Prevalence and Pathogenicity of Foot and Root Rot Pathogens of Pea in Southern Scandinavia

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ABSTRACT

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The occurrence of root pathogens of vining pea was determined in field surveys in Sweden and Denmark from 1989 to 1994. The most serious yield-reducing root pathogen, *Aphanomyces euteiches*, was found in approximately one-third of the sampled fields in both Sweden and Denmark. In a few fields severely infested with this pathogen, there was a total crop failure. The most frequently isolated pathogens were *Phoma medicaginis* var. *pinodella* and *Fusarium solani*; the latter also was isolated from vascular tissue up to the seventh node level. Other pathogens isolated from roots were *F. avenaceum*, *F. oxysporum*, *F. culmorum*, *Chalara elegans*, *Pythium irregulare*, and *Mycosphaerella pinodes*. In greenhouse pathogenicity tests, *A. euteiches* caused the most severe root damage and plant death of pea, followed by *F. avenaceum* and *P. irregulare*. There was an inverse relationship between field disease severity index and yield for fields infested with *A. euteiches*.

In many areas, root and foot rots caused by a complex of soilborne pathogens are among the most destructive diseases of pea (*Pisum sativum* L.). *Aphanomyces euteiches* Drechs. is reported to be the most important pathogen in the pea root rot complex in several countries, e.g., Sweden (15, 31), Norway (38), the U.S. (17,34), The Netherlands (32), and New Zealand (12). Specialized physiological races of *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *pisi* (C. J. J. Hall) W. C. Snyder & H. N. Hans., that cause wilted plants, are also serious problems (17). However, in many pea production areas, the introduction of resistant varieties has reduced wilt diseases to an acceptable level. Other reported pathogens causing foot and root rot are *F. solani* (Mart.) Sacc. f. sp. *pisi* (F. R. Jones) W. C. Snyder & H. N. Hans., *Phoma medicaginis* Malbr. & Roum. var. *pinodella* (L. K. Jones) Boerema, *Mycosphaerella pinodes* (Berk. & Bloxam) Vesterg., *Pythium* spp., *Chalara elegans* Nag Raj & Kendrick (synonymorph = *Thielaviopsis basicola* (Berk. & Broome) Ferraris), and *Rhizoctonia solani* Kühn (1,2,17,22,39). The importance of these pathogens varies according to location, climate, and crop management strategy.

In southern Scandinavia, vining pea has been cultivated since the 1950s. In order to avoid disease problems, pea is usually not grown in crop rotations more frequently than one in every six years in Sweden and one in every four to five years in Denmark. In Sweden, the root rot potential of pea fields has been assessed each year since 1958 (31) with a method modified from Sherwood and Hagedorn (37), whereas the method was first introduced in Denmark in 1992 (5). Despite soil indexing, problems with root rot still occur.

Our surveys were conducted to determine which pathogens are the most prevalent and serious in pea fields in southern Scandinavia. The results will be used to develop more effective control strategies.

MATERIALS AND METHODS

Field surveys. Plant samples were taken from commercial fields owned by farmers growing several different vining pea cultivars on contract for three companies. The fields were arbitrarily selected from the three growing areas. The number of previous pea crops in each field varied between zero and six. In 1989 to 1991, 223 fields were surveyed in Denmark in two separate areas, Funen and Lolland-Falster. In 1993 and 1994, 83 fields were sampled in the west and middle parts of the province of Scania in southern Sweden. Yield data were obtained in the Swedish survey for determining the relationship between disease severity and yield.

Samples were taken at the beginning of the flowering stage, which started at the end of May (early-sown crops) and lasted

until the end of July (late-sown crops). The fields were sampled in a W-pattern over the field and 20 (Denmark) or 100 (Sweden) arbitrarily chosen plants per field were removed from the soil to a depth of approximately 20 cm. The plants were put in plastic bags and transported to the laboratory, where roots and epicotyls were washed. Disease was assessed by visual examination of the roots and epicotyls according to a method modified from Sherwood and Hagedorn (37) and Olofsson (31). A disease severity index (DSI) was given to each plant as follows: 0 = healthy plant without any visible symptoms; 5 = discoloration of less than 5 mm on a single root; 10 = discoloration of about 20 mm of the root system; 25 = about 50% of the root system was dark and affected; 50 = the whole root system was dark and affected but no symptoms on epicotyl or leaves; 75 = the whole root system, as well as the epicotyl, was dark and affected and the lowest leaves were wilted; and 100 = dead plant. An average field disease severity index (FDSI) was calculated for each field.

Isolation of fungi. Isolations of fungi were made from 5 to 10 symptomatic plants per field. Roots from the arbitrarily selected plants were washed and placed under running tap water for at least 1 h. In the Danish survey, the roots were surface disinfected in 1.5% sodium hypochlorite for 2 min and dried between pieces of sterile filter paper. From the interface between apparently healthy and diseased tissue of epicotyls and roots, small transverse sections were cut and transferred to plates with selective agar media described below. In the Swedish survey, segments from the root system were plated directly on the media without surface disinfection. However, in 1993, one additional set of root pieces was surface sterilized in 1.5% sodium hypochlorite for 4 min, rinsed in water, and plated. Isolations were made from only a few wilted plants with red vascular tissue (surface sterilized) because typical *Fusarium* wilt symptoms are rare in Scandinavia. In both surveys, root pieces put on media for isolation of *A. euteiches* were not surface disinfected because such treatment can prevent the fungus from growing out (27).

In the Danish survey, plates with the *Aphanomyces*-selective MBV medium (35), potato dextrose agar (PDA), and a

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synthetic meager agar (SNA) (30) amended with 25 µg of tetracycline per liter (Sigma Chemical Co., St. Louis, MO) and 50 µg of chloramphenicol per liter (Sigma) were used. *C. elegans* was isolated on semiselective medium VDYA-PCNB (33) with a dilution plate method described by Blume and Harman (4). In the Swedish survey in 1993, we used media as follows: selective medium for *Aphanomyces* spp. (SMA) (27); semiselective medium for *Pythium* spp. (SMP) (24) with 50 mg of streptomycin sulfate per liter of distilled water; selective medium for *Phytophthora* spp. (SMPh) (26); and a medium denoted PDS that contained 19.5 g of PDA amended with 12.5 mg of metalaxyl (Ridomil, 25% a.i.) and 100 mg of streptomycin sulfate per liter of distilled water for *Fusarium* spp. and other fungi. The same media, except SMPH, were used in 1994, as no *Phytophthora* spp. were isolated in 1993.

After incubation at 20 to 24°C for approximately 5 days, fungi that developed on the media were transferred to fresh plates with nonselective media (PDA, SNA, cornmeal agar [CMA], or potato carrot agar [PCA]) (40) for 1 to 2 weeks before identification. Cultures of *Fusarium* spp. and *Ascochyta* spp. were incubated on SNA in a growth room at 24 ± 1°C in black light (Near UV; Philips, Eindhoven, The Netherlands) for a 12-h day length. Other cultures were incubated in diffuse daylight in the laboratory at approximately 20°C.

Fungal identification. *Ascochyta* spp. were identified through microscopical observations of the characteristics of the pycnidiospores (17). *Fusarium* spp. were identified through color and cultural characteristics on PDA, and through macro- and microconidia, conidiophores, and chlamydospores on SNA, with keys and methods described by Booth (8), Gerlach and Nirenberg (16) and Domsch et al. (14). *A. euteiches* was identified through observations of mycelial structures and shape of oogonia, antheridia, and oospores (36).

Pythium spp. showing pathogenicity to pea were identified to species level through observations of daily growth rate and zoospore and oospore production (for heterothallic isolates produced after crossing with compatible isolates) according to van der Plaats-Niterink (40).

Pathogenicity tests. *P. medicaginis* var. *pinodella* isolates were tested for pathogenicity with an inoculum layer technique (27). Isolates of *F. oxysporum*, *F. redolens* Wollenweb., *F. avenaceum* (Fr.:Fr.) Sacc., *F. solani*, and *F. culmorum* (Wm. G. Sm.) Sacc. were tested for pathogenicity by a slightly modified root dipping method (18). Both spores and mycelial fragments of *Fusarium* spp. were counted in a hemacytometer in order to prepare a concentration of 10⁶ spores/ml. *Pythium* spp. were tested with an inoculum/soil mixing method (24) and *A. euteiches* with zoospores (10⁴ per plant) as inoculum (25).

Pea cv. M410, susceptible to all known races of *F. oxysporum*, was used for testing this fungus. The commonly grown pea cv. Tristar was used for testing *P. medicaginis* var. *pinodella*, *A. euteiches*, *Pythium* spp., and other *Fusarium* spp. All seeds were surface sterilized in 1.5% sodium hypochlorite for 4 min. and washed several times in tap water. Seeds were planted in a 1:1 peat/sand mix and sterilized with dry heat, 150°C, for 12 h. All pathogenicity tests were performed in a greenhouse (day 23°C, 40% relative humidity, and night 19°C, 70% relative humidity). Four weeks after inoculation, the shoot fresh weights of the pea plants were recorded and DSIs were calculated as for plants sampled in the field.

RESULTS

Field surveys. Fungal species belonging to the *Fusarium* and *Ascochyta* complexes were frequently isolated from pea roots and epicotyls (Tables 1 and 2). The most frequently isolated root pathogens were *F. solani* in Denmark and *P. medicaginis* var. *pinodella* in Sweden. Other prevalent pathogenic *Fusarium* spp. were *F. oxy-*

sporum and *F. avenaceum*. In addition, *F. solani* was isolated from vascular tissue up to the seventh node level. Surface disinfection reduced the number of isolates recovered of most fungi.

Of all the *Pythium* spp. isolates found, 40% were identified as *P. irregulare* Buisman and 16% as *P. sylvaticum* W. A. Campbell & J. W. Hendrix. The other *Pythium* spp. were not identified to species. *C. elegans* was found in some fields in both Denmark and Sweden.

There was a relationship in the Swedish survey between FDSI and yield for fields where *A. euteiches* was isolated (Fig. 1). All fields with FDSI above 40 were infested with this fungus and most of these fields gave relatively lower yields.

Pathogenicity tests. *A. euteiches* isolates were very pathogenic, causing soft, straw-colored, and decayed roots and epicotyls, which resulted in very low fresh weights of test plants (Table 3). *Fusarium* spp. caused DSI that ranged from 0 to 100; the highly pathogenic isolates caused severe root discolorations and plant death. Isolates of *F. avenaceum* induced high mean DSI on plants and low plant weights. In contrast, isolates of *F. culmorum* gave lower DSI and did not reduce plant weight as much. The symptoms of plants severely attacked by these two pathogens were similar and included dark brown to black decayed plant tissues. Of the *Fusarium* spp., only *F. avenaceum* and a few *F. oxysporum* isolates caused plant death. In terms of pathogenicity on a set of differential pea lines, the only *F. oxysporum* isolates causing reproducible wilt symptoms resembled the genetic variant of race 6 (7)

Table 1. Fungi isolated from symptomatic pea plants in two separate geographic areas in Denmark, Funen and Lolland-Falster, in a disease survey in 1989 to 1991

Fungal species	Percentage of fields					
	Funen			Lolland-Falster		
	1989	1990	1991	1989	1990	1991
<i>Aphanomyces euteiches</i> ^a	0	38	35	0	0	23
<i>Chalara elegans</i> ^a	14	4	6	2	10	3
<i>Fusarium oxysporum</i>	72	81	71	38	72	80
<i>F. redolens</i>	— ^b	78	75	— ^b	82	91
<i>F. solani</i>	96	70	75	94	100	89
Other <i>Fusarium</i> spp.	98	41	83	92	63	57
<i>Mycosphaerella pinodes</i>	8	19	8	0	9	31
<i>Phoma medicaginis</i> var. <i>pinodella</i>	46	52	67	16	18	51
<i>Pythium</i> spp.	2	15	33	4	4	9
<i>Rhizoctonia solani</i>	2	0	6	8	0	0
Total no. of fields surveyed	53	27	52	48	11	35

^a Identified by direct microscopy.

^b Not recorded in 1989.

Table 2. Fungi isolated from symptomatic pea plants in the south of Sweden in a disease survey in 1993 and 1994

Fungal spp.	Percentage of fields		
	Surface-disinfected roots	Non-surface-disinfected roots	
	1993	1993	1994
<i>Aphanomyces euteiches</i>	— ^a	20	42
<i>Cylindrocarpus</i> sp.	0	1.7	8
<i>Fusarium avenaceum</i>	41	47	75
<i>F. culmorum</i>	15	7	33
<i>F. oxysporum</i>	41	68	42
<i>F. redolens</i>	44	59	17
<i>F. solani</i>	61	58	50
Other <i>Fusarium</i> spp.	17	25	62
<i>Mycosphaerella pinodes</i>	5	3	0
<i>Phoma medicaginis</i> var. <i>pinodella</i>	73	85	88
<i>Pythium</i> spp.	— ^a	47	33
<i>Rhizoctonia solani</i>	5	10	4
Total no. of fields surveyed	59	59	24

^a Root pieces placed on selective medium for *Aphanomyces* spp. and semiselective medium for *Pythium* spp. were not surface disinfected.

(data not shown). Most *F. oxysporum* induced no wilt symptoms or red vascular tissue, but only brown to black root rot and reduced plant fresh weight. *F. redolens* caused slight or no symptoms of foot rot and no weight reductions. The isolates of *F. solani* from red vascular tissue caused a severe foot and root rot but no red-colored vascular tissue. Most of the *Fusarium* spp. isolates tested caused symptoms that were concentrated on the epicotyls. *P. irregulare* was highly pathogenic to pea and caused higher mean DSI and lower fresh weights than occurred in plants inoculated with *P. sylvaticum* or the unidentified *Pythium* spp. Isolates of *P. medicaginis* var. *pinodella* and *M. pinodes* resulted in black-colored epicotyls and slight weight reductions.

DISCUSSION

Our surveys showed that *A. euteiches* was found in 20% (1993) and 42% (1994) of all sampled fields in Sweden and in up to 38% in Denmark. The variable weather conditions may explain the differences in isolation frequency between years. The growing season of 1989 was exceptionally dry, which explains the absence of plants infected with *A. euteiches*. However, the differences between regions, such as Funen and Lolland-Falster, were mainly due to the cropping history. In Lolland-Falster, pea growing started in 1986, whereas in Funen, several fields have regularly been cropped with pea over a 30-year period. Investigations of some of our isolates showed that they were highly pathogenic to pea. The pea yields in fields severely infested with *A. euteiches* were also, as expected, very low. In both Denmark and Sweden, a total crop loss was only observed in fields heavily infested with *A. euteiches*. All these findings are in accordance with earlier findings in Scandinavia by Olofsson (31) in Sweden and Sundheim and Wiggen (38) in Norway. The relatively high frequency of *A. euteiches*, its ability to cause high crop losses before pod setting, and its long persistence in infested soils strongly suggest that *A. euteiches* is the most important pea root rot pathogen in Scandinavia.

Although *A. euteiches* was the most yield-reducing root pathogen, *P. medicaginis* var. *pinodella* was the most frequently found root pathogen in our surveys. *P. medicaginis* var. *pinodella* is considered to be an important pathogen in several other countries, e.g., England (2), France (29), The Netherlands (32), and Germany (20,21). In our studies, the fungus caused black epicotyls but the reduction in plant fresh weight was small. The related pathogen *M. pinodes*, which normally occurs as Ascochyta blight, was less prevalent in Sweden than in Denmark; however, both *P. medicaginis* var. *pinodella* and *M. pinodes* are involved in the root rot complex. Their impact on yield is difficult to estimate.

In the Danish survey, *F. solani* was the most frequently isolated fungus. According

to Hagedorn (17), *F. solani* is a troublesome pathogen in all pea-growing areas and even the most serious root pathogen in some parts of the U.S. Earlier pathogenicity tests of our isolates have shown that *F. solani* isolated from pea epicotyls were all pathogenic, whereas isolates from roots could be divided in two groups, one pathogenic and one nonpathogenic (6). Many of the wilted plants that were regarded as infected by *F. oxysporum* f. sp. *pisi* turned out to be infected by *F. solani*. For these plants, red-colored vascular tissue could be found high up above the soil line and *F. solani* could be isolated up to the seventh node level. This is in contrast to earlier findings indicating that red discoloration caused by *F. solani* usually does not progress above the soil line (22). However, in the pathogenicity test, *F. solani* could not

be verified as a vascular pathogen, which indicates that growth conditions in the greenhouse might not be favorable for the expression of these symptoms. Most *F. oxysporum* isolated from roots caused a significant root rot and yield reduction instead of a typical wilt. These deviations from normally observed symptoms for both *F. solani* and *F. oxysporum* point to the importance of pathogenicity tests with representative isolates in connection with disease surveys. Among *F. solani* and *F. oxysporum*, strains obtained from different fields and plant parts show different levels of pathogenicity, which can lead to misinterpretation of the importance of a certain pathogen.

F. redolens was found to almost the same extent as *F. oxysporum*, but this fungus induced few or no symptoms on the

Fig. 1. Relationship between field disease severity index and pea yield for Swedish fields sampled in 1993. The curve shows the relationship for fields from which *Aphanomyces euteiches* was isolated ($R^2 = 0.52$).

Table 3. Mean disease severity index (DSI) and shoot fresh weight of 4-week-old pea plants in greenhouse pathogenicity tests after inoculation with fungi isolated from peas during a field survey in Sweden and Denmark

Fungi tested	DSI		Shoot fresh weight (% of controls)		Isolates tested (no.)
	Mean	SE ^a	Mean	SE ^a	
<i>Aphanomyces euteiches</i> ^b	88.4	3.0	16.0	0.4	4
<i>Fusarium avenaceum</i> ^c	63.3	2.3	34.2	3.6	23
<i>F. culmorum</i> ^c	25.6	1.5	76.3	8.9	6
<i>F. oxysporum</i> ^c	53.8	1.2	57.2	4.2	12
<i>F. redolens</i> ^c	17.5	1.4	97.9	5.2	8
<i>F. solani</i> ^c	59.5	3.1	51.7	5.2	8
<i>Phoma medicaginis</i> var. <i>pinodella</i> ^d	19.5	2.5	93.8	2.5	11
<i>Pythium irregulare</i> ^c	60.1	1.8	46.9	2.7	14
<i>P. sylvaticum</i> ^c	9.6	2.9	99.0	2.5	7
Other <i>Pythium</i> spp. ^e	4.5	0.6	93.7	4.5	9

^a Standard error of the mean.

^b Zoospore inoculation.

^c Root dipping technique.

^d Inoculum layer technique.

^e Inoculum/soil mixing technique.

test plants. In contrast, Buxton and Richards (11), who referred to *F. redolens* as *F. oxysporum* var. *redolens*, observed symptoms that were indistinguishable from wilt disease caused by *F. oxysporum* f. sp. *pisi*. *F. redolens* is also reported by others as a tracheid parasite causing wilt and sometimes a cortical rot (8,14). *F. avenaceum* and *F. culmorum* were found more frequently than expected. The pathogenicity tests showed that *F. avenaceum* caused a severe root rot. This fungus is known as a seedling pathogen and can cause foot rot and damping off of legumes (8,13,23). *F. culmorum* is known to cause common root rot on cereals but also attacks species of the family *Fabaceae* (9). In our study, *F. culmorum* was able to cause root rot on pea but only to a minor extent. We conclude that *Fusarium* foot and root rot of pea is caused by not only *F. solani* but also *F. oxysporum*, *F. avenaceum*, and *F. culmorum*. Root rot caused by *F. oxysporum* and *F. avenaceum* may be much more severe than expected.

P. irregulare and *P. sylvaticum* were isolated from pea roots on several occasions. *P. irregulare* was recorded as a pathogen on pea roots in 1927 in The Netherlands (10) and later in Germany (28) and the U.S. (19). *P. sylvaticum* is commonly isolated from soil and is pathogenic to several crops, pea among them (3). The pathogenicity test showed that *P. irregulare* induced root rot and had a clear growth-reducing effect. This is in accordance with findings by Ingram and Cook (19), who showed that *P. irregulare* caused pre-emergence death and stunting of pea. In comparison with *P. irregulare*, *P. sylvaticum* was less pathogenic; *P. irregulare* is probably a major problem in some fields.

A broad range of pathogens is involved in the root rot complex of pea. Breeding for race-specific resistance has been widely applied with great success in the control strategy of *Fusarium* pea wilt; however, the occurrence of nonspecific soilborne pathogens demonstrates that integrated control strategies are needed, including a high level of partial resistance in commercial pea cultivars.

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LITERATURE CITED

1. Basu, P. K., Brown, Crête, R., Gourley, C. O., Haas, J. H., Harper, F. R., Lawrence, C. H., Seaman, W. L., Toms, H. N. W., Wong, S. I., and Zimmer, R. C. 1973. Prevalence and se-

- verity of diseases of processing peas in Canada, 1970-1971. Can. Plant Dis. Surv. 53:49-57.
2. Biddle, A. J. 1984. A prediction test for pea foot rot and the effects of previous legumes. Pages 773-777 in: Proc. Br. Crop Prot. Conf. Pests Dis.
3. Blok, I. 1970. Pathogenicity of *Pythium sylvaticum*. Neth. J. Plant Pathol. 76:296-298.
4. Blume, M. C., and Harman, G. E. 1979. *Thielaviopsis basicola*: A component of the pea root rot complex in New York State. Phytopathology 69:785-788.
5. Bødker, L. 1993. Root diseases of peas in Denmark. Ph.D. thesis. The Royal Veterinary and Agricultural University, Copenhagen.
6. Bødker, L. 1996. The prevalence of *Fusarium solani* in wrinkled and round seeded pea genotypes. Pages 57-62 in: Monitoring Antagonistic Fungi Deliberately Released into the Environment. Development in Plant Pathology vol 8. D. F. Jensen, H.-B. Jansson, and A. Tronsmo, eds. Kluwer Academic Pub., Dordrecht, The Netherlands.
7. Bødker, L., Lewis, B. G., and Coddington, A. 1993. The occurrence of a new genetic variant of *Fusarium oxysporum* f. sp. *pisi*. Plant Pathol. 42:833-838.
8. Booth, C. 1971. The Genus *Fusarium*. Commonw. Mycol. Inst., Kew, England.
9. Booth, C. and Waterston, J. M. 1964. *Fusarium culmorum*. No. 26 in: Descriptions of Pathogenic Fungi and Bacteria. Commonw. Mycol. Inst., Kew, England.
10. Buisman, C. J. 1927. Root rots caused by Phycomycetes. Ph.D. diss. University of Utrecht, The Netherlands.
11. Buxton, E. W., and Richards, M. G. 1955. Pathogenic strains of *Fusarium oxysporum* Fr. distinguished by their differential tolerance to inhibition by various Actinomycetes. J. Gen. Microbiol. 13:99-102.
12. Chan, M. K. Y., and Close, R. C. 1987. *Aphanomyces* root rot of peas, I. Evaluation of methods for assessing inoculum density of *Aphanomyces euteiches* in soil. N.Z. J. Agric. Res. 30:213-217.
13. Clarkson, J. D. S. 1978. Pathogenicity of *Fusarium* spp. associated with foot rots of peas and beans. Plant Pathol. 27:110-117.
14. Domsch, D. H., Gams, W., and Andersson, T. H. 1980. Compendium of Soil Fungi. Vol. 1. Academic Press, London.
15. Engquist, G. 1992. Studies on common root rot (*Aphanomyces euteiches*) of peas (*Pisum sativum*) in Sweden. Pages 321-322 in: Proc. Euro. Conf. Grain Legumes, 1st. Euro. Assoc. Grain Legumes.
16. Gerlach, W., and Nirenberg, H. 1982. The genus *Fusarium*- a pictorial atlas. Mitt. Biol. Bundesanst. Land. Forstwirtschaft. Berlin-Dahlem. 209:1-406.
17. Hagedorn, D. J., ed. 1984. Compendium of Pea Diseases. American Phytopathological Society, St. Paul, MN.
18. Haglund, W. A. 1989. A rapid method for inoculating pea seedlings with *Fusarium oxysporum* f. sp. *pisi*. Plant Dis. 73:457-458.
19. Ingram, D. M., and Cook, R. J. 1990. Pathogenicity of four *Pythium* species to wheat, barley, peas and lentils. Plant Pathol. 39:110-117.
20. Jaiser, H. 1989. The prevalence and importance of diseases in West Germany. Pages 11-12 in: Rep. Meet. E. C. Pea Group, 2nd.
21. Janke, K., and Hubert, K. E. 1987. Ergebnisse der Überprüfung des Markerensortimentes der DDR auf Fuß- und Welkekrankheitsresistenz. Nachrichtenbl. Pflanzenschutzdienst. DDR 9:188-190.
22. Kraft, J. M., Burke, D. W., and Haglund, W. A. 1981. *Fusarium* diseases of beans, peas and lentils. Pages 142-156 in: *Fusarium Diseases, Biology and Taxonomy*. P. E. Nelson, T. A. Toussoun, and R. J. Cook, eds. The Pennsylvania State University Press, University Park.
23. Lamari, L., and Bernier, C. C. 1985. Etiology of seedling blight and root rot of faba bean (*Vicia faba*) in Manitoba. Can. J. Plant Pathol. 7:139-145.
24. Larsson, M. 1994. Prevalence and pathogenicity of spinach root pathogens of the genus *Pythium* in Sweden. Plant Pathol. 43:261-268.
25. Larsson, M. 1994. Pathogenicity, morphology and isozyme variability among isolates of *Aphanomyces* spp. from weeds and various crop plants. Mycol. Res. 98:231-240.
26. Larsson, M., and Gerhardson, B. 1992. Disease progression and yield losses from root diseases caused by soilborne pathogens of spinach. Phytopathology 82:403-406.
27. Larsson, M., and Olofsson, J. 1994. Prevalence and pathogenicity of spinach root pathogens of the genera *Aphanomyces*, *Phytophthora*, *Fusarium*, *Cylindrocarpum* and *Rhizoctonia* in Sweden. Plant Pathol. 43:251-260.
28. Mattusch, P. 1973. Zur Pathogenität von *Pythium*-Arten gegenüber Gemüseeerbsen. Jber. biol. BundAnst. Land. u. Forstw. Braunschweig 1972.
29. Maumene, C., Didelot, D., and Remaux, M. 1992. Root rot of combining pea. Pages 327-328 in: Proc. Euro. Conf. Grain Legumes, 1st. Euro. Assoc. Grain Legumes.
30. Nirenberg, H. I. 1976. Untersuchungen über die morphologische und biologische Differenzierung in der *Fusarium*-Sektion *Liseola*. Mitt. Biol. Bundesanst. Land. Forstwirtschaft. Berlin-Dahlem 169:1-117.
31. Olofsson, J. 1967. Root rot of canning and freezing peas in Sweden. Acta Agric. Scand. 17:101-107.
32. Oyarzun, P., and van Loon, J. 1989. *Aphanomyces euteiches* as a component of the complex of foot and root pathogens of peas in Dutch soils. Neth. J. Plant Pathol. 95:259-264.
33. Papavizas, G. C. 1964. New medium for the isolation of *Thielaviopsis basicola* on diluted plates from soil and rhizosphere. Phytopathology 54:1475-1481.
34. Papavizas, G. C., and Ayers, W. A. 1974. *Aphanomyces* species and their root diseases in pea and sugarbeet. U.S. Dep. Agric. Agric. Res. Serv. Tech. Bull. No. 1485.
35. Pfender, W. F., Delwiche, P. A., Grau, C. R., and Hagedorn, D. J. 1984. A medium to enhance recovery of *Aphanomyces euteiches* from infected plant tissue. Plant Dis. 68:845-847.
36. Scott, W. W. 1961. A monograph of the genus *Aphanomyces*. Va. Agric. Exp. Sta. Tech. Bull. No. 151.
37. Sherwood, R. T., and Hagedorn, D. J. 1958. Determining common root rot potential of pea fields. Wis. Exp. Sta. Bull. 531.
38. Sundheim, L., and Wiggen, K. 1972. *Aphanomyces euteiches* on peas in Norway. Isolation technique, physiologic races, and soil indexing. Sci. Rep. Agric. Univer. Norway 51.
39. Tu, J. C. 1987. Integrated control of the pea root rot disease complex in Ontario. Plant Dis. 71:9-13.
40. van der Plaats-Niterink, A. J. 1981. Monograph of the Genus *Pythium*. Studies in Mycology 21. Centraalbureau voor Schimmelcultures, Baarn.