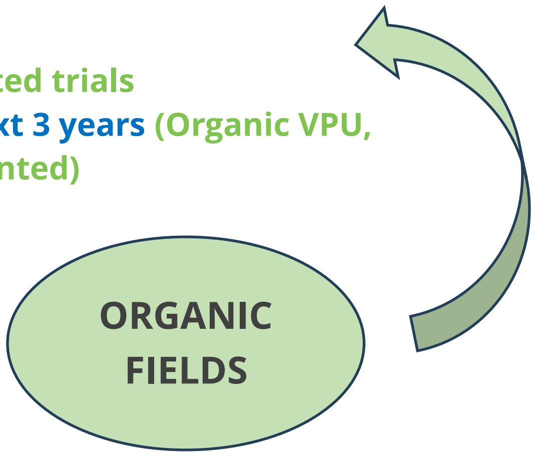
Getting started with organic potato breeding and PPB at KIS

Some basic principles in implementing PPB in organic agriculture

1. Be in line with local environmental conditions and farmer needs.
2. Invite and include farmers into breeding programme.
3. Establish field trials on organic farms.
4. Evaluate material and collect data from farmers prior to selection decisions.

As part of the ECOBREED project, a potato breeding programme for organic farming start at the KIS from 2020.

- the selection of parents
- crossing in the first year
- raising seedlings in greenhouse in the first clonal year
- raising single hill clones on a field in the second clonal year
- **raising 4 hill clones in a third clonal year**
- **selection in subsequent clonal years 4-8**
- **testing of advanced clones in several repeated trials**
- **the registration new organic varieties in next 3 years (Organic VPU, DUS – if the organic testing will be implemented)**
- establishment of nuclear stock
- start of pre-basic organic seed production



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Steps of farmers involvement in ECOBREED: PPB at KIS

- the selection of the parents - KIS
- crossing in the first year - KIS
- **raising seedlings in greenhouse in the first clonal year**
- **raising single hill clones on a field in the second clonal year**
- **raising 4 hill clones in a third clonal year**
- **selection in subsequent clonal years 4-8**
- testing of advanced clones in repeated trials - KIS
- **testing of advanced clones on farms**
- the process of registration new organic varieties in next 3 years - KIS

C: Start of farmers own selection on organic farm

B: Evaluation of clones on KIS organic fields

A: Testing of advanced clones on farm before registration

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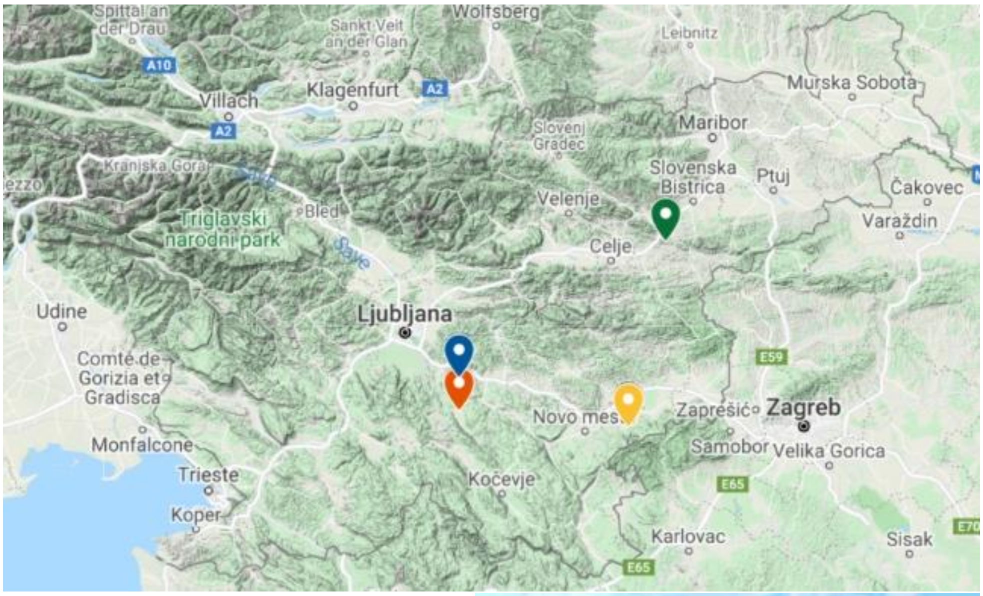
PPB: A - Testing of advanced clones on organic farms

4 farmers evaluate up to 20 advanced clones every year:

- record their observations of plant growth and disease on foliage during the vegetation period;
- after the harvest evaluate tubers characteristics and yield;
- farmers carry out their own consumer quality tests.



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PPB: B - Evaluation of clones on KIS organic fields

4 hill clones and later generations (second to sixth field generation)

Farmers gather at the KIS organic fields and perform evaluation twice a year:

- in June – evaluation of foliage
- in September at harvest – evaluation of tubers and yield

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PPB: C - Starting their own selection on farm

Aleš Marolt, organic farmer from Videm Dobrepolje started with his own selection of clones from LB resistant families provided by KIS.

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Possible outcomes of PPB of potato at KIS

Case A: results of farmers trials are used in the decision making on selection of clones for VCU trials.

In case of registration of new cultivar farmers have benefits in using particular cultivar on their farm.

Case B: the results of farmers evaluations are included in decision making process of selection at KIS every year.

Farmers benefit with access to the knowledge about potato.

Case C: after several years of on farm selection – the best clones will be included in testing of advanced clones in repeated trials at KIS.

In case of registration of new cultivar farmer has a share in the cultivar and PBR.

EU Organic Standards and compliance

Key aspects of EU organic standards

Regulation (EU) 848/2018, active from 1 January 2022, sets out the rules for organic production and labelling, with a focus on environmental protection, conservation of natural resources and animal welfare. PPB programmes are aligned with key aspects of the EU organic standard.

Prohibition of GMOs

The use of genetically modified organisms (GMOs) is strictly prohibited in organic farming. This includes a ban on the use of GMO seeds, or any inputs derived from GMOs in the breeding and cultivation process.

Use of organic seed

Organic farmers are encouraged to use organic seed. However, conventional seeds may be used under certain conditions if organic seeds are not available. Where conventional seeds are used, they must be untreated and accompanied by documentation on their origin and the absence of synthetic pesticides.

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Sharing and learning

In addition to creating new varieties tailored to local production conditions, participatory plant breeding (PPB) for organic potatoes aims to create a community of practice and knowledge-sharing platforms.

Networking with other farmers

Get in touch with other PPB farmers. Through regional agricultural cooperatives, this can be done through online workshops, field days, agricultural/trade fairs or PPB focused groups. Sharing experiences and methods can lead to mutual learning and support.

Working with researchers and breeders

Develop partnerships with other potato breeders and researchers. Their scientific background can help solve challenges and provide insightful information on the PPB process and material for PPB activities.

Social media

Use social media channels to connect with a wider PPB group. These platforms provide a space for sharing experiences and keeping up to date with the latest potato developments.

Webinars, participatory workshops and field days

Participate in or offer online trainings and webinars with a focus on PPB and organic agriculture. These digital platforms encourage knowledge sharing across geographical boundaries and open up learning to a wider audience.

Organise or participate in field days and workshops that bring together farmers, scientists and breeders to exchange ideas and discuss the latest developments in PPB and organic farming.

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Conclusion

PPB is a way to increase farmer participation and engagement in plant breeding programmes. Farmer empowerment through PPB leads to more resilient, sustainable and productive farming systems adapted to local pedo-climatic conditions, benefiting not only the farmers themselves but also other stakeholders in the potato supply chain. PPB principles have been successfully introduced into the organic potato breeding programme at KIS in Slovenia, where farmers are involved at various stages of the selection and decision-making process.

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
- Organics at a glance URL: https://agriculture.ec.europa.eu/farming/organic-farming/organics-glance_en
- 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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