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HOT WATER TREATMENT TO CONTROL PLANT PARASITIC NEMATODES OF TROPICAL CROPS

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SUMMARY

Hot water treatment is recognised as an economic alternative or addition to chemical control of plant parasitic nematodes of a number of sub-tropical and tropical crops. The treatment is a preventive measure to control those nematodes that are disseminated on or in seeds, rootstocks, bulbs, corms and other planting material. The majority of nematodes are killed immediately at 52°C but lower temperatures for varying lengths of time are effective in controlling most of the important plant parasitic nematodes. The times of immersion of the seed material in hot water and the temperature used depend to a large extent on the susceptibility of the different crops to high temperature. The time/temperature combination for treatment varies with different planting material. The difference between the heat required for nematode kill and heat damage to the plants is often very marginal and a careful regulation of the temperature is necessary throughout the treatment. Hot water treatment is used to control <u>Radopholus similis</u> in banana sets, the white tip nematode, <u>Aphelenchoides besseyi</u>, of rice seeds, and nematodes of citrus rootstocks, such as, <u>Tylenchulus semipenetrans</u> and <u>Radopholus similis</u>. It has also been successfully employed to control root-knot nematodes, <u>Meloidogyne</u> spp., of potato tubers, sweetpotato and ginger; <u>Scutellonema bradys</u> of yam tubers; nematodes of tropical ornamentals and other crops as well as a wide range of temperate crops.

INTRODUCTION

Heat treatment in a variety of forms has been advocated and practised for many years to control pests and pathogens in the soil and plant material; steam sterilisation being one of the most widely known methods. The most commonly used heat treatment for the control of plant parasitic nematodes of temperate and tropical crops is by immersion of plant material in hot water. This form of treatment is a preventive measure to control nematodes that are disseminated on, or in, seeds, rootstocks, bulbs, corms, and other planting material. It is often used as a quarantine regulatory measure to restrict the spread of nematodes on infested seed material both on a local and international level. The use of water enables heat to be applied to plant material without fear of damage being caused by desiccation and permits a greater heat penetration of the plant tissues than does dry heat. The majority of nematodes also succumb far more readily to heat when in a moist state.

The use of hot or warm water treatments to control nematodes, insect pests and pathogens in plant material was first recommended in Britain in the early part of this century for flower stocks and bulbs (Anon., 1972), and it has remained the principal control measure against the stem and bulb nematode. Hot water treatment has been attempted on a wide range of temperate crops mainly for the control of nematodes, and, in many cases, no economic or effective alternative to the treatment has been found. It can be used in conjunction with chemicals which are added to the water during treatment. The control of important nematodes of a number of tropical crops has been achieved by hot water treatment and it is an accepted practice in parts of the world for control of the burrowing root nematode, *Radopholus similis*, of bananas, and the white tip nematode, *Aphelenchoides besseyi*, of rice. Other tropical crops on which hot water treatment has been recommended or attempted include citrus, abaca, sweetpotato, ginger, yam, groundnut and ornamentals. The distinction between tropical crops and temperate crops grown in the tropics is difficult to draw and mention will be made here of a selection of other crops where hot water treatment is used.

A list of selected examples of hot water treatment of both temperate and tropical crops is presented in Table 1.

PROBLEMS OF HOT WATER TREATMENT

Hot water treatment involves immersing the infested 'seed' material in heated water for a prescribed time and, generally, constant temperature. The heat tolerance of the plant material is one of the important factors and the control method depends for its success on there being a heat differential in favour of the plants so that the temperature of the water is sufficient to kill the nematodes without damaging, or seriously inhibiting subsequent plant growth. The period of immersion and temperature required depends on the plant material being treated. The method is based on the principle that all nematodes have an instantaneous thermal death point normally in the region of 50–52°C, but are also killed when exposed to lower temperatures for varying lengths of time. Examples of these lethal time/temperature combinations are described by Woodville (1964). The stem and bulb nematode, *Ditylenchus dipsaci*, in its desiccated condition as 'eelworm wool' needs higher temperatures and longer exposure for its control than does the active banana root nematode, *Radopholus similis* (Blake, 1961; Woodville, 1964). Nematodes within plant tissues are generally more difficult to kill because of the insulation afforded them and longer heat exposures are necessary, although there are exceptions to this rule (Green, 1963). Blake (1961) found that the effect of the size of banana sets on heat penetration was considerable in controlling *R.similis*.

The difference between the heat required for nematode kill and heat damage to the plants is often very marginal and a careful regulation of the temperature is necessary to prevent abnormal losses. This involves the use of heating apparatus with temperature control and a circulatory system incorporated. Many problems occur in the design and operation of hot water treatment systems to maintain the correct temperature throughout the treatment period and these have been dealt with in detail (Anon., 1972). A number of heating tanks have been designed that can be used for nematode control varying from the small and simple to the relatively sophisticated for large

Table 1

SELECT

TO CON

TREATED PLANT MATERIAL	NEMA
BANANA sets	*Radopholus*
RICE seed	*Aphelencho*
CITRUS rootstock	*Radopholus*
	Tylenchulu
SWEETPOTATO roots	*Meloidogyn*
	Rotylenchu
	Meloidogyn
GINGER rhizome	*Meloidogyn*
YAM tubers	
	Scutelloner
	Meloidogyne
	Pratylenchu
POTATO tubers	*Meloidogyne*
	Pratylenchu
	Pratylenchu
GRAPE rootstocks	*Meloidogyne*
STRAWBERRY runners	*Aphelenchoi*
	Aphelenchoi
	Ditylenchus

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SELECTED EXAMPLES OF HOT WATER TREATMENT TO CONTROL NEMATODES IN PLANTING MATERIAL

TREATED PLANT MATERIAL	NEMATODES	TEMPERATURE °C	TIME Min.	REFERENCES
BANANA sets	*Radopholus similis*	52-53	20	Taylor, 1969
		55	20	Blake, 1961
		55	25	Blake, 1963
		65	5	Hildreth, 1962
RICE seed	*Aphelenchoides besseyi*	50-53	15	Cralley, 1952
		55-61	15	Todd & Atkins, 1959
		56-57	10-15	Yoshii & Yamamoto, 1951
		55-57	15	Vuong, 1969
CITRUS rootstock	*Radopholus similis*	50	10	Birchfield, 1954 Anon., 1968
	Tylenchulus semipenetrans	45	25	Baines, 1950
SWEETPOTATO roots	*Meloidogyne incognita* *Rotylenchulus reniformis*	50	3-5	Martin, 1970
	Meloidogyne spp.	46.8	65	Anon., 1968
GINGER rhizome	*Meloidogyne* spp.	45-55	10-50	Colbran & Davis, 1969
YAM tubers	*Scutellonema bradys*	46	60	Ayala & Acosta, 1971
		50	15	
		52	7-15	
	Meloidogyne spp.	51	30	Hawley, 1956
	Pratylenchus coffeae	50	30	Thompson *et al*, 1973
POTATO tubers	*Meloidogyne javanica*	46-47.5	120	Martin, 1968
	Pratylenchus brachyurus	50	45-60	Koen, 1969
	Pratylenchus coffeae	52	15-20	Gotoh & Ohshima, 1965
		53	10-15	
GRAPE rootstocks	*Meloidogyne* spp.	47.8	30	Lear & Lider, 1959
		50	10	
		51.7	5	
		52.8	3	
		52	5	Moller & Fisher, 1961
STRAWBERRY runners	*Aphelenchoides fragariae* *Aphelenchoides ritzemabosi* *Ditylenchus dipsaci*	46.1	10	Anon., 1972

Table 1 cont'd

TREATED PLANT MATERIAL	NEMATODES	TEMPERATURE °C	TIME Mins.	REFERENCES
STRAWBERRY roots	Meloidogyne hapla) Pratylenchus penetrans)	52·8	5	Goheen & McGrew, 1954
HOP rhizomes	Meloidogyne spp.) Xiphinema americanum)	51·7	5	(Maggenti, 1962 (Maggenti & Hart, 1963
PEACH rootstocks	Meloidogyne spp.	50-51·1	5-10	Nyland, 1955
CHERRY rootstocks	Meloidogyne spp.	50-51·1	5-10	Nyland, 1955
APPLE rootstocks	Pratylenchus penetrans	46·1-46·7	30	Bosher & Orchard, 1963
RASPBERRY rootstocks	Pratylenchus penetrans	46·7-48·3	15	McElroy, 1973
ONION & SHALLOT sets	Ditylenchus dipsaci	43·5	120	Bruinsma & Seinhorst, 1954
GARLIC cloves	Ditylenchus dipsaci	48·9	20	Lear & Johnson, 1962 Johnson & Lear, 1965
GRASS seed	Anguina agrostis	52·2	15	Courtney & Howell, 1952 Anon., 1968
WHEAT seed	Anguina tritici	49 50	30 10	) Anon., 1968)
NARCISSUS bulb	Ditylenchus dipsaci	43·9-44·4	180	Anon., 1972
BEGONIA tubers	Meloidogyne spp.	48 45	30 60	) Gillard, 1961)
	Aphelenchoides fragariae) Aphelenchoides ritzemabosi)	46	10	Rasmussen, 1971
CHRYSANTHEMUM stools	Aphelenchoides ritzemabosi	43·3 46·1	20 5	) Anon., 1972)
ANTHURIUM roots and leaves	Aphelenchoides fragariae	46·6	8-12	Hunter et al, 1974
CALADIUM tubers	Meloidogyne spp.	50	30	Rhoades, 1964, 1970

Table 1 cont'd

TREATED PLANT MATERIAL	NEM
ROSE roots	Meloidogyne
Ornamentals, roots	Helicotylen Meloidogyne

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10	Rasmussen, 1971
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8-12	Hunter et al, 1974
30	Rhoades, 1964, 1970

Table 1 cont'd

TREATED PLANT MATERIAL	NEMATODES	TEMPERATURE °C	TIME Min.	REFERENCES
ROSE roots	Meloidogyne hapla	45·5	60	Martin, 1968
Ornamentals, roots	Helicotylenchus multicinctus) Meloidogyne incognita)	50	10	Birchfield & Pelt, 1958

scale treatment (Anon., 1965; Anon., 1972; Blake, 1961; Birchfield and van Pelt, 1958; Colbran, 1967; Hughes, 1954). It is the cost or availability of the equipment and heating, together with the need for careful operation of the treatment which are the inhibiting factors in using hot water treatment for control of nematodes in plant material.

BANANAS

The burrowing nematode, Radopholus similis, is a common endoparasite of banana roots and corms occurring in all the principal banana growing areas of the world. It is the cause of root rot, corm black head, toppling disease and decline (Blake, 1969) and is now considered to be the major root pathogen of bananas (Stover, 1972). The other important nematode parasites of banana roots are Helicotylenchus multicinctus, Meloidogyne spp. and Pratylenchus spp. Hot water treatment is equally effective against all nematodes but has mainly been used for the control of R.similis.

Treatment with hot water can be used in combination with hand paring of the sets which removes all obvious traces of infected necrotic tissue. In Honduras all nematodes were eliminated from thoroughly pared sets by immersion in water at 65°C for 5 min. although there was a considerable loss in viability of treated sets (Hildreth, 1962). Blake (1961), in Australia, considered paring to be tedious and time-consuming and recommended the immersion in water at 55°C for 20 min. of unpared sets less than 13 cm in diameter for effective control of R.similis without causing significant set losses. He later modified the treatment to 55°C for 25 min. for superficially pared sets (Blake, 1963, 1972). Colbran (1967), in Queensland, similarly recommended a water temperature of 53·3-54·4°C for 20 min. for use in a hot water tank of his own design that was capable of treating 300 to 350 banana sets in an hour.

These recommendations have generally been followed in other banana growing regions and good control of R.similis and other nematodes has been achieved in Ghana (Ito et al., 1972) and Cuba (Decker et al., 1971) using water heated to 55°C for 20 min. In Fiji, Taylor (1969) found that immersing sets in water at 52-53°C for 20 min. using the Queensland tank gave satisfactory control of R.similis but germination of sets 15-23 cm in diameter was 80% and only 60% from smaller sets. In Ceylon the recommended control is by immersion of infected sets in water at either 55°C for 15 min. or at 60°C for 10 min. followed by an organomercurial dip (Senanayake, 1969).

Hot water treatment is the most effective method of disinfesting banana sets and both Blake (1972) and Colbran (1967) failed to improve on the method by immersing sets in dips of nematicides. The post-treatment losses that may occur even with careful supervision are decreased by cooling and drying the sets before planting which should be done as soon as possible after treatment (Blake, 1972; Colbran, 1967). Stover (1972) states that when hot water treatment is properly carried out germination of corms of cavendish varieties is only reduced slightly or not at all. Nematode-free "seed" corms can be produced if treatment follows the peeling away of all nematode lesions from the corms which has now become the standard practice in parts of Central America and elsewhere.

RICE

White tip disease of rice was first shown to be caused by a nematode in 1949 (Cralley, 1949). The symptoms of the disease are chlorosis of the leaf tips, stunting, a reduction both in the length of panicles and number of spikelets, and sterility of the panicles. The disease has a very wide distribution having been found in Africa, The Americas, The Middle East, Far East, Europe and Pacific (Fortuner and Orton Williams, 1975). The nematode responsible for this damage is Aphelenchoides besseyi which feeds ectoparasitically on the foliar parts of the plant eventually penetrating the developing inflorescence and infesting the grains. The nematodes are able to survive in a desiccated condition in the seeds for as long as 3 years (Yoshii and Yamamoto, 1950) and the disease is spread by infested seed (Cralley, 1952).

Hot water treatment is considered to be the best control method against white tip and is economical in that it is not needed each year. Many workers have attempted to develop an efficient method without affecting the germination of the seed (Fortuner and Orton Williams, 1975). A presoaking of the seeds has been advised to activate the nematodes before treatment. Cralley (1952) recommended a tedious treatment of presoaking, preheating in hot water for 15 sec., soaking in hot water at 50-53°C for 15 min. followed by a final soaking in cold water. He showed an increase of 5 to 10 bushels per acre with this treatment. Yoshii and Yamamoto (1951) in Japan did away with the presoaking and recommended a hot water treatment in which the dry seed is immersed directly in hot water at 56 to 57°C for 10 to 15 min. Todd and Atkins (1959) advised using presoaked seed (24 hours in cool water) treated at 51 to 53°C for large batches of rice seed, but with small quantities dry seed could be treated directly at 55-61°C for 10 to 15 min. with less seed injury.

No alternative has been found to hot water treatment for control of white tip disease although various chemicals have been tested. Todd and Atkins (1959) evaluated a large number of chemicals including fumigation with methyl bromide but none of the treatments compared favourably with the hot water method. The use of the newer systemic chemical products in recent years has produced more promising results (Fortuner and Orton Williams, 1975) but they have their limitations.

CITRUS

Citrus is attacked by a number of root parasitic nematodes of which the semi-endoparasite, Tylenchulus semipenetrans, and the endoparasite, Radopholus similis are the most important. T.semipenetrans occurs in all the major citrus growing areas of the world and is responsible for the disease of citrus known as "slow decline". R.similis causes "spreading decline" but is only a serious pathogen of citrus in Florida.

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It is possible to kill *T.semipenetrans* on roots of seedlings by dipping in hot water at 45°C for 25 min. without damaging the roots (Baines, 1950). *R.similis*, because of its endoparasitic habit, requires higher temperatures of 50°C for 10 min. (Birchfield, 1954) which has some deleterious effect on the seedlings (Cohn, 1972).

SWEET POTATO

Both the root-knot nematode, *Meloidogyne* spp., and the reniform nematode, *Rotylenchulus reniformis*, are ubiquitous parasites with a very wide host range including sweetpotato. It has been shown that *Meloidogyne* spp. can be safely eliminated from sweetpotato roots by immersing in hot water at 46·7 to 48·3°C for 65 min. (Burk and Tennyson, 1941), and both *Meloidogyne incognita* and *Rotylenchulus reniformis* were controlled by hot water at 50°C for 3 to 5 min. (Martin, 1970).

GINGER

The root-knot nematodes *Meloidogyne javanica* and *M.incognita* are serious pests of ginger (*Zingiber officinale*) in Australia and elsewhere. The nematodes are so prevalent in Queensland that it is difficult to obtain clean planting material (Colbran and Davis, 1969). Hot water treatment at 50°C for 10 min. controlled root-knot in ginger grown in Hawaii (Trujillo, 1963). The commercial value of the treatment was tested in Queensland where treatments of 45-55°C for 10 to 50 min. gave control of the nematodes but reduced the vigour of the planting material (Colbran and Davis, 1969). Hot water treatment has little value as a routine control measure but can be used to establish nematode-free planting material.

YAMS

The underground tubers of *Dioscorea* spp. are prone to attack by various nematodes of which *Scutellonema bradys* and *Pratylenchus* spp. are of particular importance. Yams are propogated by 'seed' tubers or tuber pieces which, if infested, permit the dissemination of the nematodes. Control of these and other nematodes has been described using hot water treatments. In Puerto Rico the most effective treatments for control were by immersing tubers in water at 46°C for 60 min., 52°C for 7 and 15 min., and at 50°C for 15 min., without affecting the germination (Ayala and Acosts, 1971). In the U.S.A. treatment at 51°C for 30 min. killed most nematodes (Hawley, 1956), and in Jamaica hot water at 50°C for different lengths of time reduced nematode populations but damaged the tubers (Thompson *et al.*, 1973). Treatments at 50°C and 55°C for 40 min. gave over a 98% kill of *S.bradys* in tubers from Nigeria with no damage to the tubers (Bridge, unpublished). It was found that if tubers were treated during their dormancy period they stored well and germinated normally, but when treated soon after dormancy had broken there was a delay in germination (Table 2) and if treated later than this they were inclined to rot.

Recent work in Nigeria has led to the development of viable seeds from previously sterile commercial yam varieties which produce normal tubers when planted (Sadik and Okereke, 1975). If the planting of seeds becomes an accepted practice it will effectively eliminate nematodes as pests of yams.

Table 2. Effect of time of hot water treatment (50°C for 40 min.) on germination of yam tubers.

Hot water treatment	% germination of tubers Time after onset of rains (in weeks) 6	7	12	Harvesting
Early Planting (Dec.)				
Treated Dec.	88.9%	93.3%	93.3%	93.3%
Untreated	82.2%	91.1%	97.3%	97.8%
Late Planting (March)				
Treated Dec.	95.5%	100%	100%	100%
Treated March	22.2%	57.8%	91.1%	97.8%
Untreated	46.7%	73.3%	95.5%	97.8%

GROUNDNUTS

The testas and pods of confectionery groundnuts grown in northern Nigeria were found to be heavily infested with a species of *Aphelenchoides*. Nematode populations of 50,000 plus were found in individual seed coats causing a discolouration of the seeds and a reduction in their commercial value as well as apparently reducing yields (Bridge, McDonald and Page, unpublished). A simplified hot water treatment by immersing seeds in four times their volume of water heated to 60°C and allowed to cool for 5 min. gave complete control of the nematodes without affecting germination

OTHER CROPS

Hot water treatment has been successfully used to control nematodes of other tropical and sub-tropical crops. In Rhodesia eggs and larvae of *Meloidogyne javanica* contained within infested seed potato tubers were killed by treatments of 46° to 47·5°C for 2 hours without tuber viability being affected (Martin, 1968). In South Africa all stages of *Pratylenchus brachyurus* in mature potato tubers were killed when immersed in hot water at 50°C for 45 to 60 min. (Koen, 1969) without adverse effects on the tubers.

Ornamental plants in Florida are attacked by many plant parasitic nematodes including *Meloidogyne* spp. Dipping bare-rooted plants in water at 50°C for 10 minutes gave a high degree of control without obvious injury in most plants although succulent herbaceous types were more prone to damage. Seed tubers of several horticultural varieties of *Caladium bicolor* withstood 20 min. exposure at 50°C (Birchfield and van Pelt, 1958). Treatment of *Caladium* tubers in water at 50°C for 25 min. and 30 min. improved control of *M. incognita* (Rhoades, 1964, 1970). *Aphelenchoides fragariae* was found associated with a foliar blight of *Anthurium* flowers in Hawaii which were killed in the leaves by immersion of the whole seedlings in water at 46·6°C for 8 to 12 min. although some burning injury occurred (Hunter *et al.*, 1974).

DISCUSSION

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7.8%	91.1%	97.8%
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(Hunter et al., 1974).

DISCUSSION

Hot water treatment has proved a successful method for eradicating plant parasitic nematodes from seed and planting material of a number of crops but would probably be as equally effective in many others. It has the additional value of controlling viruses and other plant pathogens, and insect pests. Outwardly this form of control appears crude but is in fact very precise due to the small temperature margins between nematode kill and heat damage to the plant. It is this precision which is the main drawback of the treatment because of the careful supervision required to maintain correct water temperatures for the prescribed length of time. Probably many failures with this treatment have been caused by inadequate temperature control or poor circulation of the heated water within treatment tanks as was the case with earlier work on control of the narcissus bulb nematode (Anon., 1972). The state of the plant material that is hot water treated can be important as often 'seed' material which has broken dormancy is easily damaged by heat whereas dormant tissues are more resistant to the treatment. The difficulty of accurately controlling temperatures and the need for relatively complicated equipment has led to various alternatives to hot water treatment being tested. Nematicide dips have been effective in a few instances but often they are phytoxic in the concentrations required to kill nematodes within planting material or have proved less efficient.

On a large commercial scale hot water treatment may remain restricted to relatively few crops where the principal means of spread of the nematodes is on planting material, but it is an important means of controlling nematodes and could have greater utilisation for the establishment of nematode-free nursery stock. By preventing the dissemination of nematodes into previously nematode-free soils, it is one of the alternatives to the repeated application of nematicides that is often necessary once a nematode has become established; prevention, with nematodes, is always less expensive than the cure.

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