Worldwide Distribution of Potato-Cyst Nematodes and Their Importance in Crop Production[1]

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Abstract: The potato-cyst nematodes *Heterodera rostochiensis* and *H. pallida* are important pathogens of potatoes, a basic food crop. When soil populations of either species are high, potato yields are often less than the seed planted. Apparently, these nematodes originated in the Andean mountains of South America, the home of the potato. One or both species have spread from this region to approximately 47 countries. The two species may occur together or separately in potato-growing areas. Although these nematodes can be spread in numerous ways, contaminated soil associated with seed potatoes, farm machinery, and reusable containers is among the most important. An integrated control program used in the U.S.A. is described. *Key Words: Heterodera rostochiensis, Heterodera pallida,* origin, spread, control.

Potato-cyst nematodes are important pathogens of potatoes (*Solanum tuberosum* ssp. *tuberosum; S. tuberosum* ssp. *andigena*), a basic world food. Tomatoes (*Lycopersicon esculentum* Mill.) and, to a lesser extent, egg plants (*Solanum melongena* L.) are the only other crops known to be attacked by these nematodes. A number of Solanaceous weeds are also hosts.

Prior to 1972, there was only one described species, *Heterodera rostochiensis* Wollenweber. This nematode was known by a number of common names, including "potato-root eelworm," "golden nematode," and "potato-cyst nematode." In 1972 a second species, *H. pallida* Stone, was described (9). In this paper, the two species will be referred to as the "potato-cyst nematodes."

YIELD LOSSES

Potato-cyst nematodes occur in most countries in which potatoes are grown commercially. In heavily-infested fields, yields often amount to less than the tubers planted. I will not attempt to estimate the worldwide value of potato yield losses caused by these nematodes but they are considerable.

In addition to suppressing potato yields, potato-cyst nematodes cause economic losses indirectly. In some areas, interactions of these nematodes with other microorganisms result in even higher yield losses than those caused by these nematodes alone. Where numbers of nematodes in soil are high, the need to grow low-yielding and less important food crops in rotation with potatoes is an indirect loss to a grower, country, or region. Restriction of the activities of those involved in agricultural industries (such as nurseries) by a potato-cyst nematode quarantine lowers total agricultural income. The actual cost of regulatory activities such as border inspections, field surveys, and treatment of soil and other materials with nematicides is substantial.

The losses caused by potato-cyst nematodes at high altitudes of the Andean mountains of South America are particularly important because potato is one of the very few crops that can be grown in these areas. Where numbers of nematodes in soil are high, and high numbers occur in most potato-producing areas in the Andes, these nematodes limit production. According to Spears (personal communication), yield in a heavily-infested soil in Chile was less than the seed planted although the fertilizer rate had been increased to 5 times that of normal rate.

Because of the rugged terrain, it is difficult to transport other food to the Andes. When food is brought from other areas, the very poor people living in the high Andes are unable to pay for it.

Potato yields in the Andes are suppressed by insects, diseases caused by viruses, fungi, and bacteria, as well as by other nematodes. In some areas, particularly in Bolivia, *Nacobbus* spp. are considered to be more serious than potato-cyst nematodes. At the present time, there is no satisfactory control measure for potato-cyst nematodes in the Andes.

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IDENTIFICATION

During a campaign against sugar beet-cyst nematodes (*H. schachtii* Schmidt) in Germany, Julius Kuhn observed a cyst-forming nematode attacking potatoes (6). He did not consider it a serious pest of potatoes and regarded it as a sub-race of *H. schachtii*. Results of later tests by a number of workers (8) proved that these nematodes were the cause of "soil sickness of potato." In Germany, Wollenweber (10) in 1923 concluded that the nematode attacking potatoes was a different nematode from the one attacking sugar beets, and he proposed the name *H. rostochiensis* for the one attacking potatoes. He proposed a new species because he observed that larvae from potatoes were slightly shorter and that the cysts were spherical rather than lemon shaped. It was not until considerably later that *H. rostochiensis* was generally recognized as a valid species.

In the late 1950s, resistance-breaking pathotypes were discovered when potato selections and varieties with resistance to *H. rostochiensis* derived from *S. andigenum* were grown in some fields in Great Britain and Europe. In 1972, resistance-breaking pathotypes with white or cream immature females were found in England and described as a new species by Stone (9). In contrast, the immature females of *H. rostochiensis* turn golden yellow. Other differences between the two species include stylet length, shape of stylet knobs, and number of cuticular ridges between anus and fenestra.

ORIGIN

For many years, potato-cyst nematodes were thought to have originated in Europe (3). Although a number of possibilities were proposed, there was no evidence to support the theory of European origin or to explain how they became important potato pests. Potatoes are thought to have originated in the Andean region of South America (7).

Spears (8) describes the discovery of these nematodes in Peru. On April 3, 1951, a ship from Peru arrived at the port of Seattle, Washington, U.S.A. Plant-quarantine inspectors of the U.S. Department of Agriculture made a routine inspection of the ship for plant pests and collected soil (from potatoes in the ship's stores) in which cysts of the potato-cyst nematode were found. In September 1951, a ship from Peru in New York harbor was inspected, and cysts of these nematodes were found in two different collections. Since these pests had not been previously reported in Peru, a careful check was made of the ship's log to make certain that stores from ports other than Peru had not been taken aboard. A field survey was made in 1952, and potato-cyst nematodes were found near Tarma, Peru. Since then, they have been found widely distributed in potato-growing areas of a number of countries in the Andes.

DISTRIBUTION THROUGHOUT THE WORLD

Prior to 1900, these nematodes were known to occur only in Germany (8). From 1900-1930, they were found in Scotland, England, Sweden, Ireland, Denmark, and Wales; from 1931-1940, in Northern Ireland, Jersey and Austria; from 1941-1950, in The Netherlands, U.S.A., Poland, Finland, France, U.S.S.R., and Belgium; 1951-1960, in Greece, Faeroe Islands, Guernsey, Peru, Saarland, Bolivia, Algeria, Iceland, Spain, Czechoslovakia, Luxembourg, Norway, Portugal, Israel, Argentina, Switzerland, and Canary Islands; 1961-1970, in India, Canada, Italy, Yugoslavia, Chile, Panama, Tunisia, and Venezuela; and from 1971-present, South Africa, Japan, Mexico, New Zealand, and Colombia (8; Spears, personal communication).

DISTRIBUTION OF *HETERODERA ROSTOCHIENSIS* AND *H. PALLIDA*

Since 1972, considerable information has been obtained concerning the distribution of the two species. According to K. Evans (personal communication), both species occur only in the central and western European countries; in the south and east of Europe, only *H. rostochiensis* occurs. In The Netherlands and Germany, *H. pallida* is distributed throughout the infested areas, but in the United Kingdom there are pockets that are predominantly either *H. rostochiensis* or *H. pallida*. These facts suggest that single-species introductions

were made and that the original introduction from the Andes predominates. Only *H. rostochiensis* has been found in the U.S.A. (M. B. Harrison, personal communication).

According to Evans et al. (4), only *H. pallida* occurs in Colombia, Ecuador, and most of Peru. In southern Peru, *H. pallida* and *H. rostochiensis* occur together (4). Few populations have been examined from Bolivia but both species were found there. The species occurring in Argentina and Chile have not been determined. Evans et al. suggest that the distribution of the two species is influenced by latitude, which in turn suggests that distribution may be determined by either the temperature regime or day length. North of 15.6°S, only *H. pallida* was found, but south of this latitude most populations examined were *H. rostochiensis* or a mixture of the two species. Another possible explanation for this distribution is that *H. rostochiensis* fails to reproduce well on *S. andigenum* and is only common where the dominant tetraploid species used by the Indians is *S. tuberosum*.

Spread from South America to Europe: Although there are few exact data related to this subject, from the information available Evans et al. (4) concluded that potato-cyst nematodes were brought to Europe with collections of potato tubers imported from South America to breed for resistance to potato late blight caused by *Phytophthora infestans*. This breeding material was collected in South America after the sudden appearance of late blight which caused high yield losses in 1845 and 1846 and resulted in the Irish famine. Although potatoes were probably transported to Europe in the late 1500s shortly after the Spanish invasion of Peru, these authors considered it unlikely that extensive potato collections were transported to Europe prior to 1845.

Spread from Europe to the Western Hemisphere: The first evidence that potato-cyst nematodes had been transported westward across the Atlantic Ocean from Europe occurred when a potato grower on Long Island, New York, U.S.A. noticed a few isolated spots in his field where vines were stunted and off color. Within 4 years, despite attempts to improve growth by practices such as fertilization and liming, the number of spots increased, and there were significant yield losses in the field. In 1941, Orson Cannon (a graduate student in the Department of Plant Pathology, Cornell University) observed swollen females on potato roots which were identified as *H. rostochiensis* by Chitwood (2). Where the inoculum originated and how and when it gained entrance into the U.S.A. is not known. A possibility is that it was transported on military equipment to a temporary camp on Long Island after World War I. From the extent of the infestation in 1941 and the history of the field, the infestation probably had been present for approximately 20 years.

Means of spread: The potato-cyst nematode is spread in many ways. A few examples from the U.S.A. and Canada serve to illustrate some important means of spread. On Long Island, New York, U.S.A., the reuse of burlap bags for picking potatoes and the movement of farm machinery by renters of land were important in local spread. More than 30 fields farmed by the same operator of the original infested field were found infested. Although there are many examples of the importance of contaminated seed potatoes in the distribution of these nematodes, this means of spread was not an important factor on Long Island because the high rate of virus spread kept seed production to a minimum. An example of the importance of reused containers in spreading nematode cysts was an infestation found on a small vegetable farm in New Jersey. The owner worked in a nearby carpet-factory and brought "cleanings" from second-hand burlap bags (from Europe) to his farm and added them to the soil. These bags, which were used as backing for carpets, were contaminated with nematode cysts, and thus many cysts were added to the soil. Spread from this infestation was eliminated by treating the soil with a nematicide and removing the land from agriculture.

The importance of contaminated soil carried along with plant materials other than potatoes is illustrated by an infestation discovered in 1965 on Vancouver Island in British Columbia, Canada (8). According to Spears (8), the infested property belonged to a grower who had previously

grown ornamental bulbs imported from Europe. The last crop of bulbs was grown in 1938; between 1938 and 1950 he grew various crops; and from 1950 until 1965, he grew potatoes every year. The history of this infestation also demonstrates the importance of the ability of encysted nematodes to survive in the absence of a host crop (more than 20 years) and the length of time (15 years in this instance) required for low soil populations to increase to damaging levels. This infestation also illustrates the importance of monocropping or narrow rotations in the build-up of these nematodes in the soil. Severe crop losses are caused by these nematodes only when a host crop is grown repeatedly.

Spread in relation to birds: Inagaki and Kegasawa (5) concluded that potato-cyst nematodes were transported from Peru to Japan along with guano used as fertilizer. Inagaki, (personal communication) in Japan and Brodie (personal communication) at Cornell University, Ithaca, New York have shown that internal temperatures of some birds are lethal to potato-cyst nematodes. Brodie (1) also showed that exposure of encysted nematodes to bird excreta is lethal. These data, in addition to the fact that Peruvian guano comes from off-shore islands on which potatoes are not grown, indicate that contaminating cysts probably come from waste soil on used burlap bags or vessel holds.

CONTROL

The control program in various countries varies from essentially no program to a very complicated one involving several control measures. Some of the control measures used in one or more countries are: *(i)* prohibition of growth of host crops, *(ii)* enforced or voluntary rotations, *(iii)* growing resistant potato varieties, *(iv)* soil treatment with nematicides, *(v)* treatment of containers and machinery with heat or nematicides, *(vi)* soil or plant surveys, and *(vii)* washing and/or chemical treatment of potato tubers to be used for seed.

The control program for *H. rostochiensis* in the U.S.A. represents one of the most extensive pest-management programs ever attempted. The major difference between this program and most pest-management programs is that, in this program, the objective is to keep *H. rostochiensis* populations below the discovery level while, in most programs, the objective is to maintain the population level of a particular pest or pests below the damaging level. The U.S.A. program is a cooperative effort among growers, state and federal regulatory agencies, USDA-ARS, and the New York State College of Agriculture. One of the most important ways to keep nematode numbers low is by not planting a host crop on soil known to be infested with living individuals of *H. rostochiensis*. The limited host range of this nematode makes such a program feasible. Planting a host crop on known infested land is prevented by quarantine regulations.

The U.S.A. integrated control program involves: *(i)* extensive surveys to determine distribution and spread of *H. rostochiensis;* *(ii)* preventing potato seed production in known infested and exposed areas; *(iii)* regulation of the use of resusable containers in potato production; *(iv)* regulation of the movement of such items as farm machinery, top soil, and plant materials; *(v)* use of nematicides to reduce numbers of nematodes in soil; and *(vi)* use of resistant varieties to prevent increase of nematode numbers in soil (rather than to obtain satisfactory yields despite high numbers).

Some advantages of the U.S.A. program are: *(i)* potato growers do not experience yield losses; *(ii)* agricultural industries other than the potato industry are protected; *(iii)* because of low populations, chances for development of resistance-breaking pathotypes of *H. rostochiensis* are reduced; *(iv)* rate of spread of *H. rostochiensis* is greatly reduced; and *(v)* new infestations in areas of the U.S.A. other than Long Island have been discovered before populations have reached high densities and thus spread from them has been minimized.

A disadvantage of this program is that it is expensive. It is particularly expensive if benefits for only a few years are considered. If such a program, with modifications based on future research, will help prevent the disasterous situation which now occurs in parts of the Andean Mountains of South America, this control program will be considered far less expensive.

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