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POTATO RESEARCH FOR THE NEXT CENTURY

P. Gregory, P. Schmiediche, and F. Ezeta*

Introduction

The world's fourth most important food crop—potato—produces more calories, high-quality proteins, and vitamins per unit area per unit time than any other food crop. In addition, it is a valuable source of feed and industrial raw materials (e.g., starch) (Table 1). Production, which has increased steadily over the last 30 years, is growing faster than that of any other staple crop, except possibly wheat. Production in India rose by more than 300% during the past 25 years and is expected to double by the end of this century. Because it is highly adaptable, potato is now being produced in non-traditional growing areas such as mid- and low-altitude rice paddies in South-East Asia.

Increased need for potatoes

At the current rates of population growth, world food production must double by year 2050 for human populations to maintain nutrition at present levels. To improve only the quality of nutrition and quantity of food supply, agricultural production will have to triple within the same period. Because little additional land can be brought into production, this dramatic increase must be achieved on existing agricultural land. Another 'Green Revolution' will be needed to accomplish such a goal, but with the important difference that emphasis will be on sustainability rather than on productivity per se.

The potato can help fuel the new revolution if its enormous potential to boost production of food, feed, and other products on existing available land in existing agro-ecologies is tapped by well-targeted, global, R&D activities. These activities must be designed to remove sustainability-related constraints.

Key constraint to sustainability

The major problem that threatens sustainability of potato production is the enormous

* Centro Internacional de la Papa (CIP), Lima, Peru.

quantities of chemical pesticides applied to control late blight, potato tuber moth (PTM), and a variety of other pests and pathogens. More pesticides are applied to potato than any other food crop, amounting to more than US$300 million annually. Moreover, the environmental damage is so great in some areas that potato production is already threatened. Before the next century begins, the collective price tag may by rise more than three times.

Over-reliance on chemicals has resulted in the buildup of pest resistance to insecticides and fungicides. Natural enemies of the insect pests are being killed or rendered harmless by spraying. This ‘pesticide treadmill’, in which farmers use chemicals more frequently and with fewer results, will destroy potato cultivation in many parts of both the developing and industrialized world unless practical integrated pest management (IPM) alternatives are implemented. The situation is particularly dangerous in the developing world where the use of chemicals, banned in industrialized countries, not only endangers potato farmers and consumers but also entire environments. Worst hit of all will be Africa, where farmers are hard pressed to purchase pesticides.

Research Challenges

Accelerating genetic improvement

Late blight disease, which caused the 19th century Irish potato famine, is still the most important potato disease worldwide. More chemicals are used to combat late blight than any other disease or pest. The recent outbreak of a new form of the disease poses a new threat to potato production worldwide. The disease has spread to virtually every potato-producing region of the world, through the sale of infected potato seed from Mexico to Europe in the late 1970s. Serious production losses are anticipated, and efforts to reduce the use of agrochemicals will be complicated.

Outbreaks were reported at several locations in the USA in 1992. The new fungal mating type (A2) is far more aggressive than the ordinary A1 type, responsible for the Irish famine. Both A1 and A2 reproduce sexually; the resulting oospores allow the fungus to survive cold temperatures, leading to higher losses and increased use of fungicides.

The most likely solution to this problem is the development of durable disease resistance. The Centro Internacional de la Papa (CIP, or International Potato Center), based in Peru, is organizing an emergency effort to accelerate a breeding programme, using the expertise of researchers from many countries and disciplines. In February 1993, an international group of specialists in late blight met in Mexico to determine the magnitude of this threat and analyse CIP's strategy to cope with it. Previously, breeding for late blight resistance was based on developing immunity (vertical resistance), which tends to break down after a new pathogen strain or race evolves and overcomes the apparent immunity based on R-genes.

Discovery of the principle of horizontal or field resistance has given us a new method to develop a different type of host resistance that is durable but may still require a limited degree of chemical control. CIP has developed a new so-called B-population of potato genetic material (R-gene free), which is now ready for large-scale testing around the world. A C-population, which exploits resistance genes found in wild potato species in the germ plasm bank held at CIP—the largest such collection in the world—is being developed. Previous research efforts by CIP and its partners focused on late-blight resistant varieties, providing an annual internal rate of return on research investment exceeding 90%.

In Central Africa, the Center's investment in potato research of just US$5.6 million is providing annual returns of US$10 million, equal to or possibly better than those achieved by high-yielding cereal crops in Asia during the 1960s and 1970s. CIP economists are confident that efforts to overcome this destructive disease could provide similar returns. Adoption could lead to production increases of at least 2 to 5 t/ha (equivalent of US$400-1000/ha) on about 2 million ha worldwide.

Immunity to potato viruses—Particularly the potato viruses ‘Y’ (PVY) and ‘X’ (PVX), which are two of the most damaging potato viruses—has been bred with traditional breeding methods. Large and highly variable genetic populations with resistance to these two viruses are available at CIP. Two classic examples of total pest and disease control, using conventional breeding methods, are the resistance against the potato wart and the cyst nematode in Europe.

Resistance breeding to late blight or other stresses will be very different in the next century as molecular methods such as RFLP and RAPD are developed. Use of molecular markers will facilitate rapid screening of materials in the laboratory, dramatically reducing the need for large numbers of lengthy, expensive field trials. This approach is being developed jointly by Cornell University and CIP to aid in transfer of the insect pest-trapping glandular trichomes of *Solanum berthaultii* to potato cultivars.

By year 2025, the use of genetic engineering and molecular techniques designed to accelerate potato breeding will be widespread. Progress in this area has been rapid, with CIP closely involved from the beginning. In cooperation with Plant Genetic Systems (a private biotechnology company), the Center developed varieties with the *Bacillus thuringiensis* (BT) gene inserted in their genome, giving them genetic resistance to the potato tuber moth (PTM) and possibly to other insect pests under laboratory and greenhouse conditions. The varieties are ready for field testing, as soon as the legal framework is established. Based on previous experience with insects exposed to BT sprays in the field, however, resistance to the insecticidal crystal protein (ICP) is expected. Scientists are already exploring several strategies to delay the development of insect resistance, such as introducing more than one type of ICP in the same host plant or alternating crops with different types of ICP. To ensure long-term success, the ICP's mode of action, gene expression technology, and resistance management are being studied.

Certain viral diseases and bacterial wilt are the next candidates for genetically engineered control. Some reports have been published on the presence of natural resistance to the highly destructive potato leaf roll virus in a wild potato species (*S. brevidens*), but reliable resistance of any consequence has not been found in the gene pool of cultivated potatoes. An alternative is to insert parts of the virus's coat protein in the potato genome, preventing its multiplication.

Natural resistance to *Pseudomonas solanacearum*, the causal organism of bacterial wilt, has been successfully identified in both cultivated and wild materials and has been incorporated into cultivated potatoes. Because expression of resistance is exceedingly complex, alternative resistances are being sought. One such alternative is to incorporate into the potato genome genes that produce a series of bacterial lysozymes, harmless to mammals.

Within the next 20 years, genome-mapping techniques may facilitate the extraction of specific genes or gene groups from wild potatoes for insertion into existing cultivars. This could well be the most significant breakthrough in potato research as it would facilitate improving specific traits without back-crossing to eliminate the undesirable traits so often associated with wild species. Just the materials in the germ plasm bank held at CIP have sufficient genetic resistance and tolerance against almost all known biotic and abiotic stresses affecting potato around the world. Currently, however, the use of genetic engineering is still very limited, but is expected to become the major method of generating host-plant resistance in the next century. This approach would also lead to novel, more efficient, ways of manipulating the quantity and quality of starch and other utilization-related components of potatoes and other roots and tubers.

Need for seed programmes

The anticipated breakthroughs in breeding discussed above will mean nothing in practical terms unless developing countries have adequate supplies of healthy seed and distribution channels.

Improved seed systems will also be needed to reduce the heavy reliance on imports from industrialized countries. Each year, developing countries import an estimated US$135 million in potato seed tubers. Seed imports are not only a drain on foreign exchange reserves, but also represent a major source of disease infection. The threat of the new late blight pathogen discussed earlier arose largely because of the pathogen’s movement through the multinational seed trade. Depending on the variety, planting techniques, and growing conditions, an average 1.5-2.0 t of seed potatoes/ha are needed. In Vietnam, that amounts to 72,000 t seed potatoes/year. In Indonesia, about 80,000 t are needed, and requirements are similar in the Philippines. In Africa, most countries depend on imported seed, and some countries in Central and South America still rely on seed imported from North America or Europe. Although the use of tissue culture to clean and multiply seed potatoes has enabled national research programmes (NARS) to meet some of their requirements for healthy, high-quality seed potatoes, NARS freely admit that they cannot possibly supply the amounts needed to improve production significantly.

Even under the most favourable agro-ecological and phytosanitary conditions, four or five multiplications cause progressive deterioration of seed, whatever its source. Bacterial wilt is the single most important factor responsible for deterioration of seed potatoes in many developing countries. Viruses and bacterial wilt alone are sufficient to severely affect any effort to multiply adequate amounts of clean seed for the growing of ware potatoes.

Initial production of clean seed has been very successful in Asia, given the widespread introduction of tissue culture-based *in vitro* methods. This success had led to the belief that NARS can now become self-sufficient and produce all their seed requirements locally. NARS decision-makers have actively supported the production of clean basic seed, gradually reducing imports from Europe and North America. Such progress is not ubiquitous, however; many countries in Africa and Latin America are progressing slowly and others are stagnant. Strong development of such programmes must be emphasized as we enter the next century, or potato agriculture will deteriorate rather than progress.

In vitro, laboratory-produced, clean planting material has to be eventually multiplied in the field under prevailing agro-ecological conditions—the most vulnerable point of this scheme. Depending on the amount of clean starting material available, 5 or 6 multiplications are necessary. When this type of seed reaches the farmers (ware seed), it is almost worthless. Growing consensus suggests that a new initiative is needed to overcome the lack of sufficient amounts of high-quality seed.

The most commonly proposed solution is to have larger amounts of starting material available to reduce the number of in-country multiplications before farmers receive material for ware production. Many Asian countries now have hard convertible national currencies, making importation of adequate amounts of clean starting material possible—unlike the case of most African and Latin American countries.

Imports of sufficient quantities of clean starting material from traditional sources in Europe and North America are expensive, given the high cost of freight. Furthermore, the well-defined growing seasons in the northern hemisphere means that many developing country farmers do not receive imported material at the right physiological age for immediate planting.

These limitations have stimulated a search for suitable seed-producing areas in South-East Asia. One area with potential is Western Australia, where potatoes are produced under almost ideal climatic and phytosanitary conditions. This is reflected by yields that are close to the believed potential of potato production: 80-100 t/ha (126 t/ha have been harvested under experimental conditions). Crops do not suffer from bacterial wilt, potato cyst nematode, late blight, nor potato virus Y. Potatoes can be planted and harvested for 9 months of the year.

Potato varieties bred and selected in South-East Asia could conceivably be multiplied in Western Australia for further multiplication in those Asian potato-growing countries that have agro-ecologies unsuitable for clean seed production. CIP, several Australian institutions, and two NARS from the region are working on a pilot scheme to test the feasibility of this idea.

Complementary Approaches

Integrated pest management

The ideal would be to have potatoes with durable resistance against, not only late blight, but also against all pests and diseases. Because, as yet, this is not possible, complementary alternatives are needed. The PTM is the most important insect pest of potatoes in developing countries, especially in semi-arid areas. To prevent damage, pesticides are heavily applied; in Mexico, for example, 20 sprays per season are normal, for a total cost of US$7.5 million per crop. By 1991, the indiscriminate use of pesticides had reached the point where spraying had virtually no effect on the PTM. Aphids and whiteflies had also begun to attack the crop because the natural enemies of these pests had either been killed or rendered harmless by the spraying. This situation, typical of many others around the world, was so bad that production was on the verge of collapsing.

Durable resistance to PTM has not yet been identified, so scientists from CIP and the Mexican Institute of Forestry, Agriculture, and Livestock Research (INIFAP) met with 70 local farmers to assess the situation and seek alternatives. The group mapped out a set of IPM recommendations and training sessions to instruct farmers on how to disrupt the life cycle of the PTM, using low-cost sex-pheromone traps and cultural practices such as removal of dead vines and hilling up soil around the plant. Sex pheromones occur naturally in most insects, and have been extremely effective in detecting pest infestation levels. Female pheromones of the PTM are being used in plastic traps to attract male moths. This allows growers to monitor infestations and thus apply insecticides only when absolutely necessary. Consequently, many fields have had their biological balance restored, and pesticide use has dropped by 75%.

True potato seed (TPS) planting schemes

Initially, TPS technology was targeted for selected tropical areas where alternatives to tuber-based planting schemes were needed to make production feasible. But more than 10 years of research on production and utilization has shown that the potential of TPS is much higher than that of tuber seed.

Farmers in traditional potato-growing areas have become interested in this novel technology because it introduces flexibility in planting dates, reduces the transmission of tuber-borne diseases, is easy to store and transport, and the cost is only a fraction of that of tuber seed. The next century will see this technology grow in popularity as new hybrids and open-pollinated progenies are selected for vigour, uniformity, yield potential, and disease and pest resistance.

Examples of the enormous potential of TPS technology to cope with the problem of seed supply for potato production in next century are:

(1) Low-income farmers in Nicaragua, who could not afford to grow potatoes because of the expensive imported seed, are now supplying the Managua market with good-quality white potatoes produced from seed tubers initially derived from TPS.

(2) The Indian Government is aiming to double potato production, by using TPS, to 30 million t (average yield 20 t/ha) by year 2000.

(3) Egyptian potato growers see reduced costs as the main factor favouring the use of seedling tubers derived from TPS.

(4) Even the most traditional potato-growing areas of the Andean region in South America are accepting TPS as an alternative to tuber seed. Potato farmers of the Peruvian highlands have found a quick way to supply themselves with good-quality seed after severe droughts by growing TPS in protected rustic greenhouses.

Strengthening research capacity of partner institutions

For these research efforts to translate into actual technological development, CIP must work closely with its research partners in the NARS. The Center's research strategy is based on the belief that its impact is directly linked with, and dependent on, the strength of its partner NARS in technology development and transfer. Assisting NARS to strengthen their scientific capacities for generating and adopting technology is therefore a major task for CIP and other sister CGIAR centres in facing the challenges of the next century.

CIP's decentralized research programme, with a strong presence in different regions, facilitates close collaboration with NARS scientists and provides valuable input for research planning, monitoring, and evaluation. Collaborative research networks form a strategy for implementing research and disseminating results among countries within agro-ecological regions. The network approach to research generally economizes on research costs by sharing responsibilities among its members. CIP provides scientific backup and participates in the governing body of every network, but decisions depend largely on the policymaking body formed by appointees of member countries.

CIP itself is a ‘global network’ for research and dissemination of technology on potatoes, sweet potatoes, and Andean roots and tubers. Almost 25 years of experience in research and institutional strengthening have equipped CIP with the tools to play a significant role in facing the challenges of food supply and sustainability that will come with the next century. We believe that by joining efforts with partner institutions with national or international responsibilities, we will reduce research costs, avoid duplication, and boost efficiency. Above all, such collaboration, which is often linked to training, helps empower NARS scientists to become self-reliant, the true essence of long-term sustainability.

Table 1. Contributions of potato as food, feed, and industrial products throughout the world.

Years	Utilization (% availability)				Waste
	Food	Feed	Seed	Processed and other uses	
1961-65	41.1	29.3	16.8	3.9	9.0
1976-80	44.3	27.0	13.5	6.6	8.6
1986-90	48.9	22.8	12.2	7.7	8.4

SOURCE: FAO.