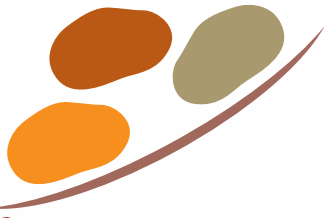


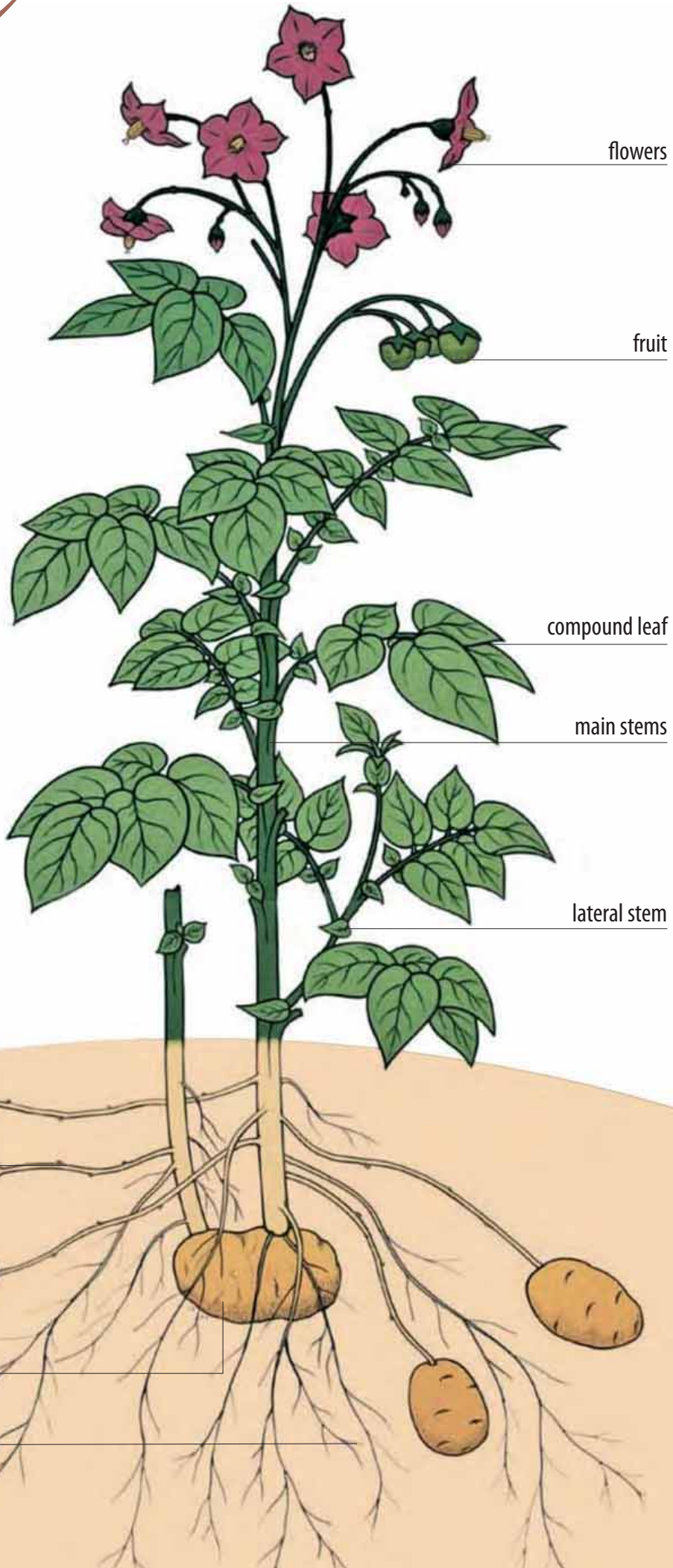
The potato

*Introducing our special guest,
Solanum tuberosum, the “humble tuber”
that spread from its Andean birthplace
across six continents, staving off hunger,
fuelling economic development
and changing the course of world history*





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CIP

The plant

The potato (*Solanum tuberosum*) is a herbaceous annual that grows up to 100 cm tall and produces a tuber – also called potato – so rich in starch that it ranks as the world’s fourth most important food crop, after maize, wheat and rice. The potato belongs to the Solanaceae – or “nightshade” – family of flowering plants, and shares the genus *Solanum* with at least 1000 other species, including tomato and eggplant. Recent research indicates that *S. tuberosum* is divided into two, only slightly different, cultivar groups: Andigenum, which is adapted to short day conditions and is mainly grown in the Andes, and Chilotanum, the potato now cultivated around the world. Also known as the “European” potato, the Chilotanum group is believed to have developed from Andean cultivars introduced first into Chile and from there, during the 19th century, into Europe.

The tuber

As the potato plant grows, its compound leaves manufacture starch that is transferred to the ends of its underground stems (or stolons). The stems thicken to form a few or as many as 20 tubers close to the soil surface. The number of tubers that actually reach maturity depends on available moisture and soil nutrients. Tubers may vary in shape and size, and normally weigh up to 300 g each.

At the end of the growing season, the plant’s leaves and stems die down to the soil level and its new tubers detach from their stolons. The tubers then serve as a nutrient store that allows the plant to survive the cold, and later regrow and reproduce. Each tuber has from two to as many as 10 buds (or “eyes”), arranged in a spiral pattern around its surface. The buds generate shoots which grow into new plants when conditions become favourable once more.

A raw potato tuber is rich in micro-nutrients – the vitamins and minerals that

Chemical composition of the potato tuber

water 72-75%

starch 16-20%

protein 2-2.5%

fibre 1-1.8%

fatty acids 0.15%





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are essential to health. A medium-size potato contains high levels of potassium and nearly half the daily adult requirement of vitamin C. It is also a good source of B vitamins, and minerals such as phosphorus and magnesium.



Micronutrients

(one raw potato, including skin, 213 g)

Minerals

potassium	897 mg
phosphorus	121 mg
magnesium	49 mg
iron	1.66 mg

Vitamins

vitamin C	42 mg
niacin	2.2 mg
vitamin B6	0.62 mg
thiamine	0.17 mg

Source: United States National Nutrient Database

Andean heritage

The story of the potato begins about 8 000 years ago near Lake Titicaca, which sits at 3 800 m above sea level in the Andes mountain range of South America, on the border between Bolivia and Peru. There, research indicates, communities of hunters and gatherers who had first entered the South American continent at least 7 000 years before, began domesticating wild potato plants that grew around the lake in abundance.

Some 200 species of wild potatoes are found in the Americas. But it was in the Central Andes that farmers succeeded in selecting and improving the first of what was to become, over the following millennia, a staggering range of tuber crops. In fact, what we know as “the potato” (*Solanum* species *tuberosum*) contains just a fragment of the genetic diversity found in the four recognized potato species and 5 000 potato varieties still grown in the Andes.

Although Andean farmers cultivated many food crops – including tomatoes, beans and maize – their potato varieties proved particularly suited to the *quechua* or “valley” zone, which extends at altitudes of from 3 100 to 3 500 m along the slopes of the Central Andes (among Andean peoples, the *quechua* was known as the zone of “civilization”). But farmers also developed a frost-resistant potato species that survives on the alpine tundra of the puna zone at 4 300 m.

The food security provided by maize and potato – consolidated by the development of



*Lake Titicaca,
a centre of Andean
civilization*

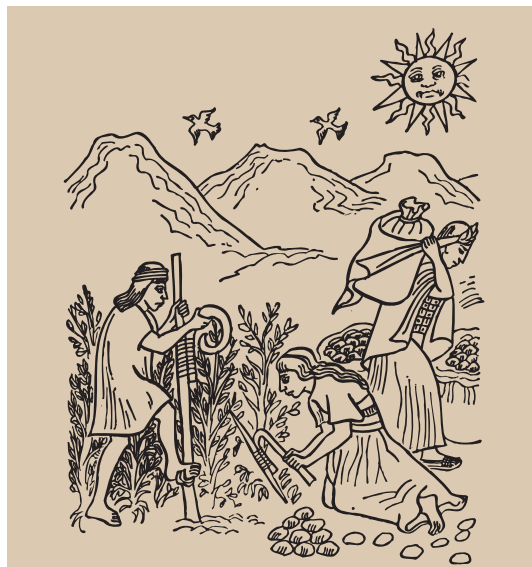
irrigation and terracing – allowed for the emergence around 500 AD of the Huari civilization in the highland Ayacucho basin. Around the same time, the city state of Tiahuanacu rose near Lake Titicaca, thanks largely to its sophisticated “raised field” technology – elevated soil beds lined with water canals – which produced potato yields estimated at 10 tonnes per hectare. At its height, around 800 AD, Tiahuanacu and neighbouring valleys are believed to have sustained a population of 500 000 or more.

Meteoric rise. The collapse of Huari and Tiahuanacu between 1000 and 1200 led to a period of turmoil that ended with the meteoric rise of the Incas in the Cusco valley around 1400. In less than 100 years, they created the largest state in pre-Columbian America, extending from present-day Argentina to Colombia.

The Incas adopted and improved the agricultural advances of previous highland cultures, and gave special

importance to maize production. But the potato was fundamental to the food security of their empire: in the Incas’ vast network of state storehouses, potato – especially a freeze-dried potato product called *chuño* – was one of the main food items, used to feed officials, soldiers and corvée labourers, and as an emergency stock after crop failures.

The Spanish invasion, in 1532, brought an end to the Incas – but not to the cultivation of potatoes. For, throughout Andean history, the potato – in all its forms – was profoundly a “people’s food”, playing a central role the Andean vision of the world (time, for example, was measured by how long it took to cook a pot of potatoes).



The dawn of agriculture

Incan myths relate that the Creator, Viracocha, caused the sun, moon and stars to emerge from Lake Titicaca. He also created agriculture when he sent his two sons to the human realm to study and classify the plants that grew there. They taught the people to sow crops and how to use them so that they would never lack food.

Farmers in some parts of the high Andes still measure land in *topo*, the area a family needs to grow their potato supply – a *topo* is larger at higher altitudes, where plots need to lie fallow for longer. They classify potatoes not only by species and variety, but by the ecological niche where the tubers grow best, and it is not unusual to find four species cultivated on a single, small plot of land.

Planting tubers remains the most important activity of the farming year near Lake Titicaca, where the potato is known as *Mama Jatha*, or mother of growth. The potato remains the seed of Andean society.



"The potato eaters" (1885)
by Vincent Van Gogh

Diffusion

The diffusion of the potato from the Andes to the rest of the globe reads like an adventure story, but it began with a tragedy. The Spanish conquest of Peru between 1532 and 1572 destroyed the Inca civilization and caused the deaths – from war, disease and despair – of at least half the population.

The conquistadores came in search of gold, but the real treasure they took back to Europe was *Solanum tuberosum*. The first evidence of potato growing in Europe dates from 1565, on Spain's Canary Islands. By 1573, the potato was known to be cultivated on the Spanish mainland. Soon after, tubers were being sent around Europe as exotic gifts – from the Spanish court to the Pope in Rome; from Rome to the papal ambassador in Mons; and from there to a botanist in Vienna. Potatoes were grown in London in 1597 and reached France and the Netherlands soon after.

But once the plant had been added to botanical gardens and herbalists' encyclopaedias, interest waned. European aristocracy admired its flowers, but the tubers were considered fit only for pigs and the destitute. Superstitious peasants believed the

potato was poisonous. At the same time, however, Europe's "Age of Discovery" had begun, and among the first to appreciate potatoes as food were sailors who took tubers to consume on ocean voyages. That is how the potato reached India, China and Japan early in the 17th century.

The potato also received an unusually warm welcome in Ireland, where it proved suited to the cool air and moist soils. Irish immigrants took the tuber – and the name, "Irish potato" – to North America in the early 1700s.

Long summer days. The widespread adoption of the potato as a food crop in the northern hemisphere was delayed not only by entrenched eating habits, but by the challenge of adapting a plant grown for millennia in the Andes to the temperate climate of the north. Only a drop of the rich potato gene pool had left South America, and it took 150 years before varieties suited to long summer days began to appear.

Those varieties arrived at a crucial time. In the 1770s, much of continental Europe was devastated by famines, and the potato's value as a food security crop was suddenly recognized. Frederick the Great of Prussia ordered his subjects to grow potatoes as

insurance against cereal crop failure, while the French scientist Parmentier succeeded in having the potato declared “edible” (around the same time, on the other side of the Atlantic, the President of the United States, Thomas Jefferson, served French fries to White House guests).

After initial hesitation, European farmers – even those in Russia, where the potato was called the “devil’s apple” – began growing potatoes on a large scale. The potato became Europe’s food reserve during the Napoleonic wars, and by 1815 it had become a staple crop across northern Europe. By then, the Industrial Revolution was transforming agrarian society in the United Kingdom, displacing millions of rural people into crowded cities. In the new urban environment, the potato became the first modern “convenience food” – energy-rich, nutritious, easy to grow on small plots, cheap to purchase, and ready to cook without expensive processing.

Increased potato consumption during the 19th century is credited with helping to reduce the scourge of diseases such as scurvy and measles, contributing to higher birth rates and the population explosion in Europe, the United States and the British Empire.

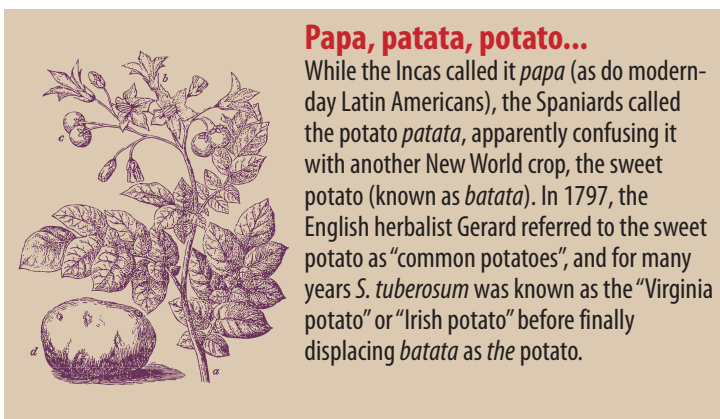
“Potato famine”. But the potato’s success proved a double-edged sword. For the tubers that were being cloned and cultivated across North America and Europe belonged to a few, genetically similar varieties. That meant they were highly vulnerable: a pest or disease that struck one plant could spread quickly to the rest.

The first sign of impending disaster came in 1844-1845, when a mould disease, late blight, ravaged potato fields across continental Europe, from Belgium to Russia. But the worst came to Ireland, where potato supplied 80 percent of calorie intake. Between 1845 and 1848, late blight destroyed three potato crops, leading to famines that caused the deaths of one million people.

The Irish catastrophe led to concerted efforts to develop more productive and disease-resistant varieties. Breeders in Europe and North America, drawing on new potato germplasm from Chile, produced many of the modern varieties that laid the foundation for massive potato production in both regions for most of the 20th century.

Meanwhile, European colonialism and emigration were taking the potato to all corners of the globe. Colonial governors, missionaries and settlers introduced potato growing to the floodplains of Bengal and Egypt’s Nile delta, the Atlas Mountains of Morocco, and the Jos plateau in Nigeria. Emigrant farmers took the potato to Australia and even to South America, establishing the potato in Argentina and Brazil.

In the Asian heartland, the tuber moved along more ancient routes, finding its way from the Caucasus to Turkey’s Anatolian





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plateau, from Russia to western China, and from China to the Korean Peninsula. In the mountain valleys of Tajikistan, some potato types have been grown long enough to be considered “old local varieties”.

The 20th century saw the potato finally emerge as a truly global food. The Soviet Union’s annual potato harvest reached 100 million tonnes. In the years following the Second World War, huge areas of arable land in Germany and Britain were dedicated to the potato, and countries like Belarus and Poland produced – and still do – more potatoes than cereals.

The potato came into its own as a snack food. The invention in the 1920s of the mechanical potato peeler helped make potato crisps America’s top-selling snack. A restaurant chain founded by the McDonald brothers in the United States in 1957 spent millions of dollars to “perfect the French fry”. A Canadian firm, McCain, that began making frozen French fries in 1957, expanded to open 57 production facilities on six continents and now supplies one third of all French fried potatoes produced internationally.

Exploding demand. From the 1960s, cultivation of the potato began to expand in the developing world. In India and China alone, total production rose from 16 million tonnes in 1960 to almost 100 million in 2007. In Bangladesh, potato has become a valuable winter cash crop, while potato farmers in Southeast Asia have tapped into exploding demand from food industries. In sub-Saharan Africa, potato is a preferred food in many urban areas, and an important crop in the

highlands of Cameroon, Kenya, Malawi and Rwanda.

The potato has an extraordinarily rich past, and a bright future. While production in Europe – the potato’s “second home” for four centuries – is declining, the potato has ample room for expansion in the developing world, where its consumption is less than a quarter that of developed countries.

Today in mountainous Lesotho, many farmers are shifting from maize to potato, assisted by an FAO project for production of virus-free seed tubers. In China, agriculture experts claim that a staggering 30 percent increase in potato yields is within reach.

And in the Andes, where it all began, the Government of Peru created in July 2008 a national register of Peruvian native potato varieties, to help conserve the country’s rich potato heritage. That genetic diversity, the building blocks of new varieties adapted to the world’s evolving needs, will help write future chapters in the story of *Solanum tuberosum*.



HARJONO DJOYOBISONO

Potato fields
in central Java,
Indonesia

Cultivation

Potato is grown in more than 100 countries, under temperate, subtropical and tropical conditions. It is essentially a “cool weather crop”, with temperature being the main limiting factor to production: tuber growth is sharply inhibited in temperatures below 10°C and above 30°C, while optimum yields are obtained where mean daily temperatures are in the 18 to 20°C range.

For that reason, potato is planted in early spring in temperate zones and late winter in warmer regions, and grown during the coolest months of the year in hot tropical climates. In some sub-tropical highlands, mild temperatures and high solar radiation allow farmers to grow potatoes throughout the year, and to harvest tubers within 90 days of planting (in temperate climates, such as in northern Europe, that can take up to 150 days).

The potato is a very accommodating and adaptable plant, and will produce well even without ideal soil and growing conditions.

However, it is also vulnerable to a number of pests and diseases. To prevent the build-up of pathogens in the soil, farmers avoid growing potatoes on the same land from year to year. Instead, they grow potatoes in rotations of three or more years, alternating with other, dissimilar crops, such as maize, beans and alfalfa. Crops susceptible to the same pathogens as the potato (e.g. tomato) are avoided, in order to break the development cycle of potato pests.

With good agricultural practices, including irrigation when necessary, a hectare of potato in the temperate climates of northern Europe and North America can yield more than 40 tonnes of fresh tubers within four months

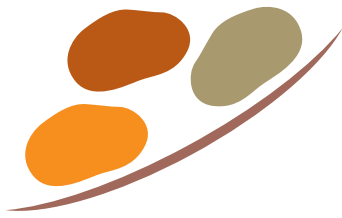
of planting. In most developing countries, however, average yields are much lower – ranging from as little as 5 to 25 tonnes – owing to lack of high quality seed and improved cultivars, lower rates of fertilizer use and irrigation, and pest and disease problems.

Selecting seed potato

Seed potato is usually the most expensive input to potato cultivation, accounting for from 30 to 50 percent of production costs.

In areas of developing countries where no formal seed supply system exists, farmers have devised their own *ad hoc* method for selecting seed tubers: they sell the largest potatoes for cash, eat the medium-sized ones at home, and keep the smallest as future planting material.





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Soil and land preparation

The potato can be grown on almost any type of soil, except saline and alkaline. Naturally loose soils, which offer the least resistance to enlargement of the tubers, are preferred, and loamy and sandy loam soils that are rich in organic matter, with good drainage and aeration, are the most suitable. Soil with a pH range of 5.2 – 6.4 is considered ideal.

Growing potatoes involves extensive ground preparation. The soil needs to be harrowed until completely free of weed roots. In most cases, three ploughings, along with frequent harrowing and rolling, are needed before the soil reaches a suitable condition: soft, well-drained and well-aerated.

Planting

The potato crop is usually grown not from seed but from “seed potatoes” – small tubers or pieces of tuber sown to a depth of 5 to 10 cm. Purity of the cultivars and healthy seed tubers are essential for a successful crop. Tuber seed should be disease-free, well-sprouted and from 30 to 40 g in weight. Use of good quality commercial seed can increase yields by 30 to 50 percent, compared

to farmers’ own seed, but expected profits must offset the higher cost.

The planting density of a row of potatoes depends on the size of the tubers chosen, while the inter-row spacing must allow for ridging of the crop (*see below*). Usually, about two tonnes of seed potatoes are sown per hectare. For rainfed production in dry areas, planting on flat soil gives higher yields (thanks to better soil water conservation), while irrigated crops are mainly grown on ridges.

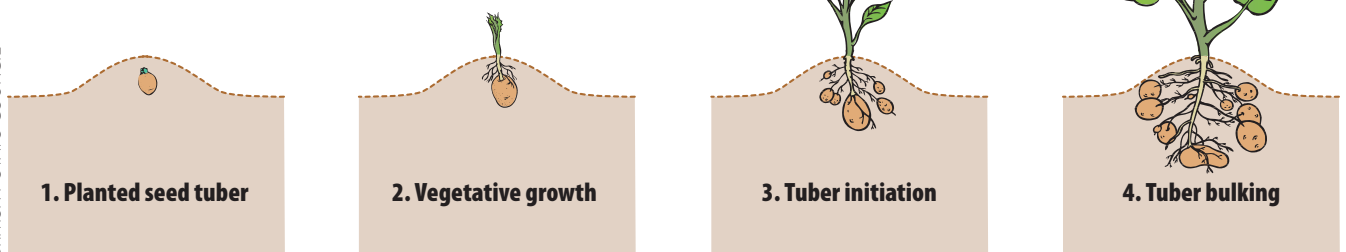
Crop care

During the development of the potato canopy, which takes about four weeks, weeds must be controlled in order to give the crop a “competitive advantage”. If the weeds are large, they must be removed before ridging operations begin. Ridging (or “earthing up”) consists of mounding the soil from between the rows around the main stem of the potato plant. Ridging keeps the plants upright and the soil loose, prevents insect pests such as the tuber moth from reaching the tubers, and helps prevent the growth of weeds.

After earthing up, weeds between the

Stages in crop development

BRITISH POTATO COUNCIL



Potato varieties

Although the potato cultivated worldwide belongs to just one botanical species, *Solanum tuberosum*, the tubers come in thousands of varieties with great differences in size, shape, colour, texture, cooking characteristics and taste. Here is a small sample of potato diversity:



1. Atahualpa

Bred in Peru, a high yielding variety good for both baking and frying



2. Nicola

Widely grown Dutch variety, one of the best for boiling, also good in salads



3. Russet Burbank

The classic American potato, excellent for baking and French fries



4. Lapin puikula

Grown in Finland for centuries, in fields bathed in the light of the midnight sun



5. Yukon Gold

A Canadian potato with buttery yellow flesh suitable for frying, boiling, mashing



6. Tubira

CIP-bred variety grown in West Africa. White flesh, pink skin



7. Vitelotte

A gourmet French variety prized for its deep blue skin and violet flesh



8. Royal Jersey

From the Isle of Jersey: the only British vegetable with an EU designation-of-origin



9. Kipfler

Hails from Germany. Elongated with cream flesh, popular in salads



10. Papa colorada

Brought to the Canary Islands by passing Spanish ships in 1567



11. Maris Bard

Bred in the United Kingdom, a white variety with a soft waxy texture good for boiling



12. Désirée

Red-skinned, with yellow flesh and a distinctive flavour



13. Spunta

Another popular commercial tuber, good for boiling and roasting



14. Mondial

A Dutch potato with smooth good looks. Boils and mashes well



15. Unknown

One of more than 5 000 native varieties still grown in the Andes

CIP [1,6], NIVAP HOLLAND [2,12,13,14], CANADIAN FOOD INSPECTION AGENCY [3,5,11], LAPIN KEITTIÖMESTARIT [4], ABSTRACT GOURMET [9], WIKIMEDIA [7,8,10], J-L GONTERRE [15]

growing plants and at the top of the ridge are removed mechanically or by using herbicides. Ridging should be done two or three times at an interval of 15 to 20 days. The first should be done when the plants are about 15-25 cm high; the second is often done to cover the growing tubers.

Manuring and fertilization

The use of chemical fertilizer depends on the level of available soil nutrients – volcanic soils, for example, are typically deficient in phosphorus – and in irrigated commercial production, fertilizer requirements are relatively high. However, the potato can benefit from application of organic manure at



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the start of a new rotation: it provides a good nutrient balance and protects the structure of the soil. Crop fertilization requirements need to be correctly estimated according to the expected yield, the potential of the variety and the intended use of the harvested crop.

Water supply

The soil moisture content must be maintained at a relatively high level. For best yields, a 120 to 150 day crop requires from 500 to 700 mm of water. In general, water deficits in the middle to late part of the growing period tend to reduce yield more than those in the early part. Where supply is limited, water should be directed towards maximizing yield per hectare rather than being applied over a larger area.

Because the potato has a shallow root system, yield response to frequent irrigation is considerable, and very high yields are obtained with mechanized sprinkler systems that replenish evapotranspiration losses every one or two days. Under irrigation in temperate and subtropical climates, a crop of about 120 days can produce yields of 25 to 35 tonnes/ha, falling to 15 to 25 tonnes/ha in tropical areas.

Pests and diseases

A few basic precautions against diseases – crop rotation, using tolerant varieties and healthy, certified seed tubers – can help avoid great losses. There is no chemical control for bacterial and viral diseases but they can be controlled by regular monitoring (and when necessary, spraying) of their aphid vectors. The severity of fungal diseases such as late blight depends, after the first infection, mainly on the weather – persistence of favourable conditions, without chemical spraying, can quickly spread the disease.

Insect pests can wreak havoc in a potato patch. Recommended control measures include regular monitoring and steps to protect the pests' natural enemies. Even damage caused by the Colorado potato beetle, a major pest, can be reduced by destroying beetles, eggs and larvae that appear early in the season, while sanitation, crop rotations and use of resistant potato varieties help prevent the spread of nematodes.

Harvesting

Yellowing of the potato plant's leaves and easy separation of the tubers from their stolons indicate that the crop has reached maturity. If the potatoes are to be stored rather than consumed immediately, they are left in the soil to allow their skins to thicken – thick skins prevent storage diseases and shrinkage due to water loss. However, leaving tubers for too long in the ground increases their exposure to a fungal incrustation called black scurf.

To facilitate harvesting, the potato vines should be removed two weeks before the



Potatoes awaiting sale
in La Plata, Argentina

potatoes are dug up. Depending on the scale of production, potatoes are harvested using a spading fork, a plough or commercial potato harvesters that unearth the plant and shake or blow the soil from the tubers. During harvesting, it is important to avoid bruising or other injury, which provide entry points for storage diseases.

Storage

Since the newly harvested tubers are living tissue – and therefore subject to deterioration – proper storage is essential, both to prevent post-harvest losses of potatoes destined for fresh consumption or processing, and to guarantee an adequate supply of seed tubers for the next cropping season.

For ware and processing potatoes, storage aims at preventing “greening” (the build up of chlorophyll beneath the peel, which is associated with solanine, a potentially toxic alkaloid) and losses in weight and quality. The tubers should be kept at a temperature of 6 to 8°C degrees, in a dark, well-ventilated environment with high relative humidity (85 to 90 percent). Seed tubers are stored, instead, under diffused light in order to maintain their germination capacity and encourage development of vigorous sprouts. In regions, such as northern Europe, with only one cropping season and where storage of tubers from one season to the next is difficult without the use of costly refrigeration, off-season planting may offer a solution.

Uses of potato

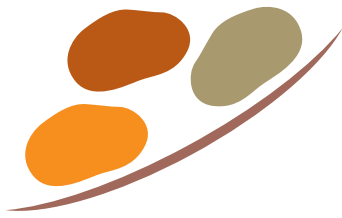
Once harvested, potatoes are used for a variety of purposes, and not only as a vegetable for cooking at home. In fact, it is likely that less than 50 percent of potatoes grown worldwide are consumed fresh. The rest are processed into potato food products and food ingredients, fed to cattle, pigs and chickens, processed into starch for industry, and re-used as seed tubers for growing the next season’s potato crop.

Food uses: fresh, “frozen”, dehydrated

FAO estimates that just over two-thirds of the 320 million tonnes of potatoes produced in 2005 were consumed by people as food, in one form or another. Home-grown or purchased in markets, **fresh potatoes** are baked, boiled or fried and used in an astonishing range of recipes: mashed potatoes, potato pancakes, potato dumplings, twice-baked potatoes, potato soup, potato salad and potatoes *au gratin*, to name a few.

However, the global consumption of potato as food is shifting from fresh potatoes to added-value, **processed food products**.





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UMAMI

One of the main items in that category goes by the unappetizing name of *frozen potatoes*, but includes most of the *French fries* (“chips” in the United Kingdom) served in restaurants and fast food chains worldwide. The production process is fairly simple: peeled potatoes are shot through cutting blades, parboiled, air dried, par fried, frozen and packaged. The world’s appetite for factory-made French fries is estimated at more than 11 million tonnes a year.



M. ALVES

Another processed product, the *potato crisp* (“chips” in the United States), is the long-standing king of snack foods in many developed countries. Made from thin slices of deep-fried or baked potato, they come in a variety of flavours – from simple salted to “gourmet” varieties tasting of roast beef and Thai chili. Some crisps are produced using a dough made from dehydrated potato flakes.



JIANGSU CORP.

Dehydrated potato flakes and granules are made by drying a mash of cooked potatoes to a moisture level of 5 to 8 percent. Flakes are used in retail mashed potato products, as ingredients in snacks, and even as food aid: as part of its international food assistance, the United States has distributed potato flakes to more than 600 000 people. Another dehydrated product, *potato flour*, is ground from cooked, whole potatoes and retains a distinct potato taste. Gluten-free and rich in starch, potato flour is used by the food industry to bind meat mixtures and thicken gravies and soups.



JIANGSU CORP.

Modern starch processing can retrieve as much as 96 per cent of the starch found in raw potatoes. A fine, tasteless powder with “excellent mouth-feel”, *potato starch* provides

higher viscosity than wheat and maize starches, and delivers a more tasty product. It is used as a thickener for sauces and stews, and as a binding agent in cake mixes, dough, biscuits and ice-cream.

Finally, in eastern Europe and Scandinavia, crushed potatoes are heated to convert their starch to fermentable sugars that are used in the distillation of *alcoholic beverages* such as vodka and *akvavit*.

Non-food uses: Glue, animal feed and fuel-grade ethanol

Potato starch is also widely used by the pharmaceutical, textile, wood and paper industries as an adhesive, binder, texture agent and filler, and by oil drilling firms to wash boreholes. Potato starch is a 100% biodegradable substitute for polystyrene and other plastics and used, for example, in disposable plates, dishes and knives.

Potato peel and other “zero value” wastes from potato processing are rich in starch that can be liquefied and fermented to produce **fuel-grade ethanol**. A study in Canada’s potato-growing province of New Brunswick estimated that 440 000 tonnes of processing waste could produce 4 to 5 million litres of ethanol.

One of the first widespread uses of the potato in Europe was as **farm animal feed**. In the Russian Federation and other East European countries, as much as half of the potato harvest is still used for that purpose. Cattle can be fed up to 20 kg of raw potatoes



C. FROGENHALL

a day, while pigs fatten quickly on a daily diet of 6 kg of boiled potatoes. Chopped up and added to silage, the tubers cook in the heat of fermentation.

Seed potatoes: renewing the cycle...

Unlike other major field crops, potatoes are



D. MARJINE

reproduced vegetatively, from other potatoes. Therefore, a part of each year's crop – ranging from 5 to

15 percent, depending on the quality of the harvested tubers – is set aside for re-use in the next planting season. Most farmers in developing countries select and store their own seed tubers. In developed countries, farmers are more likely to purchase disease-free “certified seed” from dedicated suppliers. More than 13 percent of France's potato growing area is used to produce seed potatoes, and the Netherlands exports some 700 000 tonnes of certified seed a year.

OSCAR MARIN REPELLER



Traditional dish of the Canary Islands

Potatoes in the kitchen

What has made the “humble tuber” the world's No. 4 food crop is not only its nutritional value but its amazing versatility in the kitchen. Potatoes are the world's most popular vegetable, and have been welcomed into the cuisines of countries around the globe. Potatoes are used in curries in India and in pasta in Italy, stewed with bananas in Costa Rica, baked with rice in Iran, stuffed with liver in Belarus, stir-fried with green beans in Ethiopia, and simmered with smoked haddock in winter soups in Finland.

The secret of the potato's success is its great diversity: in Peru, a potato salad may include three or four different types. While the choice of tubers is more limited elsewhere, modern varieties of *Solanum tuberosum* offer a wide range of cooking characteristics suitable for hundreds of different dishes. Some give soups a creamy density, providing a delicate taste that highlights other ingredients. Other potatoes are great when baked, served as a simple snack or with a filling as a complete meal. Roast potatoes – crisp and golden outside and fluffy inside – are the perfect



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accompaniment to roast meat. Smooth, creamy, mashed potato is said to be the “ultimate comfort food”, while “new” potatoes, steamed or boiled, are considered a special delicacy.

Most potato recipes are easy to prepare. But choosing the right potato variety is essential for a successful potato dish – in the kitchen, potatoes are classified according to their starch content, which determines how they react to cooking. Basically, the more starch they contain, the more easily the tuber’s starch cells burst when heated.

Choosing the “right potato”

High-starch potatoes, also called “floury” potatoes, generally have coarse, corky skin and a dry texture (due to lower levels of moisture). Boiled, they tend to fall apart. But they are unbeatable for baking, making French fries, and yielding light, fluffy mashed potato. Common high-starch varieties are Russets, Bintje, King Edward and Maris Piper.

S. GILBERT



J. JULIAN



Medium-starch (or “all purpose”) potatoes include long white, round white and yellow potatoes, such as Yukon Gold, German Butterball and Nicola, as well as purple-fleshed tubers. They are more moist than baking potatoes, but – some say – have a blander taste. Ideal for steaming, they go well in stews and in baked, roasted, pan-fried and *au gratin* dishes.

Low-starch potatoes are called “waxy” for their glossy skins. These moist tubers keep their shape during cooking, making them the best choice for boiling, sautés, stews and salads (in France, waxy varieties are preferred for making thick mashed potato). Use fingerling and round reds, or “new” (immature, of any variety) potatoes.

K. PUGH



Factsheets. To deepen understanding of the potato’s role in world agriculture, the economy and global food security, FAO specialists compiled a series of factsheets on key issues in potato development.



Potatoes, nutrition and diet

Potatoes can be important staple foods, but balanced diets need to include other vegetables and whole grain foods

Key Points

The potato is a good source of dietary energy and some micronutrients, and its protein content is very high in comparison with other roots and tubers.

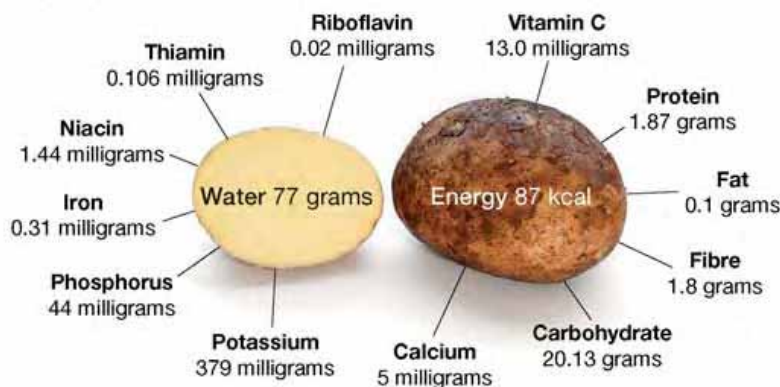
Potato is low in fat – but preparing and serving potatoes with high fat ingredients raises the caloric value of the dish.

Boiling potatoes in their skins prevents loss of nutrients.

Potatoes are important in many diets, but need to be balanced with other vegetables and whole grain foods.

Further research is needed to determine the link between potato consumption and Type 2 diabetes.

Nutrient content of potatoes



(Per 100 g, after boiling in skin and peeling before consumption)

Source: United States Department of Agriculture, National Nutrient Database

Potato is a versatile, carbohydrate-rich food highly popular worldwide and prepared and served in a variety of ways. Freshly harvested, it contains about 80 percent water and 20 percent dry matter. About 60 to 80 percent of the dry matter is starch. On a dry weight basis, the protein content of potato is similar to that of cereals and is very high in comparison with other roots and tubers. In addition, the potato is low in fat.

Potatoes are rich in several micronutrients, especially vitamin C – eaten with its skin, a single medium-sized potato of 150 g provides nearly half the daily adult requirement (100 mg). The potato is a moderate source of iron, and its high vitamin C content promotes iron absorption. It is a good source of vitamins B1, B3 and B6 and minerals such as potassium, phosphorus and magnesium, and contains folate, pantothenic acid and riboflavin. Potatoes also contain dietary antioxidants, which may play a part in preventing diseases related to ageing, and dietary fibre, which benefits health.

Effects of potato preparation methods

The nutritive value of a meal containing potato depends on other components

served with them and on the method of preparation. By itself, potato is not fattening (and the feeling of satiety that comes from eating potato can actually help people to control their weight). However, preparing and serving potatoes with high-fat ingredients raises the caloric value of the dish.

Since the starch in raw potato cannot be digested by humans, they are prepared for consumption by boiling (with or without the skin), baking or frying. Each preparation method affects potato composition in a different way, but all reduce fibre and protein content, due to leaching into cooking water and oil, destruction by heat treatment or chemical changes such as oxidation.

Boiling – the most common method of potato preparation worldwide – causes a significant loss of vitamin C, especially in peeled potatoes. For french fries and chips, frying for a short time in hot oil (140 °C to 180 °C) results in high absorption of fat and significantly reduces mineral and ascorbic acid content. In general, baking causes slightly higher losses of vitamin C than boiling, due to the higher oven temperatures, but losses of other vitamins and minerals during baking are lower.

Potato's role in the developing world's "nutrition transition"

In many developing countries, and especially in urban areas, rising levels of income are driving a "nutrition transition" toward more energy-dense foods and prepared food products. As part of that transition, demand for potato is increasing. In South Africa, potato consumption has been growing in urban areas, while in rural areas maize is still the staple. In China, higher income and increased urbanization have led

to increased demand for processed potatoes. Thus, the potato already plays a role in diet diversification in many countries. However, where other staple crops are available to meet energy requirements, potato should not replace them but rather supplement the diet with its vitamins and mineral content and high quality protein. Potatoes can be important staple foods, but balanced diets need to include other vegetables and whole grain foods.

As part of the trend toward greater consumption of "convenience foods", demand for fried potatoes is increasing. Over-consumption of these high-energy products, along with reduced physical activity, can lead to overweight. Therefore the role of fried potato products in the diet must be taken into consideration in efforts to prevent overweight and diet related non-communicable diseases, including heart disease and diabetes. Type 2 diabetes is caused by many factors, and further research is needed to determine whether potato consumption and Type 2 diabetes may be linked.



Toxic components of potato

As part of the potato plant's natural defences against fungi and insects, its leaves, stems and sprouts contain high levels of toxic compounds called glycoalkaloids (usually solanine and chaconine). Glycoalkaloids are normally found at low levels in the tuber, and occur in the greatest concentrations just beneath the skin.

Potatoes should be stored in a dark, cool place in order to keep glycoalkaloid content low. Under exposure to light, potatoes turn green in colour due to increased levels of chlorophyll, which can also indicate higher levels of solanine and chaconine. Since glycoalkaloids are not destroyed by cooking, cutting away green areas and peeling potatoes before cooking ensures healthy eating.

About IYP 2008

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www.potato2008.org

Credits:

Information provided by the Nutrition and Consumer Protection Division of FAO
Photo: © FAO/Giulio Napolitano



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Potato and biodiversity

By conserving – and utilizing – the potato genetic diversity developed by their ancestors, small farmers in the Andes are helping ensure world food security



Key points

Potato farming systems need a continuous supply of new varieties drawn from the entire potato gene pool.

Potato biodiversity is under threat – ancient varieties cultivated for millennia have been lost and wild species are threatened by climate changes.

Smallholder farming systems in the Andes encourage cross-pollination of potato flowers, vital to sustaining the diversity of local, farmer-developed varieties.

With CIP support, Andean communities have created a "potato park" holding some 1 200 traditional varieties of potato.

The history of the potato provides a grim warning of the need to maintain genetic diversity in our staple food crops. In the 19th century, Ireland was heavily reliant on only a few varieties of potato, and those types contained no resistance to the devastating disease known as late blight. When late blight destroyed the 1845-1846 potato crop, widespread famine followed. An estimated one million people starved to death and more than a million were forced to migrate abroad.

To combat pests and diseases, increase yields, and sustain production on marginal lands, today's potato-based agricultural systems need a continuous supply of new varieties. That requires access to the entire potato gene pool. But potato biodiversity is under threat: ancient varieties cultivated by Andean peoples for millennia have been lost to diseases, climate change and social upheaval.

Species and crop-associated diversity

While most varieties of potatoes belong to a single species, *Solanum tuberosum*, about 10 other *Solanum* species have been cultivated, and 200 wild species have been recorded. Climate change may threaten the survival of those wild relatives: it is forecast that as many as 12 percent will become extinct as their growing conditions deteriorate. If climate



Farmers sort varieties at Peru's "potato park". Photo: © CIP

Centre of origin

In the Andean region, generations of farmers have domesticated thousands of potato varieties. Even today, farmers cultivate up to 50 varieties on their farms. In the biodiversity reserve of the Chiloé archipelago in Chile, local people cultivate about 200 varieties of native potato. They use farming practices transmitted orally by generations of mainly women farmers.

changes drastically, the area where wild potatoes grow naturally could be reduced by as much as 70 percent.

Since potatoes mostly propagate vegetatively, most commercial varieties of potato have a reduced ability to flower and breeders do not select for traits that make the flower attractive to pollinators. However, natural potato pollination remains important to sustaining the diversity of land races (farmer-developed varieties that are adapted to local environmental conditions). Fortunately, the diverse smallholder farming systems in the Andes harbour a variety of flowering plants that do attract pollinators, such as honeybees and bumblebees, which promote cross-pollination of potato flowers, thus increasing seed production and sustaining diversity.

International Treaty

The potato is included in the multilateral system established under FAO's International Treaty on Plant Genetic Resources for Food and Agriculture.

The Treaty, which entered into force in 2004, aims at the conservation and sustainable use of crop plant diversity and the fair and equitable sharing of benefits derived from their use.

Conserving potato biodiversity in the Andes

Having lost many of their traditional potato varieties, Peruvian farmers in the Andes are now taking measures to conserve and sustainably use those that remain. A pact has been signed by six Quechua communities with the International Potato Center that recognizes the rights of the communities over potato strains they have developed.

Under the agreement, the Center's genebank returns potato genetic resources – and knowledge associated with them – to the communities, which have established a "potato park" (*Parque de la papa*) in a conservation area where they grow and manage the plants. This repatriation of biological diversity effectively keeps control of genetic resources local. The 15 000 ha park is a "living library" of potato genetic diversity, holding some 1 200 varieties of potato cultivated in the highlands. A long-term goal is to re-establish all the world's 4 000 known potato varieties in the valley, allowing the park to function as a second centre of origin for this vital staple crop.



Inside CIP's gene bank. Photo: © CIP

Diversity conserved in trust

The International Potato Centre in Peru maintains the world's largest bank of potato germplasm, including some 1 500 samples of about 100 wild species collected in eight Latin American countries, and 3 800 traditional Andean cultivated potatoes. The collection is maintained and managed under the terms of an agreement with the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture and, like all collections eligible for funding from the Global Crop Diversity Trust, is available to plant breeders worldwide upon request.

Credits:

Information provided by the Global Crop Diversity Trust and the Plant Production and Protection Division, FAO.

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Potato and gender

Around the world, rural women are essential to conservation, seed selection, planting, harvesting, storing and marketing of potatoes



Key points

Women in developing countries play a central role in guaranteeing family food security and provide most of the labour for potato production.

Andean women possess a unique reservoir of knowledge and skills in domesticating wild potatoes and adapting new varieties.

New strategies are helping to empower small-scale farmers and ensure that gender issues are incorporated in potato development policies and programmes.

Since the beginning of Andean agriculture, seeds have been associated with reproduction and femininity. The Incas believed the moon conferred fertility on women and moved *Pachamama* (Mother Earth) to germinate and offer up her potatoes (known as *Mama Acxo*) at harvest time. Men deposited the seeds and women received them, to harbour and nurse. In the Andes today, and in many other parts of the developing world, potato growing is still highly labour-intensive. Rural women provide most of the labour in both small- and large-scale potato production – from conservation and seed selection to planting, harvesting, storing and marketing.

China: Increasing gender awareness

In China, most potatoes are grown in mountain areas of Inner Mongolia and Shaanxi provinces, both as a staple food and as a cash crop. Research in Wuchuan County, Inner Mongolia, shows how the labour-intensive nature of potato production, coupled with strong gender inequalities, can pose a threat to the sustainability of local livelihoods.

Says Zhang Ailian, a woman farmer: "Potato growing is very tiring, especially at harvest time, and the burden of household tasks is already very heavy. The Agriculture and Animal Husbandry Bureau provides technical training in potato production, but heads of the village usually tell men to attend. Women make up fewer than 10 percent of total participants."

A project in Wuchuan is working to ease the burden of potato production on women by supplementing agricultural training with gender-sensitive materials. The project uses participatory approaches such as "farmer field



A group of farmers harvests potatoes near Cajamarca. Photo: © CIP

schools", and brings gender issues into potato development policies. It advocates a more equitable division of labour and financial decision making powers for women, and facilitates their access to extension services and training.

Peru: Women as conservationists

In the high-altitude Peruvian Andes, the genetic diversity found in hundreds of native potato varieties guarantees rural communities' food security. Over centuries, Andean farmers and the descendants of *ayllu* family groups, primarily women, have selected countless varieties of potato to preserve and enhance plant diversity, allowing them to cultivate in different agro-ecological zones and cope with pests, diseases and climatic changes. The "bitter potato", for example, is the result of crossing with frost-resistant varieties adapted to the freezing temperatures of the *Puna* agro-ecological zone.

Male migration to urban centres has left women farmers responsible for almost 70 percent of family farm work. In the Chetilla community in Cajamarca, the



Andean women also handle marketing. Photo: © FAO

tasks of seed selection and storage are exclusively women's. Their participation in seed fairs is invaluable in preserving Andean potato biodiversity. Surveys have found that women attending fairs are able to identify up to 56 different varieties. However, the heavy burden placed on women in potato production highlights the need for a more equitable division of labour to ensure the conservation of agro-biodiversity.

Uganda: Enabling rural innovation

Potatoes have become an important staple and cash crop in sub-Saharan Africa's highland zones, and Uganda is a major potato producer in the region. Virtually all households in southwestern Uganda grow potatoes, harvesting over 60 percent of the national crop. Most tubers are grown in highland areas of Kabale and Kisoro as a staple food and as the main source of income.

"Enabling rural innovation" is a gender-sensitive strategy being used in various development programmes. The idea is to empower both men and women farmers and rural communities to develop market



Potato cultivation is expanding in Africa. Photo: © FAO

opportunities. In Kabale, for example, farmer field school training covered integrated potato pest and disease management. It also helped the Nyabyumba United Farmers group to establish an enterprise that now supplies potatoes for french fries at fast-food restaurants in Kampala.

Gender roles in agriculture

FAO's Gender Plan of Action underscores the need for rural and agricultural development policies that acknowledge the roles of both men and women in achieving food security. The Plan aims at promoting gender equality in access to food, in the control over and management of natural resources and agricultural support services, in policy- and decision-making processes at all levels in the agricultural and rural sector, and in opportunities for on- and off-farm rural employment.

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The global potato economy

Developing countries are now the world's biggest potato producers – and importers – and consumer demand is shifting from fresh tubers to processed products



Key points

In 2005, for the first time, the developing world's potato production exceeded that of the developed world

Subsistence potato growing in developing countries is declining as producers reorient toward domestic and international markets

Global consumption is shifting from fresh potatoes to added-value processed products

In international trade, both the value and volume of traded processed products far outweigh trade in fresh tubers

Developing countries are net importers in international potato trade, which in 2005 was estimated to be worth US\$6 billion.

Despite its importance as a staple food and in combating hunger and poverty, potato has been neglected in agricultural development policies for food crops

Potato production in developed countries

especially in Europe and the Commonwealth of Independent States, has declined on average by one percent per annum over the past 20 years. However, output in developing countries has expanded at an average rate of five percent per year. Asian countries, particularly China and India, fuelled this growth.

In 2005, the developing countries' share of global potato output stood at 52 percent, surpassing that of the developed world. This is a remarkable achievement, considering that just 20 years ago the developing countries' share in global production was little more than 20 percent. Even so, world potato production and consumption are currently expanding more slowly than the global population.

Fresh potato consumption, once the mainstay of world potato utilization, is decreasing in many countries, especially in developed regions. Currently, more potatoes are processed to meet rising demand from the fast food, snack and convenience food industries. The major drivers behind this development include growing urban populations, rising incomes, the diversification of diets and lifestyles that leave less time for preparing the fresh product for consumption.

Potatoes are commonly regarded as a bulky, perishable commodity with high transport costs and limited export potential, confined mostly to cross-border transactions. These constraints have



In 2006, the world produced some 315 million tonnes of potatoes. Photo: © FAO

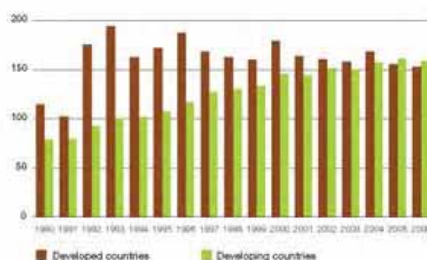
not hampered the international potato trade, which has doubled in volume and risen almost fourfold in value since the mid-1980s. This growth is due to unprecedented international demand for processed products, particularly frozen and dehydrated potato products. To date, developing countries have not been beneficiaries of this trade expansion. As a group, they have emerged as leading net importers of the commodity.

International trade in potatoes and potato products still remains thin relative to production, as only around 6 percent of output is traded. High transport costs, including the cost of refrigeration, are major obstacles to a wider international marketplace.

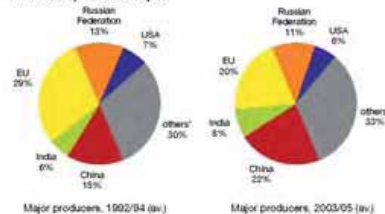
Trade policies

Ad valorem import tariffs are used to protect domestic potato markets. Other

World potato production 1990-2006

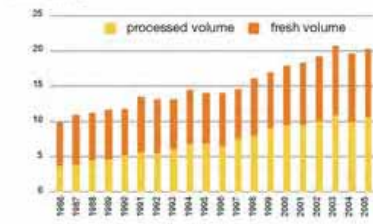


China and India now account for 30 percent of world potato output

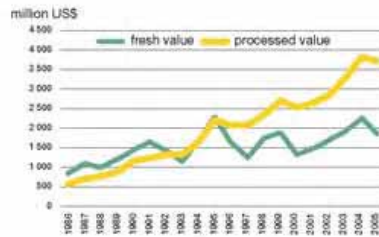


* Including Ukraine, Belarus, Canada, Islamic Republic of Iran, Turkey, Bangladesh, Peru, Brazil

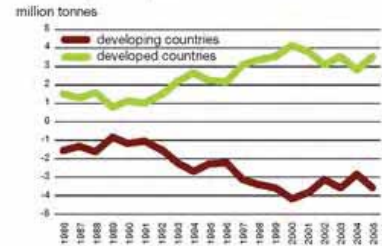
Imports and exports of processed products now dominate world potato trade
Global potato trade volume (tuber equivalent), 1986-2005
million tonnes



Global transactions worth close to US\$6 billion, driven by processed potatoes
Global potato trade value, 1986-2005
million US\$



Net trade position of developing countries continues to deteriorate
Potato net trade (exports-imports) in tuber equivalent, 1986-2005
million tonnes



policies that restrict access to markets include sanitary and phytosanitary measures and technical barriers to trade.

Import tariffs on potatoes and potato products are applied by most countries. The binding rates agreed under the aegis of the World Trade Organization vary considerably. Potato provides a classic example of "tariff escalation", where importing countries protect processing industries by levying higher duties on processed products than on raw material. By preventing countries from diversifying their export base into higher-value processed products, tariff escalation can therefore keep them "trapped" as providers of raw material.

Countries wishing to supply potato commodities to the international market – especially to the more lucrative developed country markets – also face

considerable hurdles in the form of food health standards and technical regulations. The Doha Development Round of trade negotiations recognizes the negative impacts of tariff escalation and contains important provisions aimed at ensuring that standards and regulations do not become de facto barriers to trade or hidden protectionist policies, while at the same time putting public health concerns foremost. Unfortunately, negotiations pertaining to the Doha agenda have suffered a series of setbacks, and agreement on a final solution has yet to materialize.

Potato potential

Potato's positive attributes, particularly its high nutritional value and potential to boost incomes, have not received the attention they deserve from governments. The lack of established marketing channels, inadequate institutional support and infrastructure, and restrictive trade policies are impediments to commercialization of the sector. National and international stakeholders need to place potato higher on the development agenda.

Product	WTO Bound Tariff (%)	
	Trade Weighted Average	Maximum
Fresh potatoes (inc. seed)	29	378
Frozen potatoes	16	414
Potato flour*	38	446
Potato starch	109	550

* includes flour, meal, flakes, granules and pellets

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Potato and food price inflation



The potato is a highly recommended food security crop that can help shield low-income countries from the risks posed by rising international food prices

Key Points



Prices of cereals are rising faster than those of potato and other root crops.

Countries with low levels of dietary diversity and high dependency on cereal imports could benefit greatly from expanded potato cultivation.

Potato flour can be blended easily with wheat flour, providing countries with a means of reducing costly wheat imports.

Potato is increasingly a valuable source of cash income for low-income farm households

Intense competition for reduced international supplies of cereals and other agricultural commodities is driving worldwide food price inflation, which brings with it the risk of food shortages and social unrest in low-income countries. One strategy that could help reduce the risk is diversification of food production to nutritious and versatile staple crops that are less susceptible to the vagaries of international markets. One such crop is potato.

Unlike rice, wheat and maize, the potato is not a globally traded commodity and its prices are determined usually by local supply and demand. A recent FAO survey in more than 70 of the world's most vulnerable countries found that inflation in potato prices is much lower than that for cereals. The potato is, therefore, a highly recommended food security crop that can help low-income countries ride out turmoil created by food price increases.

Potato for nutrition – and income

In many developing countries, the poorest and most undernourished farm households depend on potatoes as a primary or secondary source of food and

nutrition. These households value potato because it produces large quantities of dietary energy and has relatively stable yields under conditions in which other crops might fail.

The potato is highly adaptable to a wide variety of farming systems. With its short vegetative cycle – high yields within 100 days – it fits well into double cropping systems with rice, and is also suitable for intercropping with maize and soybeans. Potatoes can be grown at altitudes of up to 4 300 m and in a variety of climates, from the barren highlands of the Andes to the tropical lowlands of Africa and Asia.

Potato is also rapidly becoming a valuable source of cash income – a primary requisite of food security - for many small scale producers. In many developing countries, growth in urban populations and incomes and the diversification of diets have led to rising demand for potatoes from the fast food, snack and convenience food industries. The structural transformation of agriculture-based economies into more urbanized societies opens up new market opportunities for potato growers

FAO Cereal Price Index

1998-2000=100



Rising prices of maize, wheat and rice pose a threat to low-income countries

and to their trading and processing partners in the value chain.

Investing in potato production

With its adaptability to a wide range of uses, the potato has a potentially important role to play in the food systems of developing countries. However, policy makers have traditionally focused on cash crops for export and on cereals, leaving potato and other root crops at the periphery of agricultural development efforts. Redressing this imbalance is important if potato sectors are to thrive.

Investment in potato production should be considered as insurance against international market turbulence and as a food security safeguard. In the current climate of high food prices, it is often forgotten that until recently international prices for cereals had reached historic lows when adjusted for inflation. A boom followed by bust in cereal prices could easily undermine investments in the potato sector if consumers revert back to purchasing cheap, subsidized imported cereals.

Strengthening the potato 'value chain'

In developing countries, potatoes are often sold through fragmented marketing chains with little co-ordination and a lack of market information, giving rise to supply disruptions and high transactions costs. Many small scale farmers are excluded from markets owing their low yields, and inadequate storage and transport. Inefficient and unfair pricing discourages them from making on-farm investments in production.

Enhancing the value chain requires substantial public and private investment, especially in breeding programmes and in infrastructure to support and co-ordinate activities along the chain.

Production initiatives can be strengthened by research focused on specific end uses, rapid multiplication of good quality planting material, and varieties with pest and disease resistance. Producers of potato seed tubers need to offer yield-improving and input-saving technologies that boost yields and



reduce costs. The formation of producer groups would help farmers share expertise and strengthen their bargaining power. Production would also benefit from improvements in the supply of irrigation water and chemical fertilizers, and in cold storage and transport infrastructure.

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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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www.potato2008.org

Credits:

Information provided by the Research and Extension Division and the Plant Production and Protection Division, FAO



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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.

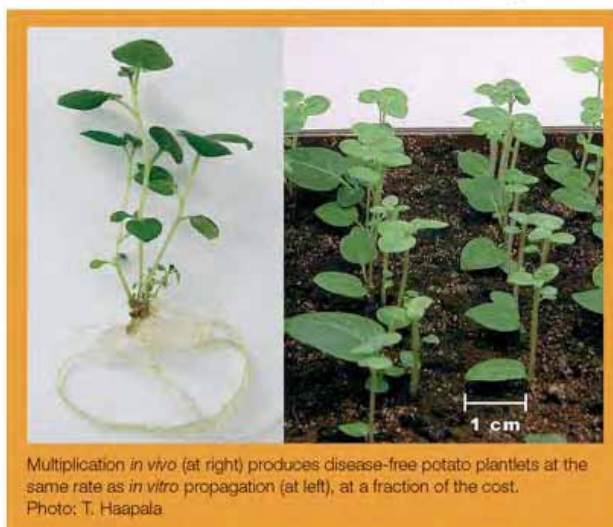
Potatoes are susceptible to a variety of diseases that lower yields and tuber quality. What's more, pathogens accumulate in successive clonings of tubers and in the soil used to grow them. That is why sustainable potato production depends on a constantly renewed supply of disease-free planting material.

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



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

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.

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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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.

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.

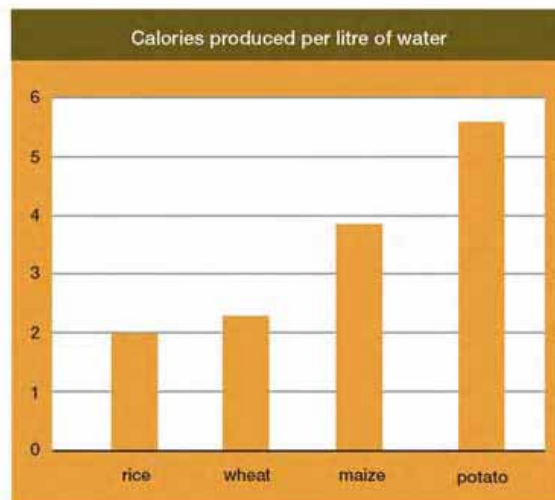
An increase in the proportion of potato in the diet would alleviate pressure on water resources. Currently, producing the foods – especially animal



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

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.



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.

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.



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

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,

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.



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.



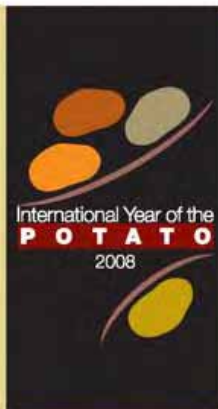
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Potato and soil conservation

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.

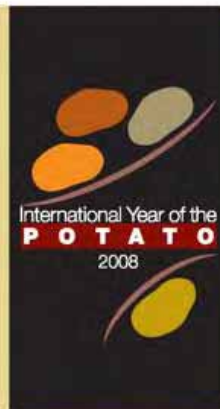
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