POTATO PRODUCTION SYSTEMS AND DISEASE RESISTANCE

L.M. Kawchuk
Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge, Canada

Keywords: Disease prevention, Irish potato, marker-assisted selection, pathogens, pests, potato, resistance, R- genes, Solanaceous, tubers, vegetative.

Contents

Summary

Potato, commonly known as Irish potato, is the most important non-grain food in the world producing more food energy per unit of land area than any other crop. Potato structure, genetic uniformity, and vegetative growth are critical to management decisions that result in maximum yield and highest quality tubers. *Solanum* is a large and diverse genus of annual and perennial plants with thousands of species although many are not tuber bearing. The genus presently contains roughly 1,500-2,000 species, is the largest genus in the Solanaceae, and one of the largest genera of flowering plants.

The potato is basically a temperate region crop which can be grown on almost any type of soil, provided it retains a reasonable amount of moisture, is well drained and holds a good structure and aeration.

World potato production has been estimated at 325 million tons in 2007 with production and consumption in developing countries now exceeding that in many developed nations, in part due to the relatively low costs of production. Probably the most critical aspect of production involves the planting of healthy seed and maintaining a healthy soil environment. Diseases are a continuous threat and many countries have established certification systems for the prevention of disease. Lack of resistance often results in poor yields and quality that contributes to food shortages, as occurred with the Irish Famine in the middle of the 19th century.

Considerable progress has been made in the development of diagnostics and disease resistant cultivars. A major application of isolated R genes to date has been in the development of disease resistant varieties through marker-assisted selection, considerably accelerating cultivar screening and development. This has improved the economics associated with potato production and trade.

1. Introduction

Potato (*Solanum tuberosum* ssp. *tuberosum* L.), sometimes called European or Irish potato to differentiate it from the sweet potato (*Ipomoea batatas*), is the most important non-grain food in the world and a key component of the global sustainable food system producing more food energy per unit of land area than any other crop. Its importance as a food source throughout history and susceptibility to disease is highlighted by the role played in the Great Irish Famine of 1845 and, more recently, increases in worldwide production. The increase in production and consumption by countries in Asia, Africa, and Latin America has recently surpassed the demand in Europe, North America, and countries from the former Soviet Union. The United Nations named 2008 the International Year of the Potato to highlight its importance as a food source.

The potato originated almost 10,000 years ago in the Andes Mountains and is usually a crop of cool, temperate regions or of high elevations. Cultivated potatoes are derived from many tuber bearing species but the most commonly grown potato is the tetraploid *Solanum tuberosum L*. Cultivated potato varieties have little genetic diversity and the vegetatively propagated crop has very specific requirements and many production challenges such as diseases. Potato is closely related to tomato, pepper, tobacco, and eggplant. *Solanum* species exhibit great morphological and reproductive diversity and many species of the genus have been used as model organisms for the examination of many biological questions.

2. Taxonomy

Solanum is a large and diverse genus of annual and perennial plants. They grow as vines, shrubs, and small trees, and often have attractive fruit and flowers. Many formerly independent genera like *Lycopersicon* (tomatoes) or *Cyphomandra* (tree tomatoes) are now included in *Solanum* as subgenera or sections. Thus, the genus presently contains roughly 1,500-2,000 species, is the largest genus in the Solanaceae, and one of the largest genera of flowering plants.

The potatoes cultivated in the Andes are not all the same species. However, the major species grown worldwide is *Solanum tuberosum* (a tetraploid with 48 chromosomes) and varieties of this species are the most widely cultivated (Pieterse and Hils, 2007). More than 5,000 potato varieties exist worldwide, arising from a few species mostly found in the Andes, mainly in Peru, Bolivia, Ecuador, Chile, Mexico, and Colombia. There are two major subspecies of *Solanum tuberosum*: *andigena* (Andean) and *tuberosum* (Chilean). The Andean potato is adapted to the short-day conditions prevalent in the mountainous equatorial and tropical regions where it originated. The Chilean potato is adapted to the long-day conditions prevalent in the higher latitude region of southern Chile.

There are also diploid species (with 24 chromosomes), triploid species (with 36 chromosomes), and one pentaploid cultivated species (with 60 chromosomes). Many of the wild species can be crossbred with cultivated varieties to transfer value-added traits such as resistance to certain pests and diseases. Germplasm of the *Solanum* species is maintained and is available from germplasm repositories for research and breeding applications.

Cultivated potato was domesticated some 10,000 years ago from a group of wild potato species. Most modern potato varieties originate from European introductions dating back to approximately 1500 AD and not directly from the South American sources. However, introgressions have been made from other centers of genetic variability for potato such as Mexico, where important wild species are found that have been used extensively in modern breeding. For example, the hexaploid *Solanum demissum,* is a source of resistance to the devastating late blight disease. One of the most destructive diseases of potato, late blight contributed to the Great Irish Famine of 1845. Another plant native to this region, *Solanum bulbocastanum*, a close relative of the potato, has been used to develop potatoes that effectively resist potato blight.

3. Botany and Composition

The potato plant's basic structure and vegetative growth are critical to management decisions that result in maximum harvest and tuber quality. It is an annual, herbaceous, dicotyledonous plant and although propagation from true seed is common in potato breeding programs, most commercial production propagates the potatoes from tubers. Stems are angular in cross-section with secondary branches arising from axillary leaf meristems. Leaves are pinnately compound and arranged in a spiral pattern around the stem. Potatoes are cross-pollinated mostly by insects, including bumblebees that carry pollen from other potato plants, but self-fertilizing may occur as well. After potato plants flower, some varieties will produce small green fruits that resemble green cherry tomatoes, each containing up to 300 true seeds. Potato fruit may contain large amounts of the toxic alkaloid solanine, and is therefore unsuitable for consumption.

Potato tubers are the enlarged tips of underground adventitious stems called stolons and contain approximately 80% water and 20% dry matter. Carbohydrates are stored as starch that constitutes approximately 80% of the dry matter and the remainder consists of protein and at least 12 essential vitamins and minerals including vitamin C, thiamine, iron, folic acid, and potassium. Size, shape, appearance, absence of diseases or defects, flavor, and texture all contribute to a potato's quality, visual appeal, consumer preference, and ability to meet market specifications. Tuber eyes are the buds from which next season's growth will emerge. Eyes are concentrated near the apical end of the tuber, with fewer near the stolon or basal end. Eye number and distribution are characteristic of the variety. Tubers form in response to decreasing day length, although this tendency has been minimized in commercial varieties.

The tuber skin is composed of several layers of cells called the epidermis, covering several layers of cells called the periderm. The cells in one layer of the periderm often contain a pigment that produces colored potatoes. Below the periderm is the cortex, followed by the vascular ring, which contains the cells that transport sugars and nutrients between the tuber and the above ground stems. Internal to the vascular ring is the medulla which represents the primary storage area for the potato tuber. Sugars and nutrients produced by the potato plant are transported to the medulla via the vascular tissue. Cells in the medulla increase in number and size as they are supplied with sugars and nutrients, causing the tuber to increase in size.

4. Ecology and Growing Conditions

By far the greatest number of *Solanum* species occur in South America, especially on the slopes of the Andes, but additional centers of endemic diversity are found in North America and Mexico, Central America, eastern Brazil, the West Indies, Australia, Africa, and Madagascar. Within their range, *Solanum* species occupy a huge diversity of habitats, from the wettest forests in the world to the driest deserts. *Solanum* species are found throughout a huge altitude range, from sea level to over 4500 m in the case of some potatoes.

Growth and quality of potatoes are influenced by environmental factors including temperature, moisture, light, soil type and nutrients. These natural factors define in first instance the aerial distribution of the crop, worldwide. In addition, growth and production quality can be affected and improved by technological and management conditions, including crop variety, size of seed, plant density, moisture supply (rain fed or by irrigation), nutrition, pest and disease management, planting and harvest dates, etc.

4.1. Climate

4.1.1. Temperature

The potato is basically a cool-season crop, since optimum tuber formation takes place at a mean daily temperature of about 18 °C. Highest yields are therefore obtained in temperate climates. However, potatoes are also grown successfully in subtropical areas under irrigation in the cool season, and in the tropics at altitudes above 1200 m.

The temperature range for potato growth is between 8 and 30 °C, with an optimum between 16 and 20 °C. The growth of tubers is inhibited at temperatures below 10 °C and above 27 °C. The optimal soil temperature for tuber formation is 18 °C. Tuber development declines as soil temperatures rise above 20 °C. The number of tubers per plant is greater at lower temperatures; high temperatures encourage the development of large tubers. Overall, yields are highest with average daytime temperatures of about 21 °C.

Night temperatures below 15 °C and cool weather favor tuber development. Cool night temperatures are important because they affect the accumulation of carbohydrates and specific gravity of the tubers. Lower night temperatures slow down respiration and enhance storage of starch in the tubers. The crop is damaged by frost.

In Canada and a number of other countries the energy requirements for crops are expressed as cumulative degree days above a critical temperature (i.e. approximately 7 °C) referred to as heat units. The varieties currently grown in Canada for example usually require anywhere from 800 to 1000 heat units to reach full maturity. An early-maturing variety such as *Norland* requires 800 heat units, and later maturing varieties such as *Russet Burbank* require 1000 heat units. Growing potato varieties in an area with insufficient heat units will reduce yield and affect tuber quality such as accumulation of solids and fry color. Accumulation of heat units is often insufficient to produce late season varieties where the crop must be fully mature before harvest. These areas may still be suitable for seed or table production, where the crop is killed or harvested before full maturity.

4.1.2. Rainfall or Moisture Supply

Potatoes require a consistent supply of water along with adequate soil aeration. Since the plant's root system is shallow, potatoes are susceptible to water stress. For optimal growth, rainfall should therefore be evenly distributed, with a minimum of 100 mm per month, and an overall precipitation of 400 to 700 mm over the growth cycle. The length of the growing season is crop-dependent and varies from 90-100 days (early varieties) to 120-150 days (medium-maturing varieties) to almost 180 days (late maturing varieties). Potatoes do not tolerate flooding nor drought. Too much moisture enhances rotting of the tubers; water shortage hastens maturation and reduces yields.

Yields are greatest when soil moisture is maintained above 65% of the available soil water capacity. Tuber set is particularly sensitive to moisture stress. There are generally fewer tubers set when available soil moisture is maintained below 65% of the available soil water capacity. The amount of water needed by potatoes varies with the soil type (moisture retention), temperature, air humidity and air movement (evaporative losses), plant density, variety and cultural practices. In Alberta and Saskatchewan for example, too little moisture and fluctuating moisture levels are more common than excessive moisture. In Manitoba, the situation is reversed.

Too much moisture generally causes more problems than too little moisture. Low or fluctuating moisture levels can contribute to common scab, early dying, hollow heart, knobby tubers, low dry matter, low tuber set, and low yield. Excessive soil moisture resulting in poor aeration and water logging of the soil, reduces yields and in extreme cases causes tuber rot. An excess of moisture may also lead to enlarged lenticels, which are openings of the epidermis. This detracts from their appearance and allows entry of disease organisms, causing tuber rot in storage.

4.1.3. Photoperiod

Day-length and photoperiod play an important role in the tuber development, which is triggered when the length of daylight falls below a critical threshold. This varies from one variety to another. The short days of tropical regions always favor tuber development though, after all, the major factor in this process remains the (cool) night temperature.

4.2. Soils

Potatoes can be grown on almost any type of soil, provided it has a good moisture holding capacity, is well drained and aerated, and has a minimum depth of 50-75 cm. The crop prefers light to medium-textured soils (sandy clay or clay loam to loam and silt loam), especially when mechanical harvesting is operated. Heavy clays cause poor emergence, poorly shaped tubers and harvesting problems. The soils must also be well structured and easily workable.

Potatoes require a moderate to high soil fertility, with an organic matter content as high as possible. The crop can support a wide range of pH (from 4.2 to 8.2), but grows best under slightly acid conditions (pH between 5.5 and 7.0). The nutrient removal (kg/ha/growing cycle) to produce 25 tons/ha is estimated at: 115 kg N, 45 kg P_2O_5, 200 kg K_2O, and 70 kg Ca. To compensate for this export of minerals a complete NPK fertilization is needed. Nitrogen application promotes vegetative growth. Phosphate increases the starch content in the tubers, and potassium improves tuber quality and resistance to diseases. The crop is, however, susceptible to chlorides and to salinity. Alkaline conditions (pH above 8.5) adversely affect skin quality and might enhance micronutrient deficiencies.

-

-

Bibliography

Ballvora, A., Ercolano, M.R., Weiss, J., Meksem, K., Bormann, C.A., Oberhagemann, P., Salamini, F., and Gebhardt, C. (2002). The R1 Gene for Potato Resistance to Late Blight (Phytophthora infestans) belongs to the Leucine Zipper/NBS/LRR Class of Plant Resistance Genes. *Plant J.*, **30:** 361-371. [Article describes the first late blight resistance gene isolated and describes one of the most common structures observed in plant disease resistance genes].

Brigneti, G., Voinnet, O., Li, W.-X., Ji, L.-H., Ding, S.-W., and Baulcombe, D.C**.** (1998). Viral Pathogenicity Determinants are Suppressors of Transgene Silencing in Nicotiana benthamiana. *EMBO J.*, 17: 6739–6746. [Research describes discovery of a virus protein that turns off the plant RNA silencing pathways that protect against infection].

Fire, A., Xu, S., Montgomery, M.K., Kostas, S.A., Driver S.E., and Mello, C.C. (1998). Potent and Specific Genetic Interference by Double-stranded RNA in Caenorhabditis Elegans. *Nature*, 391: 806-811.

[RNA silencing work awarded a Nobel prize for explaining the mechanism behind a critical defense and regulatory pathway observed in many organisms].

Flor, H.H. (1971). Current Status of the Gene-For-Gene Concept. *Annual Review of Phytopathology*, 9**:** 275-296. [Early model for disease resistance developed from genetic analysis that was later supported by molecular advances].

Gheysen, G., and Vanholme, B**.** (2007). RNAi from Plants to Nematodes. *Trends Biotechnol*, 25**:** 89-92. [Recent review describing the advances in discovery and application of RNA silencing pathways that protect against infection].

Hoekema, A., Huisman, M.J., Molendijk, L. van den Elzen, P.J.M., and Cornelissen, B.J.C. (1989). The Genetic Engineering of Two Commercial Potato Cultivars for Resistance to Potato Virus X. *Biotechnology*, 7**:** 273-278. [An early application of advances in molecular disease resistance that introduced potato virus resistance into commercial potato cultivars].

Holger, N., Kawchuk, L., Zimmermann, S., Junghans, H., Winter, S., Fischer, R., and Prüfer, D. (2008). Plantibody-mediated Inhibition of the Potato Leafroll Virus P1 Protein Reduces Virus Accumulation. *Virus Research*, 136**:** 140-145. [A recent study that showed that other virus proteins such as the genome linked protein may be targeted to help prevent infection and reduce disease levels].

Jones, D.A., Thomas, C.M., Hammond-Kosack, K.E., Balint-Kurti, P.J., and Jones, J.D. (1994). Isolation of the Tomato Cf-9 Gene for Resistance to Cladosporium Fulvum by Transposn Tagging. *Science*, **266:** 789-793. [First description of a cell surface receptor for disease resistance and one of the largest disease resistance genes identified].

Kasschau, K.D. and Carrington, J.C**.** (1998). A Counter-defensive Strategy of Plant Viruses: Suppression of Post-transcriptional Gene Silencing. *Cell*, 95: 461–470. [Research describes discovery of a virus protein that turns off the plant defence pathway involving RNA silencing].

Kawchuk, L.M., Lynch, D.R., Martin, R.R., Kozub, G.C., and Farries, B. (1997). Field Resistance to the Potato Leafroll Luteovirus in Transgenic and Somaclone Potato Plants Reduces Tuber Disease Symptoms. *Can J. Plant Path*., 19**:** 260-266. [Field evaluation of commercial potato varieties developed with disease resistance to one of the most destructive potato viruses].

Kawchuk, L.M., Hachey, J., Lynch, D.R., Kulcsar, F., van Rooijen, G., Waterer, D.R., Robertson, A., Kokko, E., Byers, R., Howard, R.J., Fischer, R., and Prufer, D**.** (2001). Tomato Ve Disease Resistance Genes Encode Cell Surface-like Receptors. *Proc. Natl Acad. Sci*. USA, 98**:** 6511-6515. [Isolation of the gene found in most commercial tomato varieties that provides disease prevention against a common fungal pathogen].

Leister, D., Ballvora, A., Salamini, F., and Gebhardt, C**.** (1996). A PCR-based Approach for Isolating Pathogen Resistance Genes from Potato with Potential for Wide Application in Plants. *Nat. Genet*., 14**:** 421-429. [An approach is described to help with the isolation of additional disease resistance genes based on the conserved features found in those isolated to date].

Pieterse, L. and Hils, U. 2007. World Catalogue of Potato Varieties. AgriMedia. [Description of many potato varieties and their development that provides information regarding agronomic and disease response].

Powell, P.A., Nelson, R.S., De, B., Hoffmann, N., Rogers, S.G., Fraley, R.T. and Beachy, R.N. (1986). Delay of Disease Development in Transgenic Plants that Express the Tobacco Mosaic Virus Coat Protein Gene. Science, 232:738-743. [First development of virus resistance plants using the virus and genetic engineering of the plant].

Rolot, J.L. (s.d.). Potato. In: R. Raemaekers, ed.: *Crop Production in Tropical Africa*. Dir. Gener. Intern. Coop., Ministry Foreign Affairs Belgium, Brussels, 188-204 [Excellent publication giving for a wide range of crops their growth and production requirements, including fertilizer needs].

Song, J., Bradeen, J.M., Naess, S.K., Raasch, J.A., Wielgus, S.M., Haberlach, G.T., Liu, J., Kuang, H., Austin-Phillips, S., Buell, C.R., Helgeson, J.P., and Jiang, J. (2003). Gene RB Cloned from Solanum Bulbocastanum Confers Broad Spectrum Resistance to Potato Late Blight. *Proc. Natl Acad. Sci*. USA, 100**:** 9128-9133. [A highly effective late blight disease resistance gene isolated from a wild potato species].

Stark, J.C. and Love, S.L. 2003. *Potato production Systems. Educational Communications,* University of Idaho. [Provides details on the fundamentals of potato production ranging from genetic engineering and breeding to product quality].

Waterhouse, P.M., Wang, M.B., and Lough, T. (2001). Gene Silencing as an Adaptive Defence against Viruses. *Nature*, 41**:** 834-842. [The gene silencing mechanisms in plants available to protect against viruses is described showing the different features of these critical pathways].

Biographical Sketch

Dr. Lawrence Kawchuk is a research scientist with the Canadian Federal Government, Department of Agriculture and Agri-Food Canada, at the Lethbridge Research Centre, and an Adjunct Professor with the Department of Biology at the University of Lethbridge. He obtained his graduate degrees from the University of Manitoba and University of British Columbia and has over 20 years experience in plant disease research. His main interests involve the prevention of disease through advances in understanding host-pathogen interactions at a molecular level. Research activities include the positional cloning and marker-assisted selection of disease resistance genes, development of diagnostics for pathogens and value-added traits, and application of silencing strategies to prevent disease and improve food production.

Dr. Kawchuk is an Australian Endeavour Fellow and recipient of the Gordon Green Medal of the Canadian Phytopathological Society, has served as an editor for several scientific journals, and chaired international scientific and industry initiatives. He has authored about 100 peer-reviewed publications in scientific journals and books.