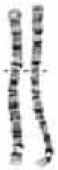
Potato and biotechnology

***In vitro* conservation, molecular markers and recombinant DNA technologies are creating new opportunities in potato production and transformation**

Key points

- The potato industry has benefited from major recent discoveries about the plant's genetics, physiology and pathology.
- Micropropagation is helping developing countries produce low-cost, disease-free tuber "seed" and increase potato yields.
- Use of molecular markers helps identify desirable traits in potato collections, thus simplifying the development of improved varieties.
- Sequencing of the complete potato genome, now under way, will significantly increase knowledge and understanding of genetic interactions and functional traits.
- Genetically modified varieties have the potential to produce more stable yields, improve nutritional quality and facilitate non-food industrial uses, but must be carefully assessed before release.

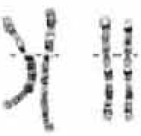
New molecular biology and plant cell culture tools have enabled scientists to understand better how potato plants reproduce, grow and yield their tubers, how they interact with pests and diseases, and how they cope with environmental stresses. Those advances have unlocked new opportunities for the potato industry by boosting potato yields, improving the tuber's nutritional value, and opening the way to a variety of non-food uses of potato starch, such as the production of plastic polymers.

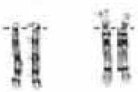


Producing high-quality propagation material

Unlike other major field crops, potatoes are vegetatively reproduced as clones, ensuring stable, "true-to-type" propagation. However, tubers taken from diseased plants also transmit the disease to their progenies. To avoid that, potato tuber "seed" needs to be produced under strict disease control conditions, which adds to the cost of propagation material and therefore limits its availability to farmers in developing countries.

Micropropagation or propagation *in vitro* offers a low-cost solution to the problem of pathogens in seed potato. Plantlets can be multiplied an unlimited number of times, by cutting them into single-node pieces and cultivating the cuttings. The plantlets can either be induced to produce small tubers directly within containers or transplanted to the field, where they grow and yield low-cost, disease-free tuber "seed". This technique is very popular and routinely used commercially in a number of developing and transition countries.* For example, in Viet Nam micropropagation directly managed by farmers contributed to the doubling of potato yields in a few years.





Protecting and exploring potato diversity

The potato has the richest genetic diversity of any cultivated plant. Potato genetic resources in the South American Andes include wild relatives, native cultivated species, local farmer-developed varieties, and hybrids of cultivated and wild plants. They contain a wealth of valuable traits, such as resistance to pests and diseases, nutrition value, taste and adaptation to extreme climatic conditions. Continuous efforts are being made to collect, characterize and conserve them in gene banks, and some of their traits have been transferred to commercial potato lines through cross-breeding.

To protect collections of potato varieties and wild and cultivated relatives from possible diseases and pest outbreaks, scientists use a variation of micropropagation techniques to maintain potato samples *in vitro*, under sterile conditions. Accessions are intensively studied using molecular markers, the identifiable DNA sequences found at specific chromosomal locations on the genome and transmitted by the standard laws of inheritance.

Obtaining improved varieties

Potato genetics and inheritance are complex, and developing improved

* Source: FAO-BioDeC database on biotechnologies in developing countries www.fao.org/biotech/inventory_admin/dep/default.asp

varieties through conventional cross breeding is difficult and time consuming. Molecular-marker based screening and other molecular techniques are now widely used to enhance and expand the traditional approaches to potato in food production. Molecular markers for characteristics of interest help identify desired traits and simplify the selection of improved varieties. Such techniques are currently applied in a number of developing and transition countries, and commercial varieties are expected to be released within the next few years.

Through the Potato Genome Sequencing Consortium, significant progress is being made in mapping the complete DNA sequence of the potato genome, which will enhance our knowledge of the plant's genes and proteins, and of their functional traits. Technical advances in the fields of structural and functional potato genomics – and the ability to integrate genes of interest into the potato genome – have expanded the possibility of genetic transformation of the potato using recombinant DNA technologies. Transgenic varieties with resistance to Colorado Potato Beetle and viral diseases were released for commercial production in the early 1990s in Canada and the USA, and more commercial releases can be expected in the future.

Transgenic potato varieties offer the possibility of increasing potato productivity and production, as well as creating new opportunities for non-food industrial use. However, all biosafety and food safety aspects must be carefully assessed and addressed before their release.

Glossary

cell culture – *in vitro* growth of cells isolated from multi-cellular organisms;

functional genomics – research aimed at determining patterns of gene expression and interaction in the genome;

genome – the entire complement of genetic material present in each cell of an organism;

genome sequencing – process of determining the exact order of chemical building blocks that make up the DNA of an organism;

genetically modified – transformed by the insertion of one or more transgenes;

in vitro – in an artificial environment (e.g. cells, tissues or organs cultured in glass or plastic containers);

micropropagation – miniaturized *in vitro* multiplication or regeneration of plant material under aseptic and controlled environmental conditions;

molecular biology – study of living processes at molecular level;

molecular marker – a genetic marker that is assayed at the DNA level;

trait – one of the many characteristics that define an organism;

transgene – an isolated gene sequence – often derived from a different species – used to transform an organism.

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Production of disease-free seed tubers

A simple, low-cost technology can help developing countries produce the healthy seed tubers farmers need for sustainable potato production

Key Points

- Potato diseases can dramatically reduce both tuber yields and quality.
- Tissue culture of plantlets *in vitro* for production of disease-free seed tuber requires expensive technology and highly trained staff.
- A low cost alternative is the use of cuttings - a single-node, leaf-bud or other type of very small plant cutting - for propagation of plantlets under non-sterile conditions.
- The cuttings root easily and produce plantlets as efficiently as *in vitro* propagation – each cutting can yield up to 100,000 progeny within six months.

Tissue culture and micropropagation

Elementary methods of tissue culture were developed in the 1950s, and micropropagation has been used commercially for multiplying stock plant material since the late 1960s.

The annual volume of plants micropropagated from tissue culture is estimated at hundreds of millions of plants, representing tens of thousands of varieties.

Commonly micropropagated plants include flowers, strawberry, ornamental shrubs and forestry trees.

Potatoes are susceptible to a variety of diseases that lower yields and tuber quality. What's more, pathogens accumulate in successive clonings of tubers and in the soil used to grow them. That is why sustainable potato production depends on a constantly renewed supply of disease-free planting material.

A major innovation for the potato industry in developed countries was the widespread adoption in the 1970s of tissue culture – or micropropagation - as a means of multiplying disease-free plants that can then be used to produce healthy seed tubers for farmers. First, viruses and other pathogens are eliminated by growing potato plants in a controlled environment at high temperature. The disease-free shoot tips of the plants are then placed on a standard nutrient medium in glass containers (*in vitro*) in a completely sterile laboratory environment. The tips develop into plantlets that are then transferred to either a greenhouse or a field protected from insect pests, where they grow at the same rate as normal potato plants but produce smaller tubers (called "mini-tubers").

After harvesting, mini-tubers need to be stored at low temperature. After about 45 days – and for a period of up to seven months thereafter – they can be moved to a warmer environment to induce sprouting. Once planted, they go on to produce normal-size, disease-free seed tubers ready for delivery to farmers. (While growing, the plants need to be protected from insect pests to avoid new disease infections.)

A low-cost alternative: small cuttings

While the above process does deliver healthy seed tubers, micropropagation of plantlets is costly, requiring sophisticated technology and well-trained staff. In many developing countries, simpler and less expensive ways of propagation are needed. FAO is promoting a promising, low-cost alternative: the use of very small cuttings, i.e. a single-node, leaf-bud or other type of plant cutting of about 1.5 cm, which can be grown to produce plantlets on a commercial scale.

Multiplication *in vivo* (at right) produces disease-free potato plantlets at the same rate as *in vitro* propagation (at left), at a fraction of the cost. Photo: T. Haapala

The starter plant material remains a small number of disease-free micropropagated plantlets, which, in regions such as sub-Saharan Africa, are often imported from developed countries. However, they are multiplied not *in vitro* but *in vivo* (i.e. in non-sterile, natural conditions). Cuttings are propagated in a growing room or a shaded greenhouse in a mixture of peat and sand (or other rooting media) in plastic trays placed on metal stands.

The cutting technique takes advantage of etiolation – i.e. growing the plantlets under low light intensity. Etiolated plants retain their juvenile characteristics, producing new shoots for further cuttings that root easily. In addition, the plants remain small, so many can be grown in a limited space

- each tray can hold up to 500 cuttings per square metre. The cuttings grow into new plantlets within three weeks, providing a source for further cuttings. Within six months, a single cutting can yield up to 100 000 progeny.

Once the plant material is multiplied to the quantity needed, plantlets can be transferred to an environment free of insect pests (in a greenhouse or an open field under shade). Planted in deep soil, the plantlets root easily within a week, grow into perfectly normal potato plants and produce mini-tubers.

The technique produces plantlets at the same rate as *in vitro* propagation at a fraction of the cost. However, it is essential that the disease-free starting plant material is kept *in vitro* and all standard phytosanitary measures are followed throughout the propagation process.

The importance of timing

Potato plantlets in a greenhouse, soon to be planted outdoors. Photo: CIP

The cutting technique is suited to developing countries that need simpler and less expensive ways of propagating seed tubers. However, producing good quality starter planting material is only one element in the process of potato seed tuber production. Seed supply schemes can fail because propagation from cuttings and storage of mini-tubers is not coordinated with farmers' cropping calendars. Unless the field and storage phases are well planned and implemented, the benefits of micropropagation may be lost.

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Potato and water resources

Agriculture faces a double challenge: to grow enough food for the world's expanding population while reducing its share of the Earth's freshwater resources. The potato can help...

Key Points

- Agriculture must significantly improve its volume of production per unit of water used.
- The potato produces more food per unit of water than any other major crop.
- From the same amount of water, the potato produces more dietary energy than rice, wheat and maize.
- Tailoring the timing and depth of water applications to specific stages of the potato's growth cycle can help reduce water usage.

To reduce potato's water needs, scientists are developing varieties that are drought-resistant with longer root systems. Drawing: CIP

Over the past century, human appropriation of fresh water has expanded at more than twice the rate of population increase. An estimated 3 830 cubic km (or 3 830 trillion litres) of water are now withdrawn for human use each year, with the lion's share – some 70 percent – being taken by the agricultural sector.

An irrigated potato field in Cape Verde.
Photo: ©FAO/Marzio Marzot

But agriculture's thirst is not sustainable in the long term. Facing intense competition from urban and industrial users, and mounting evidence that human use of water is jeopardizing the efficiency of the Earth's ecosystems, the sector must significantly improve the volume of production per unit of water used.

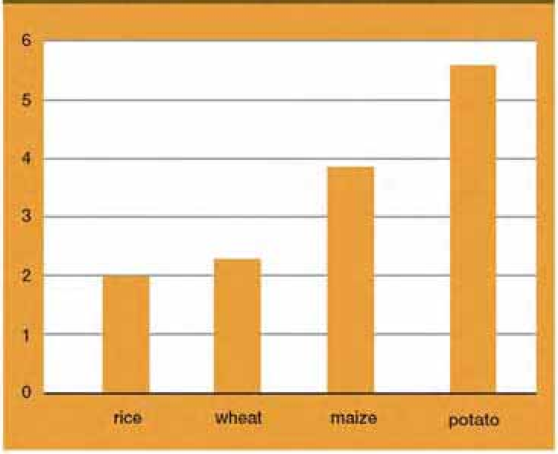
Nutritional productivity

The potato stands out for its productive water use, yielding more food per unit of water than any other major crop. Along with groundnut, onion and carrots, its "nutritional productivity" is especially high: for every cubic metre of water applied in cultivation, the potato produces 5 600 calories of dietary energy, compared to 3 860 in maize, 2 300 in wheat and just 2 000 in rice. For the same cubic metre, the potato yields 150 g of protein, double that of wheat and maize, and 540 mg of calcium, double that of wheat and four times that of rice.

An increase in the proportion of potato in the diet would alleviate pressure on water resources. Currently, producing the foods – especially animal products – consumed in the average diet in the developed world requires water withdrawals estimated at 4 000 litres per capita per day (it takes, for example, around 13 000 to 15 000 litres of water to produce 1 kg of grain-fed beef). But one recent study estimated that a balanced diet based on potato, groundnut, onion and carrot would require per capita water consumption of just 1 000 litres per day.

While a potato-based diet is impractical – 4 kg would be needed to cover per capita daily energy and protein requirements – increased consumption of processed potato products and extraction of potato's nutrients offer a water-efficient means of meeting nutritional needs.

Calories produced per litre of water



Potato's water requirements

Modern potato varieties are sensitive to soil water deficits and need frequent, shallow irrigation. A 120 to 150 day potato crop consumes from 500 to 700 mm of water, and depletion of more than 50 percent of the total available soil water during the growing period results in lower yields.

To reduce potato's water needs, scientists are developing varieties that are drought-resistant with longer root systems. But significant water savings can be made in cultivation of today's commercial varieties by tailoring the timing and depth of water applications to specific stages of the plant's growth cycle.

In general, water deficits in the middle to late part of the growing period – during stolonization and tuber initiation and bulking – tend to reduce yield, while the crop is less sensitive during early vegetative growth. Water savings can also be achieved by allowing higher depletion toward the ripening period so that the crop uses all available water stored in the root zone, a practice that may also hasten maturity and increase dry matter content.

Some varieties respond better to irrigation in the earlier part of tuber bulking, while others show a better response in the latter part. Varieties with few tubers are usually less sensitive to water deficit than those with many tubers.

While soil should be maintained at a relatively high moisture content to maximize yield, frequent irrigation with relatively cold water may reduce the soil temperature below the optimum value for tuber formation (15 to 18°C), thus affecting yields. Also, wet and heavy soils can create soil aeration problems.

The most common irrigation methods for potato use furrow or sprinkler systems. Furrow irrigation has relatively low water use efficiency and is suitable when water supply is ample. In

For every unit of water, the potato produces twice as much protein as wheat and maize. Photo: ©FAO/Giulio Napolitano

areas with water scarcity, sprinkler or drip irrigation is preferred, especially on soils with low water retention capacity.

Tuber quality and yield

Water supply and scheduling have important impacts on tuber quality – frequent irrigation reduces the occurrence of tuber malformation. Water deficit in the early phase of yield formation increases the occurrence of spindled tubers (more noticeable in oval than in round tuber varieties) and, when followed by irrigation, may result in tuber cracking or tubers with "black hearts".

Using good agricultural practices, including irrigation when necessary, a crop of about 120 days in temperate and subtropical climates can yield 25 to 40 tonnes of fresh tubers per hectare.

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Potato pest and disease management

Combating pests and diseases with intensive use of insecticides and fungicides often does more harm than good. An array of alternatives is available...

Key points

- Intensive potato cultivation tends to increase pest and disease pressure, which often leads to intensive use of harmful pesticides.
- Resistant potato varieties and improved cultural practices can reduce or eliminate many common pests and diseases.
- Integrated pest management has helped farmers drastically reduce the need for chemical controls while increasing production.

The use of chemical pesticides on potato is increasing in developing countries, as farmers intensify production and expand cultivation into areas and planting seasons beyond the crop's traditional range. The chemicals used are frequently highly toxic and applied with little or no protective equipment.

The result is alarming levels of pesticide poisoning in farming communities. Insecticide absorbed by soil often penetrates subsequent crops and runs off to contaminate water supplies. Overuse of pesticides even compounds pest and disease problems: in Colombia, outbreaks of a viral disease have been linked to insecticides that wiped out natural predators of the disease's vector.

Increasing potato production while protecting producers, consumers and the environment requires a holistic crop protection approach encompassing a range of strategies – encouraging natural pest predators, breeding varieties with pest/disease resistance, planting certified seed potatoes, growing tubers in rotation with other crops, and organic composting to improve soil quality.

Photo: © FAO

Ecuador: training reduces pesticide poisoning

In Ecuador's Carchi province, a programme supported by CIP and FAO used Farmer Field Schools to drastically reduce high rates of pesticide poisoning. Continuous cropping of potato had produced not only high yields, but highly favourable conditions for insects and fungal diseases, leading to massive applications of insecticides and fungicides. As a result of pesticide exposure, CIP scientists say, 60 percent of people in the area showed reduced neuro-behavioural functions. IPM training enabled farmers to reduce agrochemical application costs – including fertilizer, pesticide and labour costs - by an average of 75 percent with no effect on productivity. Follow-up studies show that the reduced exposure to pesticides was associated with recovery of previously suppressed nervous system functions.

There is no effective chemical control, for example, against bacterial wilt. But planting healthy seed in clean soil, using

Some of potato's main enemies

Diseases

Late blight: the most serious potato disease worldwide, is caused by a water mould, *Phytophthora infestans*, that destroys leaves, stems and tubers.

Bacterial wilt: caused by the bacterial pathogen, leads to severe losses in tropical, subtropical and temperate regions.

Potato blackleg: a bacterial infection, causes tubers to rot in the ground and in storage.

Viruses: disseminated in tubers, can cut yields by 50 percent.

Pests

Colorado potato beetle *(Leptinotarsa decemlineata)*: a serious pest with strong resistance to insecticides.

Potato tuber moth: most commonly Phthorimaea operculella, is the most damaging pest of planted and stored potatoes in warm, dry areas.

Leafminer fly *(Liriomyza huidobrensis)*: A South American native common in areas where insecticides are used intensively.

Cyst nematodes *(Globodera pallida and G. rostochiensis)*: serious soil pests in temperate regions, the Andes and other highland areas.

tolerant varieties in rotation with non-susceptible crops, and other sanitation and cultivation practices can lead to significant reduction of the disease. Incidence of potato tuber moth can also be reduced by preventing soil cracking that allows moths to reach the tubers.

Both the International Potato Center (CIP) and FAO advocate Integrated Pest Management (IPM) as the preferred pest control strategy during production. IPM aims at maintaining pest populations at acceptable levels and keeping pesticides and other interventions to levels that are economically justified and safe for human health and the environment.

FAO has promoted IPM in many developing countries using Farmer Field Schools, which centre around a "living laboratory" where farmers are trained to identify insects and diseases and compare results on two subplots – one using conventional chemical pest control and the other using IPM. On the improved management plot, participants strive to improve ecosystem health by cutting pesticide use while increasing productivity through management intensification. Farmers experiment with a variety of techniques, such as weevil traps, different strains of potatoes and targeted applications of lower toxicity pesticides.

In Peru's Cañete River valley, CIP entomologists designed an IPM package to help growers protect their crops against the leafminer fly, which had become a major problem after massive use of insecticides exterminated its natural enemies. The IPM programme included traps to lure and kill adult flies and reintroduction to the valley of parasitic wasps. Participating growers were able to reduce spraying from 12 times per season to only one or two carefully timed applications of insect growth regulators.

Virus control

Because virus-infected potato plants cannot be cured, CIP is working to incorporate into new varieties resistance to the three most common potato viruses. Some virus resistance is now available in about a quarter of CIP-bred genotypes.

Beating late blight

The mould responsible for late blight has consistently overcome resistant cultivars and mutated into strains that survive spraying with powerful fungicides. The Global Initiative on Late Blight, a network of scientists, technologists and agricultural knowledge agents in 72 countries, is exploring new control strategies, including "organic management" using improved sanitation in storage, risk forecasting and genetic resistance.

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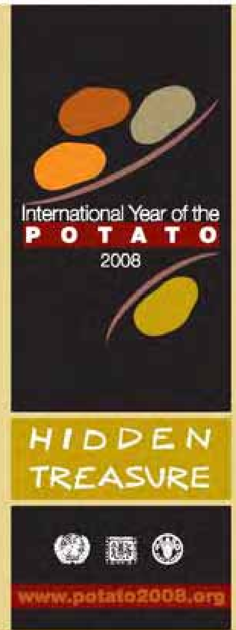

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Potato and soil conservation

Mulch planting and the "no-till" potato can help reduce the soil degradation, erosion and nitrate pollution often associated with potato production

Key Points

- Land preparation, weeding and harvesting of potato often involve intensive soil disturbance.
- Cover crops sown before planting and as the crop matures protect the soil and facilitate harvesting.
- Cultivation of potato without tillage helps restore soil, produces good yields and reduces the need for fertilizer and fuel.

Potato cultivation usually involves intensive soil tillage throughout the cropping period, which often leads to soil degradation, erosion and leaching of nitrates. During soil preparation, the entire topsoil is loosened and - particularly on sticky soils - pulverized into small aggregates to avoid the formation of clods in the potato beds. Mechanical weeding and mechanized harvesting also involve intensive soil movement. Conservation agriculture – a resource-saving crop production system – offers several useful techniques for soil conservation in potato production.

Mulch planting for potatoes

In conventional, tillage-based potato cropping systems, the risk of soil erosion and nitrate leaching can be reduced using the mulch planting technique. The potato beds are prepared well in advance of planting - if potato is to be planted in spring, the beds would be prepared before winter – and seeded with a green manure cover crop. The potato is later planted into the beds which, by then, are covered by the dead mulch of the manure crop.

For mechanical planting, planters are equipped with special discs that cut through the mulch and split the potato beds. The mulch protects the soil from erosion during the first weeks of the crop. As the potato plants grow, the reshaping of the beds incorporates the mulch. A second green manure crop can be seeded towards the end of the potato crop, as the potato plants are drying off. The cover crop helps to dry out the potato beds, contributing to healthier tubers with reduced risk of damage during harvest. The green manure is separated from the potato by a mechanical potato harvester and is left as a mulch cover after harvest, protecting the soil from erosion.

Mulch planting is being used for potatoes in parts of Germany and Switzerland, particularly in watersheds where drinking water sources might be prone to nitrate pollution from conventional cultivation methods. Nevertheless, while mulch planting of potatoes reduces the risk of erosion and nitrate leaching, it still involves major soil movement.

The 'no-till potato'

Soil conservation can be enhanced further using a basic CA technique, "no-till" cultivation. The "no-till" potato is pressed into the soil surface, then covered with a thick layer of mulch - preferably straw, which is fairly stable and does not rot quickly. (Potatoes need to be kept in the dark to avoid the formation of chlorophyll, which renders the tubers green, bitter and toxic.)

The advantages of conservation agriculture

Conservation agriculture (CA) aims at enhancing natural biological processes both above and below ground. It is based on three principles: minimum mechanical soil disturbance, permanent organic soil cover, and diversified crop rotations for annual crops and plant associations for perennial crops. By minimizing soil disturbance, CA creates a vertical macro-pore structure in the soil, which facilitates the infiltration of excess rainwater into the subsoil, improves the aeration of deeper soil layers, and facilitates root penetration.

In some cases - for example in dry areas under drip irrigation - black plastic sheets can also be used as mulch. Holes are punched in the plastic to allow the potato plant to grow through it. The young potato tubers form under the mulch but above the soil surface. During harvesting, the sheets are removed and the potatoes are simply "collected". Currently, the "no-till" potato is only grown in small fields using manual labour - for example, in Peru under plastic covers and in the Democratic People's Republic of Korea under rice straw.

No-till potato in the Democratic People's Republic of Korea

Farmers in the Democratic People's Republic of Korea are using conservation agriculture in rice and potato production in order to restore degraded soils and achieve good potato yields with reduced need for fertilizer and fuel. The potato-rice crop rotation system produces two crops in a relatively short growing season, resulting in higher overall food production when compared to output from a single main crop. The seed potato is inserted into the soil under a mulch cover formed by the residues of the preceding rice crop. The potatoes grow through the rice straw and are harvested within three months. Immediately afterward, "no-till" rice is transplanted as the main summer crop. Per hectare, the system can produce 25 tonnes of potatoes and 7.5 tonnes of rice. and in cold storage and transport infrastructure.

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