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SOME PHYTOTOXIC PROPERTIES OF IODINE IN RELATION TO THE IODOTHERAPY OF CERTAIN PLANT PATHOGENS

Thesis for the Degree of M. S.

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Robert David Beier

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THESIS

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By

ROBERT DAVID BEIER

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
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THESIS

This study is dedicated to Professor Carrick Earl Wildon, whose tireless efforts, interest, inspiration, and encouragement have contributed foremost to the author's education at Michigan State University.

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SOME PHYTOTOXIC PROPERTIES OF IODINE IN RELATION TO THE IODOTHERAPY OF CERTAIN PLANT PATHOGENS

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AN ABSTRACT

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ROBERT DAVID BEIER ABSTRACT

The merits of colloidal iodine and other iodine containing substances were investigated to determine the feasibility of their use in the eradication of certain plant pathogens.

Phytotoxic ranges of iodine were established on bean, chrysanthemum, cucumber, radish, snapdragon, begonia, and tomato using four methods of iodine application as foliar sprays, soil drenches, sublimation, and seed soaks. Iodine treatments of the plant species used indicated different degrees of tolerance to iodine. Soil drenches and seed soaks were generally very detrimental to the treated plants, while sprayed sublimated iodine were less injurious to most species.

Lethal ranges of colloidal iodine were established in vitro on Xanthomonas campestris, Xanthomonas phaseoli, Verticillium dahliae, and Fusarium oxysporum f. conglutinaus. All plant pathogens were effectively controlled by relatively low concentrations of colloidal iodine.

After establishment of the phytotoxic and lethal ranges of iodine on plants and plant pathogens, infected plant materials were treated with iodine within the established ranges. Spray treatments of plants infected with fusarium of radish, verticillium of chrysanthemum, and powdery mildew of cucumber resulted in the complete control of mildew only. Soil drench treatments of soil infested with Rhizoctonia was not effective in preventing seedling damp-off on five susceptible plant species. Treatment with a 10 per cent iodine dust and sublimation of iodine to eradicate Xanthomonas phaseoli from infected bean seeds gave no results because the iodine treated seeds did not germinate.

In an effort to better understand the mechanism of phytotoxic action, radioactive iodine was employed to study the movement and distribution of iodine when applied to different plant parts. Foliage applications of radioactive iodine revealed that it was not translocated to other parts of the plant, however, root application revealed plant uptake of iodine and complete distribution throughout the plant.

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INTRODUCTION

Early in 1953, the author was introduced to colloidal iodine by some fellow students in the School of Veterinary Medicine at Michigan State University. They acclaimed the use of colloidal iodine in treatment of some fungal dermatitis in animals, and related its strong fungistatic properties as well as excellent tissue penetration qualities.

Therefore, the inquisitive or curious person interested in phytology would wish to apply colloidal iodine to plants. The material had shown good results against some animal fungi, so possibly similar results could be accomplished with some parasitic plant fungi. The penetration qualities of colloidal iodine would be of great importance in the eradication of deeply imbedded tissue diseases, such as some vascular diseases, if the active material could reach the area of infection.

The purpose of this investigation was to determine the merits of colloidal iodine and other iodine containing substances in the control of certain plant pathogens. Fungal and bacterial plant diseases were used which attack or affect different plant parts in order that a more specific understanding could be reached if the iodine materials used were effective.

REVIEW OF LITERATURE

Many investigators have employed iodine and compounds containing iodine in an attempt to eradicate plant pathogens. Various degrees of success are reported by investigators using numerous methods of treatment.

Iodine has long been associated as the active agent in many germicidal and pesticidal treatments in plants. Soon after the discovery of iodine in 1811 by Bernard Courtois, Rivet (34) acclaimed the value of iodine-containing seaweed manure in preventing fungal infection of grapes. Many such general observations were made by others, but only in the last one hundred years have the merits of iodine plant chemotherapy been subjected to controlled tests.

Soil and Plant Treatments

Iverson and Kelly (18) and Ark (3) stated that iodine was one of the most effective disinfectants for potato cutting knives for preventing the spread of bacterial ring rot. A combination of iodine, potassium iodide, glycerine, and water was made into a solution containing approximately 3, 850 ppm iodine. They have indicated that this iodine solution must be kept to strength because it will deteriorate with use or prolonged storage.

Treatment of the potato tuber itself with iodine is sometimes effective. Goodwin, Salmon, and Ware (15) reported zoospores of hop downy mildew and potato blight were quickly killed by iodine vapor. Ark (3) found that dipping cut seed potatoes in a 5, 000 ppm solution of iodine was not lethal against ring rot, but was injurious to the starchy substance of potato.

Bulb- and tuber-infested nematodes were killed using a 250 ppm solution of iodine as a soak treatment as reported by Poate (28). Others (39, 48) found that using similar iodine concentrations, both nematode and Fusarium bulb rot were controlled by hot water-iodine treatments with no harm to the subsequent growth of bulb or tuber.

Crown gall on almond trees was very satisfactorily eradicated by painting the galls on bearing almond trees with solutions of iodine, methyl alcohol, glacial acetic acid, and glycerine (4).

Agatov (1) found that tobacco mosaic virus was completely inactivated with an aqueous solution of iodine. At hydrogen-ion concentration indicated by pH of 4. 5 and 8. 0 inactivation was most effective, while at pH 5. 5 and 6. 0 results were poor. Anson and Stanley (2) had similar results in their experiments with tobacco mosaic virus.

Newton (27) concluded, after using many compounds, that iodine must be applied in a free state or in compounds which readily release iodine for best results against various plant pathogens. Very limited success was experienced using potassium iodide and potassium iodate, while iodine in the free state acted as a "protoplasmic poison" on the pathogens.

Many investigators (39, 42, 43, 44) show no positive results using various iodine treatments against certain pathogens. Many report some control, but extreme damage to the treated plant. Cotton root rot, tomato eelworms, and potato scab are examples where poor results were obtained.

Organically combined iodine, however, has been found definitely fungicidal in some forms. Ethyl mercuric iodide was a highly efficient soil disinfectant (20, 23), and was also used successfully to inhibit growth of *Fusarium oxysporum cubense* on banana plants (23). Muirhead (25) found that tetraiodoethylene and diiodoacetylene had important fungistatic properties.

Seed Treatments

Methyl mercury iodide and ethyl mercury iodide are among the iodine compounds which control seed borne diseases of cereals (13). However, practical use of these compounds is limited by their poisonous nature, and consequent risk attending their use.

Sayre and Thomas (35, 36) claimed excellent results against oat smut by applying a dust of 5 per cent iodine in diatomaceous earth to the seeds. These experimental results stimulated many others to do research with inorganic and organic iodine compounds.

Moore et al. (24) found that vapors from ethyl mercury iodide did not greatly reduce incidence of Alternaria solani in tomato seed. Muskett and Calhoun (26) showed that an alcoholic solution of iodine did not provide a satisfactory control of seed-borne diseases of flax. Contrary to previous work, Horsfall (17) found iodine dust ineffective against oat smut. Leukel (21) used five different iodine dusts to control wheat bunt. None of the iodine dusts reduced the percentage of bunt sufficiently to qualify as a bunt fungicide. Furthermore, Leukel stated that the corrosive nature of iodine and its detrimental effect on germination eliminated it from further consideration.

Many good results have been reported in recent years using iodine in various forms to treat seeds. Ray (32) found that cotton seed treated with ethyl mercury iodide gave a significantly higher emergence count than untreated seed. Lehman (20) had similar results. The Wisconsin Agricultural Experiment Station (49) reported that seed treated with potassium iodide gave complete control from barley stripe. The same dusts also gave excellent preliminary results to control oat smut. Brentzel (5) reported that Abavit B, an iodine-containing proprietary powder, completely prevented covered smut or bunt of wheat. Good results with the same compound were realized in the control of root-rot, seedling blight, and loose smut of wheat.

Fruit Preservation

R. G. Tomkins (45, 46, 47) investigated the use of iodine-impregnated wrappers for fruit. His tests showed that wraps treated with iodine retarded germination and growth of fungi responsible for fruit spoilage without damaging fruit or impairing its appearance and flavor. Passion fruit, oranges, tomatoes, grapes, and melons that were wrapped in iodine-impregnated paper and stored, lasted longer and had less rot than fruits with no treatment.

Rattray (29, 30, 31) and duPlessis (10, 11, 12) of Africa found that wrappers treated with an iodine solution containing 1 or 1.5 per cent of iodine and 1 to 2 per cent of potassium iodide were most effective in controlling wastage in grapes due to Botrytis infection. Iodized wrappers did not appear to inhibit growth of this fungus within the grape, but they did prevent spread of the infection from one grape to another. Greater benefits were observed when, in addition to iodized wraps, the grapes were further enclosed in a vapor retaining "Crystalline" paper to prevent volatilization.

Dreyer (9) concluded that under commercial conditions, grapes packed in iodized wrappers decreased wastage due to spoilage by 50 per cent when compared to grapes in plain wraps.

Singh and Jakhanwal (40) used iodized wood shavings to pack and ship tomatoes. The wood shavings were used to cut the cost of wrapping individual fruits. Results of the experiment indicated that iodized wood shavings had a definite advantage over iodized paper wraps for preventing rot in tomatoes.

Nevertheless, many investigators, including Tomkins (44, 47) do not regard the use of iodine impregnated materials as entirely satisfactory. Not only is iodine volatile and easily lost, but also it stains packing material yellow, and it cannot be applied to some varieties of fruit without injury. Gerhardt and Ryall (14) whose tests with various volatile chemicals used for impregnating fruit-packing materials have shown that elemental iodine effectively checks Penicillium and Rhizopus rot but only when used in concentrations sufficient to produce some surface injury to fruit.

METHODS AND MATERIALS

The experimental work may be grouped in four major categories, as follows:

1. Phytotoxicity studies to determine the concentration of iodine which numerous plant species can tolerate.

2. Culture of specific pathogens and determination of the lethal range of iodine in vitro.

3. Innoculation of plants and treatment with iodine within established toxic ranges in order to determine effectiveness of iodine therapy.

4. Use of radioactive iodine to study uptake and movement of iodine within the plant.

Plant Material

Ten species of cultivated plants were used in the course of this work: white pea bean, Phaseolus vulgaris Linn. var. Michelite; chrysanthemum, Chrysanthemum hortorum Ram. var. Cameo; cucumber, Cucumis sativus Linn. var. National Pickling cucumber; radish, Raphanus sativus Linn. var. Scarlet Globe medium red and White Icicle; snapdragon, Antirrhinum majus Linn. var. Haney #26; begonia, Begonia semperflorens Link and Otto var. Red ball; geranium, Pelargonium zonale Linn. var. Madam

Buchner; tomato, Lycopersicon vulgare Bailey var. M. S. Forcing WR3; pepper, Capsicum annuum Linn. var. Oakview Wonder; and stock, Matthiola incana R. Br. var. Haney #3-16-3 10-week white.

Common cultural practices were followed in propagating and handling all plants, except as noted. In most cases, the plants were grown in a greenhouse soil mixture composed of one part peat moss, one part medium sand, and three parts of loam soil. This soil mixture was sterilized with steam. Some plants treated with radioactive iodine were placed in nutrient solutions.

Plant Pathogens

Six disease organisms were used. Two bacterial plant pathogens were Xanthomonas campestris (Pam.) Dows[1], causing black rot of radish, and Xanthomonas phaseoli (E. F. Sm.) Dows[2], causing bacterial blight of beans. Four fungi were Verticillium dahliae Kleb.[3], causing verticillium wilt of chrysanthemums, Pellicularia filamentosa (Pat.) Rogers (Rhizoctonia solani)[1] causing a damp-off and seedling blight of beans, Erysiphe cichoracearum (D. C.)[1] causing powdery mildew of cucumbers, and Fusarium oxysporum f. conglutions (Wr.) Sny. and Jen. race 2 Pound and Fowler[4] causing fusarium wilt of radish.

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[1]Obtained from D. J. deZeeuw, Botany and Plant Path., Michigan State Univ.
[2]Obtained from A. L. Anderson, Botany and Plant Path., Michigan State Univ.
[3]Obtained from C. J. Olson, Yoder Brothers, Barberton, Ohio
[4]Obtained from C. S. Pound, Botany and Plant Path., University of Wisconsin

Materials Used for Treatments

Three types of iodine preparations were used for treatments. Solutions of colloidal iodine at various concentrations, a ten per cent iodine dust, and elemental iodine crystals were used in various ways.

Iodine Suspensoid Merck is an elemental iodine emulsion composed of 20 per cent iodine and 80 per cent gum arabic and water. This emulsion is stabilized by the gum arabic, and it consists of many minute globules which are approximately two-tenths of a micron in diameter (6).

Eight concentrations of colloidal iodine or Iodine Suspensoid Merck were used. The iodine was used in a series of concentrations progressively by 500 ppm to 4, 000 ppm. All solutions were made to calculated strengths by dilution with distilled water in 2-liter lots.

Six liters of each colloidal iodine solution were used. Three separate batches of colloidal iodine were made, as required by the progress of the experiments. Each 2-liter treatment was titrated with sodium thiosulfite to determine iodine content, as described by Scott (38) (Table 1).

The actual concentration of iodine varies somewhat from the intended concentrations because of the difficulty in measuring the 20 per cent colloidal iodine. Colloidal iodine is dark brown in color, thick, and viscous, thus precise measurements were not feasible in making up the various concentrations used.

Table 1

The Intended and Actual Ppm of Colloidal Iodine in the Treatment Solution Used in Determining Phytotoxic Properties of Colloidal Iodine in Relation to the Iodotherapy of Certain Plant Pathogens.

Intended Ppm of Colloidal Iodine	Ml. of 20% C.I. per 2 Liters	Actual Ppm of C.I.*		
		1st Batch	2nd Batch	3rd Batch
0	0.0	0	0	0
500	4.6	533	487	530
1000	9.2	1028	941	1009
1500	13.8	1513	1460	1456
2000	18.4	1977	2071	2061
2500	23.0	2482	2425	2473
3000	27.6	2999	3051	2031
3500	32.2	3578	3458	3504
4000	36.8	3956	3981	3956

*Iodine determination, Scott (38)

When the first batch of solutions was made, two measurements were made in addition to determining the exact concentration of the solution, which were pH and density. The pH of the eight solutions ranged between 3.5 and 4.0 using a Beckman pH meter. The density of the distilled water used was 0.9973 at 26°C, the 20 per cent colloidal iodine was 1.1135 at 26°C, and the 533 ppm colloidal iodine was 0.9968 at 26°C, as determined using an analytical balance to weigh a precise quantity of each solution in weighed glassware.

The second preparation was a 10 per cent iodine dust made by mixing iodine crystals with bentonite. The iodine crystals were ground to a very fine powder in a mortar with a pestle. One part of iodine was thoroughly mixed with nine parts of bentonite to give the resulting 10 per cent iodine-bentonite dust.

The third preparation was elemental iodine crystals for use in some treatments. Each quantity used was weighed on an analytical balance in a covered container to prevent loss of iodine due to sublimation.

Phytotoxicity Tests

In order to establish a range of iodine concentration which was not toxic to a particular plant species, various methods and intensities of treatment were used on eight plant species. Results of these tests indicated certain concentration ranges that could later be employed in connection with innoculated plant studies.

Eight treatments were used, and six had numerous concentrations in each treatment. Sprays of colloidal iodine from 500 ppm to 4, 000 ppm were used, and all species were sprayed until dripping. Soil drenches of colloidal iodine from 500 ppm to 4, 000 ppm were used at the rate of 50 milliliters per 4-inch pot, and 25 milliliters per 4-inch pot. Flats (12 x 24 inches) were also drenched with all concentrations of colloidal iodine at the rate of one liter per flat. Sublimation of iodine crystals was accomplished on a hot plate so sublimation would occur at a rapid rate using one gram and two grams per 1, 500 cubic feet. Seeds were soaked in all colloidal iodine concentrations at the rate of 100 milliliters per 100 seeds for one-half hour and one hour respectively (Table 2).

Table 2

The Treatments Various Species Received and Concentrations Used in Establishing the Phytotoxic Range of Various Plant Species Using Crystalline Iodine and Colloidal Iodine

Plant	Sprayed[1]	Drenched[1]			Sublimation[2]		Colloidal Iodine Soak[1]	
		50 ml.	25 ml.	1 liter	1 g.	2 g.	1/2 hr.	1 hr.
Bean								
Plants	0-4000*	0-4000	0-4000*	--	x	x	--	--
Seeds	--	--	--	--	--	--	0-400	0-4000
Begonia	0-4000	--	0-4000	--	x	--	--	--
Chrysanthemum	0-4000*	0-4000	0-4000	--	x	x	--	--
Cucumber	0-4000	--	0-4000	--	x	x	--	--
Geranium	3000	--	3000	--	--	x	--	--
Radish								
Red Globe	0-4000	--	--	0-4000	--	--	--	--
Wh. Icicle	0-4000	--	--	0-4000	--	--	--	--
Snapdragon	0-4000	--	0-4000	--	x	x	--	--
Tomato	0-4000	--	0-4000	--	--	x	--	--

*Repeated

[1]Concentrations used in ppm.

[2]Quantities used per 1, 500 cubic feet

Bean plants, begonias, chrysanthemums, cucumbers, geraniums, snapdragons, and tomatoes for every treatment were grown in standard 4-inch pots using the soil mixture already mentioned throughout. Four replications of one plant each were used per treatment when sprays or drenches were used. The radishes grown in flats for different treatments were not replicated, but 50 plants of each variety were present in each flat that was treated by sprays or the 1-liter drench per flat. In both sublimation studies, two replications of one plant each for each plant species were used, and all plants were grown in standard 4-inch pots. Bean seeds that were soaked in 100 ml. of the various colloidal iodine concentrations were germinated in a moist chamber. The moist chember was maintained by rolling the 100 treated seeds in a moist paper towel and inserting them into 1-gallon jars in groups of nine treatments per jar. Fifty milliliters of water was poured into each jar, and a large beaker was fitted over the top so that the humid condition necessary for germination of bean seeds would be present. Ten days after treatment, counts were made to determine the per cent of germination per treatment.

While no set experimental design was used, every effort was made throughout this experiment to maintain uniformity. Plants grown from seed to be treated were selected for uniformity. In order to maintain uniformity of Cameo chrysanthemums, biweekly vegetative propagation of standard 4-inch cuttings was done.

Spray treatments were applied using a compressed air paint type sprayer in a DeVilbiss spray booth. Plants were placed on a turn-table and continually rotated as the spray was applied.

Experimental results were recorded by daily notes on plant color, burning of leaves, stunting, seed germination, and root injury, depending on the treatment used and the plant involved. Photographs were made of some treatments.

Culture Tests

Verticillium, Fusarium, Bacterial Blight and Black Rot were used in the cultural tests. Rhizoctonia was not used because of the difficulty involved in growing it in culture, while mildew will not grow in vitro at all.

Three methods were used in an effort to establish a lethal range of colloidal iodine against the four plant pathogens used.

The first method employed was the use of standard sized paper discs made from Whatman No. 1 filter paper. The discs were soaked in the various concentrations of colloidal iodine and applied to inoculated petri dishes. Potato-Dextrose agar (P. D. A.) (33) was the medium used. No clear zone of inhibition of the pathogens was found. It was thought that the starch present in the P. D. A. might have tied up the minute amount of iodine which could be applied on a small paper disc. Coon's media (7) containing a simple carbohydrate source was then employed. The results were inconclusive in this case also.

The second method involved the use of standard drops of the colloidal iodine concentrations delivered from a fine pipette. Coon's medium was again used. As in the disc method, a measurable zone of inhibition usually is expected. The zones of inhibition were absent or indistinct.

The third method involved the addition of 2 ml. of the colloidal iodine solutions per petri dish by hypodermic syringe. In every method used, four replications of one plate each per treatment were used. Petri dishes and media were steam sterilized in an autoclave prior to use.

The media were inoculated with measured quantities of inoculum grown in potato dextrose broth (14). Verticillium and Fusarium were shaken continuously during growth, so spore bud cells would be formed copiously. When the still liquid agar media to be inoculated reached the temperature of approximately 40° C, the pathogen-containing inoculum broth was added to the media, mixed, and plates poured. Six hours after the plates were poured, they were treated, using all concentrations of colloidal iodine at the rate of 2 ml. per plate. Daily notes were taken to determine the growth or inhibition of the pathogen in the medium.

Coon's medium was used in experiments with Verticillium and Fusarium. Potato Dextrose agar was used with Bacterial blight and Black Rot because they would not grow satisfactorily on Coon's medium.

Infected Plant Material

The infecting organisms and plant species used were as follows:

1. Verticillium of chrysanthemums
2. Fusarium of radishes
3. Black Rot of radishes
4. Bacterial Blight of beans

5. Rhizoctonia of peppers, tomatoes, beans, radishes and stocks.

6. Powdery Mildew of cucumbers.

Three Cameo chrysanthemums, which were freshly rooted in sand and selected for uniformity, were planted in each of eleven 6-inch pots, using sterilized soil. Ten of the pots had the soil inoculated three days previous to planting, using inoculum grown in potato dextrose broth. One pot uninoculated represented the control. Nine other pots that had been inoculated were spray treated with the eight concentrations of colloidal iodine plus one with distilled water as a spray. The extra inoculated pot was reserved for making index cultures in order to determine the effectiveness of inoculation (8). After inoculation and incubation for three days, all plants were treated with iodine as described, and then cultured to determine the effect of iodine treatments in eradication of Verticillium from chrysanthemum plants.

Exactly the same procedure was used with Fusarium of radish, except 20 seeds were planted per pot. After germination, each pot was thinned to six plants. After infection had occurred, treatments were made with iodine. Two days after iodine treatments, cuttings from the plants were cultured to determine if the disease had been controlled with colloidal iodine sprays.

The same procedure was followed using Black Rot of radish. Only the inoculating organism was different, but all tests and procedures remained the same.

Experiments for the control of bacterial blight of beans consisted of twelve treatments of 100 seeds each. Two lots of seed were used, one uninfected and the other heavily infected with the bacterial blight organism. The infected seeds were selected for the typical yellow seed coat disculoration from a large quantity of discolored beans[1].

Table 3

The Iodine Treatments Used on Uninfected and Infected Bean Seeds to Eradicate Bacterial Blight of Beans.

Type of Seed	Treatment per 100 Seeds	Heat for Sublimation
Uninfected Infected	None	None
Uninfected Infected	Wet seeds rolled in 10% I dust	None
Uninfected Infected	Seeds dusted with 10% I dust	None
Uninfected Infected	None	60° C for 2 hours
Uninfected Infected	0.5 g. iodine sublimated	60° C for 2 hours
Uninfected Infected	1.0 g. iodine sublimated	60° C for 2 hours

[1]Obtained from F. Stuart, Michigan Elevator Exchange, Jackson, Mich.

Each lot of seed was planted in a flat containing sterilized sand and the percentage germination was recorded. Each lot of seeds receiving the heat treatment was in a separate air-tight, one-pint jar. All treatments were planted at the same time. The dusted treatments received approximately 10 grams of 10 per cent dust per 100 seeds so that the treatment would be comparable to the one gram iodine sublimation treatment. The dust was applied directly over the seeds after planting so they would come up through the dust. Rolled seeds were dampened first so the dust would adhere to the seeds.

Rhizoctonia cultures were mixed with sterilized soil in pans (8 x 10 inches) in nine of ten treatments. After inoculation the mixtures were kept damp and allowed to stand for three days in order to obtain a uniform soil infestation. Twenty seeds of tomato, pepper, stocks, radish and bean were planted in each pan. Two treatments received no iodine; one had been inoculated and the other was uninoculated. Only 300 ml. of water was added to these treatments when the seeds were planted. The other eight inoculated pans were treated with 300 ml. of colloidal iodine, using all concentrations from 0 ppm to 4, 000 ppm. Two weeks from planting and treatment time, germination counts were made to determine the effect of colloidal iodine as a soil drench for prevention of Rhizoctonia damp-off on the plants used.

Twenty cucumber plants were inoculated with powdery mildew spores by wetting the plants with a fine spray and then dusting mildew spores on the plants. Four treatments of colloidal iodine sprays were used--1, 500, 2, 000, 2, 500 and 3, 000 ppm concentrations were tried, plus control plants. Each treatment had four replications of one plant each.

All treatments were applied two days after inoculation. Two days after treatment, spores from the inoculated plants were used in an effort to inoculate another set of twenty uninfected cucumber plants. After one week the second set of plants was examined to see whether spores from the treated plants could infect the previously uninfected plants. This experiment was repeated three times, using the same procedure, so results were comparable.

Radioactive Iodine Study

Radioactive iodine-131 was employed in this experiment to study the movement and distribution of iodine applied to various portions of plants.

Eighty-five microcuries of radioactive iodine-131 as sodium iodide were used[1]. Two thirds of this material went to make 250 ml. of solution

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[1] Obtained through L. F. Wolterink, Physiology and Pharmacology, Michigan State University.

used for drenches. The ten 25 ml. drenches contained 5,666 microcuries of iodine-131 per treatment. One-third of the iodine-131 was used in making 10 ml. of solution for placing as drops on the foliage. By calculating seven drops per mililiter, 0.4049 microcuries of iodine was present in each drop applied[2].

The 2,000 ppm colloidal iodine was used to dilute the iodine-131 in making up the two solutions previously mentioned.

In using the sodium iodide with the 2,000 ppm colloidal iodine, an assumption was made that the sodium iodide would ionize so some would be in the form of elemental iodine as is present in the original solution. The quantity of radioactive iodide-131 added was very minute compared to the colloidal iodine used.

Thirty freshly rooted Cameo chrysanthemums were selected for uniformity and divided into six groups of five plants each for treatment, (Table 4).

All foliage treatments were put in one-half Hoagland solutions (16) two days prior to treatment so as to become acclimated. Oxygen was continuously bubbled through the 2-gallon glazed crocks which contained five plants per crock. The 2,000 ppm radioactive colloidal iodine treatments were applied with a hypodermic syringe, using a 27-gauge needle.

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[2]Dilutions by W. G. Long, Department of Horticulture, Michigan State University.

Table 4

Radioactive Iodine-131 Treatments Used to Determine the Movement and Distribution of Iodine when Applied with 2,000 Ppm Colloidal Iodine Solution to Various Plant Parts.

Plant Part Treated	Amount of 2,000 Ppm Colloidal Iodine Applied and the Microcuries of I-131 Present
Apex of shoot	1 drop - 0.4049 m.c. I-131 per plant
4th leaf below apex	3 drops - 1.2147 m.c. I-131 per plant
8th leaf below apex	3 drops - 1.2147 m.c. I-131 per plant
Basal leaf 12 to 14 leaves below apex	3 drops - 1.2147 m.c. I-131 per plant
Soil drench	25 ml. - 5.666 m.c. I-131 per plant
Water culture	25 ml. - 5.666 m.c. I-131 per plant

One drop was applied to each apex treated, while three drops were applied to each leaf treated. One drop was applied to each of the basal lobes of the leaf, while the third drop was put toward the tip of the leaf. All drops applied to leaves were deposited on the upper surface of the leaf.

Plants that were soil drenched were potted in 4-inch unglazed pots two days prior to treatment. Twenty-five mililiters of the treatment solution were applied directly to the soil surface.

The five plants treated in water solution were placed in 500 ml. flasks two days prior to treatment, and had oxygen constantly bubbled through the distilled water in which they were growing. 450 ml. of distilled water was used, plus the 25 ml. of treatment solution per plant. Each plant was in a separate container, and cotton was packed around the stem of each plant and into the neck of the flasks to prevent iodine loss.

Plants of all treatments were harvested 52 hours after treatment. Individual plants were then pressed and arranged on blotting paper as botanical specimens are prepared. All plants were dried in an electric forced-air oven at 70° C until dry. Each plant was then mounted on heavy white paper, and covered with cellophane.

Autoradiograms were then made of all treated plants, using the method described by Wittwer and Lundahl (50). Kodak 8 x 10 inches no-screen X-ray film was used, and the exposure duration was 5 days.

RESULTS

Phytotoxicity Tests

Concentration ranges of colloidal iodine and iodine containing materials were established denoting ranges of no injury and degrees of injury due to iodine applications on many plant species. Results of applying iodine to plants or plant parts by sprays, soil drenches, sublimation, and seed soaks will be described in that order.

Foliar Spray Treatments

Spray treatments of various plants (Figure 1) revealed that plant species treated differed in tolerance to iodine in the concentration range used.

Beans that were sprayed (Figures 1 and 2) exhibited little tolerance toward iodine. The treatments produced some chlorosis of leaves which increased in severity as treatment solutions were increased in strength. In addition to chlorosis, necrotic areas on leaves also increased with higher concentrations of iodine, however, none was present below the concentration of 1, 500 ppm colloidal iodine.

Cucumbers that were sprayed (Figure 1) showed no toxic effects until the concentration of 2, 500 ppm colloidal iodine was used. Marginal chlorosis was present on older leaves using 2, 500 ppm and 3, 000 ppm colloidal iodine. The two highest concentrations used resulted in severe burning and necrosis of leaves.

Chrysanthemums, as contrasted to beans and cucumbers, receiving sprays (Figures 1 and 3) were slow to exhibit injury. However, two weeks after treatment marginal and interveinal chlorosis plus necrotic spots appeared on lower leaves of the plant. Foliage injury increased with increased concentrations of colloidal iodine, and stunting appeared in the three most concentrated spray treatments used.

Geraniums were sprayed with only the 3, 000 ppm colloidal iodine solutions (Figure 4). This treatment resulted in extreme chlorosis and eventual death of older leaves.

Radish plants (Figure 1) as compared to chrysanthemum plants, were quite tolerant to iodine when sprayed on the foliage. Severe injury was not observed, but spotty gray-brown necrotic areas appeared on leaves in increasing numbers from the foliar application of the 3, 000 ppm to 4, 000 ppm of colloidal iodine. No difference was observed between the two varieties of radish used.

Tomatoes (Figure 1) were quite tolerant of iodine sprays, and no adverse effects were present until concentrations of 3, 000 ppm to 4, 000 ppm were used. The injury was characterized by slight interveinal chlorosis of the basal leaves, and increased with some necrotic spotting when the strongest concentration of colloidal iodine was used.

Begonias and snapdragons (Figure 1) were very tolerant of iodine applied in the concentrations used. No adverse effects were observed on either species.

Soil Drench Treatments

Soil drench treatments of various plant species with colloidal iodine (Figure 5) revealed that plants were less tolerant, in general, to the same iodine concentrations applied by this method.

Beans that were drenched (Figures 5 and 6) with colloidal iodine at any of the concentrations used were killed using the 50 ml. or 25 ml. drench per 4-inch pot.

Cucumbers (Figure 5) reacted to the drench treatments in a similar manner as bean plants. All iodine treated plants died, using the 25 ml. drench per 4-inch pot.

Chrysanthemums (Figures 5 and 7) were not tolerant to the treating drench solutions receiving either 50 ml. or 25 ml. of colloidal iodine. The lower leaves of iodine treated plants were most severely affected. Interveinal chlorosis and necrotic areas increased in number and area on leaves as the concentration of treatment solutions increased. Easily noted stunting and reduction of the number of active roots was also observed with increasing iodine concentrations (Figures 8 and 9).

Tomatoes (Figure 5) soil drenched with colloidal iodine showed toxic symptoms which were slow to appear. Marginal and interveinal chlorosis plus some necrotic areas appeared on lower leaves in greater intensity as treatment solutions increased on concentrations using only 25 ml. per 4-inch pot. As a result of the soil drench treatments with colloidal iodine, water uptake appeared to be greatly decreased, indicating root injury, in comparison to untreated plants or those treated by foliar application.

Geraniums (Figure 10) soil drenched with 3, 000 ppm colloidal iodine solution using 25 ml. per 4-inch pot showed severe damage to the older leaves of the treated plants. As in the case of soil drenched tomatoes, geraniums exhibited wilting and decreased water uptake by treated plants in comparison to untreated controls, again indicating root injury due to soil drenches.

Snapdragons (Figure 5) were not tolerant to soil drenches at any concentration when applied at 25 ml. per 4-inch pot. Soil drenches of 1, 500 ppm to 2, 500 ppm colloidal iodine caused stunting and terminal yellowing while soil drenches of 3, 000 ppm to 4, 000 ppm caused stunting and extreme wilting which increased in severity with concentration applied.

Radishes (Figure 5) soil drenched with 1 liter of colloidal iodine per flat suffered severe chlorosis and drying of leaves at the four highest concentrations. In lower concentrations the same type of leaf damage was observed, but to a lesser extent as the concentration of soil drench was reduced. However, examination of the radish roots showed no adverse effects attributable to treatment. No difference was observed between radish varieties in the same flat in the degree of injury suffered from drench treatments.

Begonias (Figure 5) soil drenched with 25 ml. per 4-inch pot showed a stunting which was more pronounced as the concentration of colloidal iodine increased. Foliage was not adversely affected by treatment, but root injury expressed by the number of roots increased proportionally with increase in concentration of the treatment solutions.

Sublimation

Sublimation of elemental iodine crystals at the rate of 2 grams per 1,500 cubic feet resulted in injury to some plant species very similar to that observed using sprays at the higher concentrations (Figure 11). Begonias and snapdragons were not affected by the iodine sublimation. Sublimation of iodine crystals at the rate of 1 gram per 1,500 cubic feet gave results similar to foliage sprays of the same plant species using intermediate strength concentrations of colloidal iodine (Figure 11).

Seed Soaks

Bean seeds soaked for one-half hour and one hour at all colloidal iodine concentrations were injured, and germination was greatly reduced (Figure 12). Results do not follow the expected pattern, indicating differential absorption of the treatment solutions by the bean seeds.

Culture Tests

The use of standard sized paper discs and standard drops in relation to iodine treatment of plant pathogens to establish lethal ranges with various concentrations of colloidal iodine gave results which were inconclusive or absent in culture.

Treatment with all concentrations of colloidal iodine at the rate of 2 ml. per Petri dish established the lethal ranges (Figure 13). Verticillium of chrysanthemum, and black rot of radish were killed in culture with all treatments containing iodine. Fusarium of radish, and bacterial blight of bean were effectively controlled between 1, 500 ppm and 4, 000 ppm of colloidal iodine.

Infected Plant Material

Various concentrations of colloidal iodine applied as a spray in experiments on the eradication of powdery mildew of cucumber, Fusarium of radish, Verticillium of chrysanthemum, and black rot of radish resulted in control of only the powdery mildew of cucumber (Figure 14). Inoculation of radishes with Xanthomonas campestris was not successful because of unfavorably high temperatures. For that reason the uninfected plants were not sprayed in an attempt to eradicate the disease.

Bean seeds, infected and uninfected with Xanthomonas phaseoli and treated in various ways with iodine dust and sublimated iodine, showed reductions in germination due to iodine treatments and heat treatments used in the sublimation process (Figure 15). Seeds treated with 10 per cent iodine dust were severely injured by the treatments, while heat treatments and sublimated iodine reduced germination approximately one-third each in comparison to seeds treated with no heat or iodine. The infected seeds failed to germinate when treated with iodine, therefore no degree of control could be established.

Rhizoctonia solani infested soils in which seeds of five susceptible plant varieties had been planted were soil drenched with all concentrations of colloidal iodine with little success in preventing damp-off (Table 5).

Table 5

The Effect of Colloidal Iodine Soil Drenches of Various Concentrations as a Control of Rhizoctonia Damp-off of Five Plant Species.

Treatments and Concentrations Used (300 ml. per 8 x 10" Pan)	Number of Seeds Germinating					
	Tomatoes	Radishes	Beans	Peppers	Stocks	Total* per Treat.
Uninoculated - 0 ppm.	14	18	14	20	7	73
Inoculated - 0 ppm.	16	0	1	9	0	26
Inoculated - 500 ppm.	12	2	0	1	1	16
Inoculated - 1, 000 ppm.	5	2	0	0	1	7
Inoculated - 1, 500 ppm.	0	1	0	1	1	3
Inoculated - 2, 000 ppm.	0	0	0	1	4	5
Inoculated - 2, 500 ppm.	0	0	0	0	0	0
Inoculated - 3, 000 ppm.	0	0	0	0	0	0
Inoculated - 3, 500 ppm.	0	0	0	0	0	0
Inoculated - 4, 000 ppm.	0	0	0	0	0	0

*20 seeds of each species was planted per pan, thus 100 seeds are present in each treatment.

Iodine treatments resulted in less total seed germination throughout, and observation revealed a mycosis on seeds two days following treatment. Results indicate that none of the treatments effectively inhibited or controlled the pathogen, but did contribute in injuring the seeds, and reducing total germination.

Radioactive Iodine Study

Of thirty Cameo chrysanthemums treated in various ways with I^{131}, three autoradiograms were selected to represent results.

Plants treated by applying radioactive iodine to the foliage indicated no translocation of the iodine material applied had taken place (Figure 16). In every instance where I^{131} had been applied to a certain leaf or the apex only the localized spots indicating no translocation appeared on the autoradiograms.

Plants soil drenched with I^{131} were able to take up the iodine material applied. Greater concentrations of the radioactive iodine appeared in the terminal meristematic region and toward the base of the plant's stem (Figure 17). The concentration of iodine indicated in Figure 17 on the basal leaf in the bottom, right-hand corner is not typical of the treatment, but the overall clarity of the autoradiogram made its selection over others receiving the same treatment desirable.

Plants treated with I^{131} in water culture provided autoradiograms showing complete distribution of the radioactive I^{131} colloidal iodine treatment solutions throughout the whole plant (Figure 18). Concentrations of the I^{131} were again in the terminal meristematic region and the roots and lower stem. By comparing Figures 17 and 18, it is observed that at least twice as much I^{131} was taken up by the plant treated in water culture. This observation may give a gross indication of the amount of iodine inactivated by the greenhouse soil mixture used throughout this experiment.

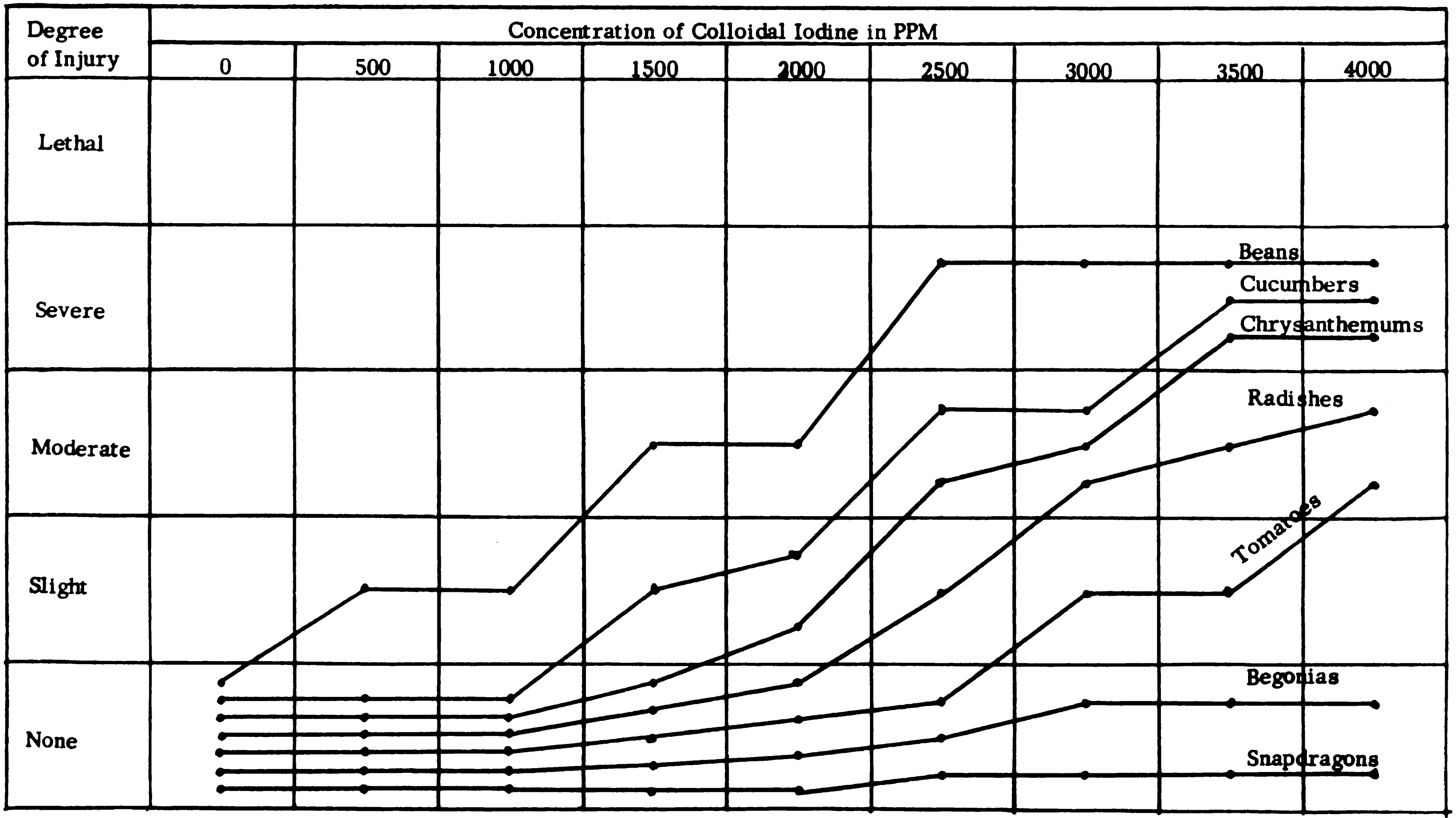


Figure 1. Degrees of injury caused by different concentrations of colloidal iodine applied as foliar sprays to various plants.

Figure 2. Michelite beans sprayed with various concentrations of colloidal iodine until dripping. A, control; B, 1, 000 ppm. ; C, 2, 000 ppm; D, 3, 000 ppm; and E, 4, 000 ppm. spray of colloidal iodine. Note increased injury as spray concentrations increased.

Figure 3. Cameo chrysanthemums sprayed with various concentrations of colloidal iodine until dripping. A, control; B, 1,000 ppm.; C, 2,000 ppm.; D, 3,000 ppm.; and E, 4,000 ppm. spray of colloidal iodine. Note increased injury to lower leaves and stunting of treatments D and E as spray concentrations increase.

Figure 4. Madame Buchner geraniums sprayed with the 3, 000 ppm. colloidal iodine (S30) and with distilled water (C) until dripping. Note injury to older leaves of the plant sprayed with colloidal iodine.

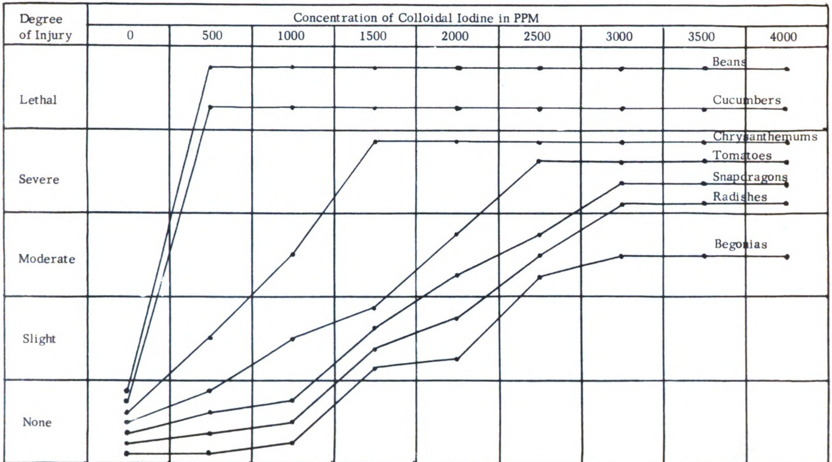


Figure 5. Degrees of injury caused by different concentrations of colloidal iodine applied as a soil drench to various plants.

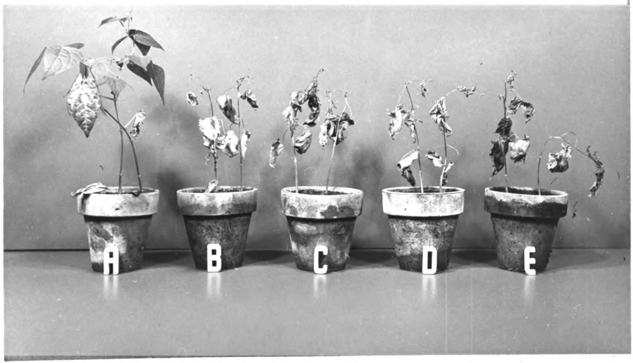


Figure 6. Michelite beans soil drenched with various concentrations of colloidal iodine using 25 ml. per 4-inch pot. A, control; B, 1, 000 ppm. ; C, 2, 000 ppm. ; D, 3, 000 ppm. ; and E, 4, 000 ppm. drench of colloidal iodine. Note all iodine treated plants had died.

Figure 7. Cameo chrysanthemums soil drenched with various concentrations of colloidal iodine using 25 ml. per 4-inch pot. A, control; B, 1,000 ppm.; C, 2,000 ppm.; D, 3,000 ppm.; and E, 4,000 ppm. colloidal iodine. Note increased damage to leaves and stunting as the drench concentrations increase.

Figure 8. Cameo chrysanthemums soil drenched with 25 ml. per 4-inch pot of the 2, 000 ppm. colloidal iodine (C) and with distilled water (A). Note damage stunting, and reduction of active roots in the iodine treated plant in comparison to the plant treated with no iodine.

Figure 9. Cameo chrysanthemums soil drenched with 25 ml. per 4-inch pot of the 4, 000 ppm. colloidal iodine (E), and with distilled water (A). Note the stunting, great reduction of roots, and dead roots present in the iodine treated plant in comparison to the plant treated with no iodine. Also, compare severity between treatments shown in Figure 8 and Figure 9.

Figure 10. Madame Buchner geraniums soil drenched with 25 ml. per 4-inch pot of the 3, 000 ppm. colloidal iodine (D30), and with distilled water (C). Note extreme injury to larger and more mature leaves characterized by chlorosis are followed by necrosis.

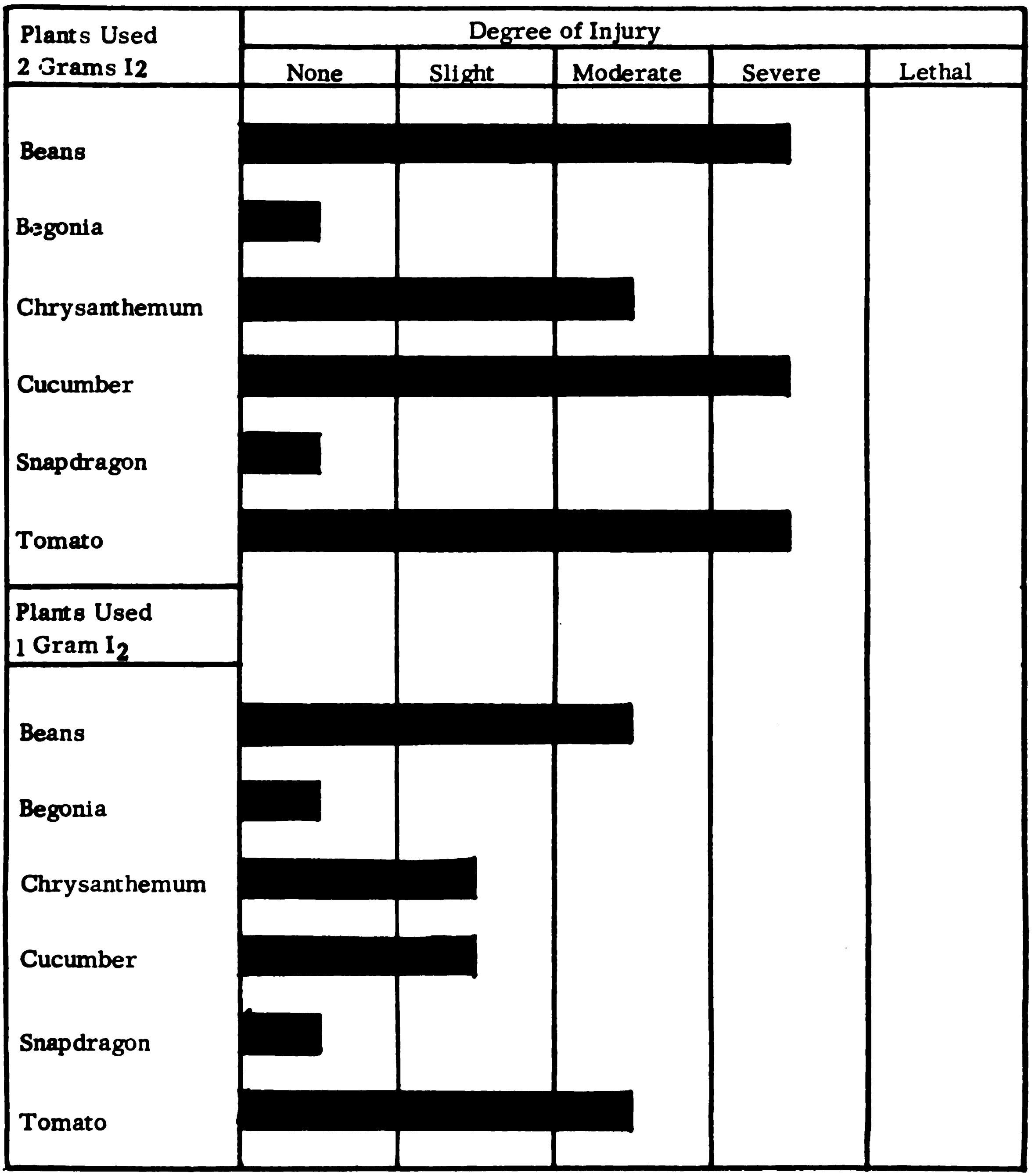


Figure 11. Degrees of injury to various plants from the sublimation of one and two grams of iodine in a 1500 cubic foot area.

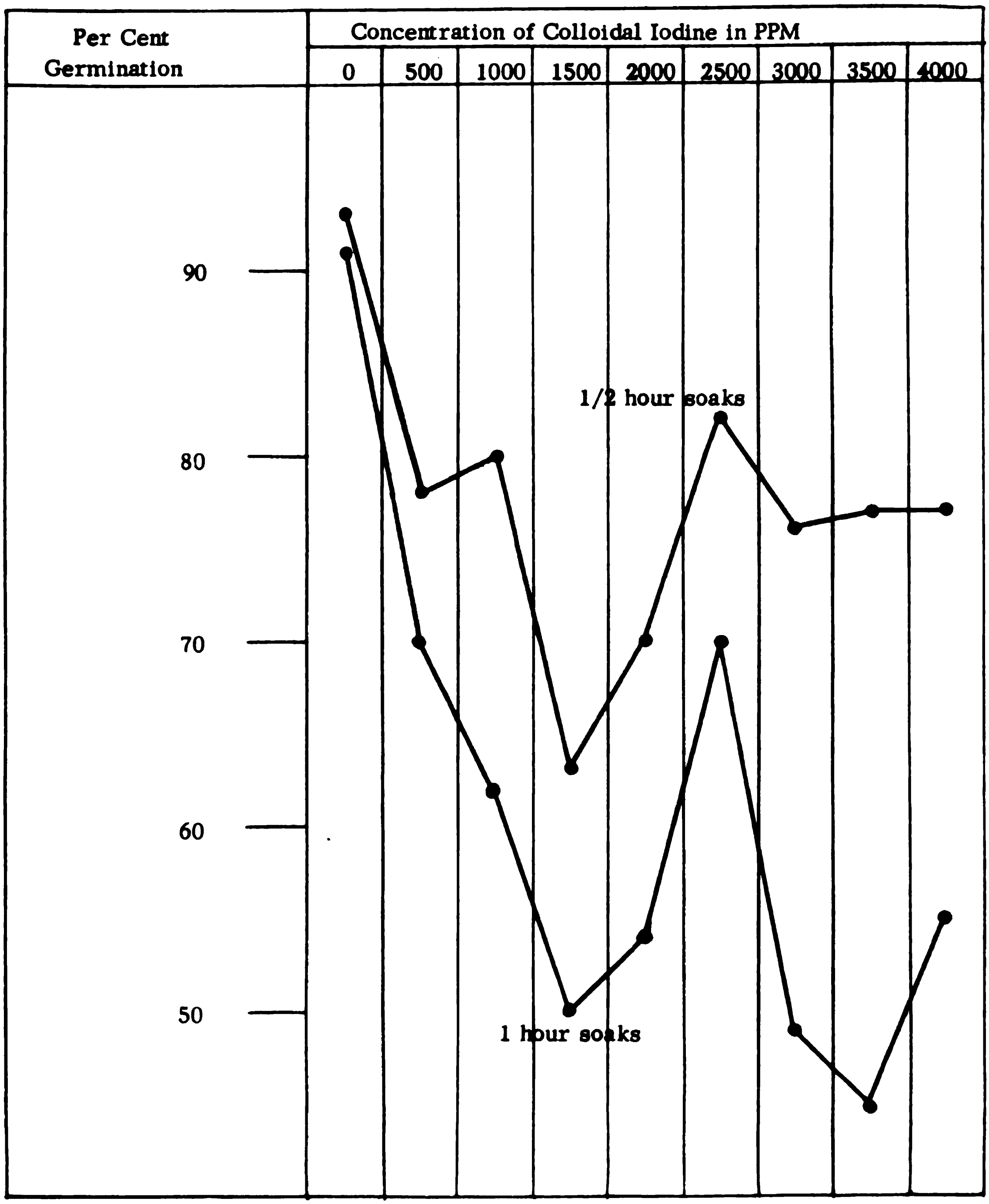
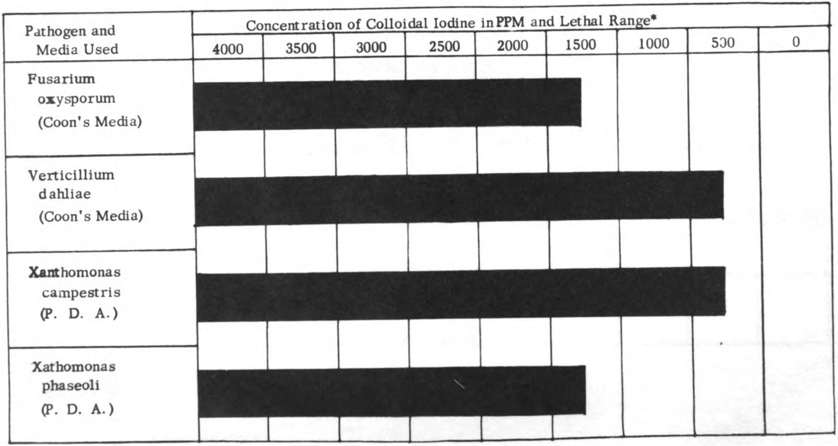


Figure 12. The per cent germination of bean seeds treated for one-half hour and one hour using various concentrations of colloidal iodine as soaks.



*Lethal range indicated by black bars.

Figure 13. The lethal range of colloidal iodine on four plant pathogens grown in culture and treated with various concentrations of colloidal iodine at the rate of two milliliters per petri dish.

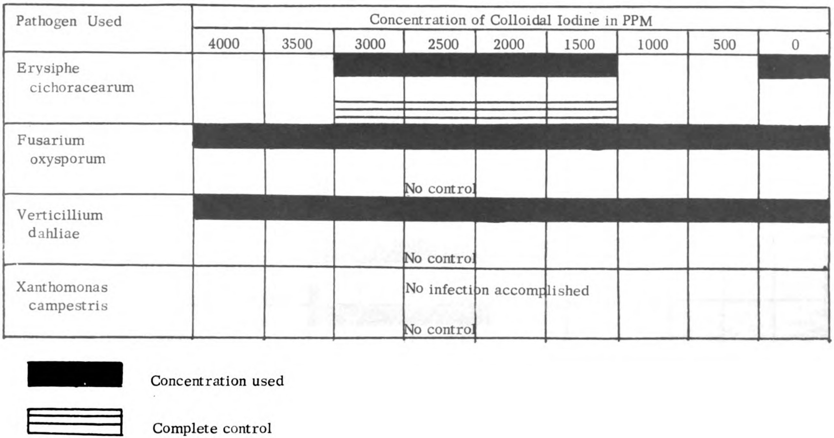


Figure 14. The effectiveness of various concentrations of colloidal iodine applied as a spray in the eradication of four plant pathogens.

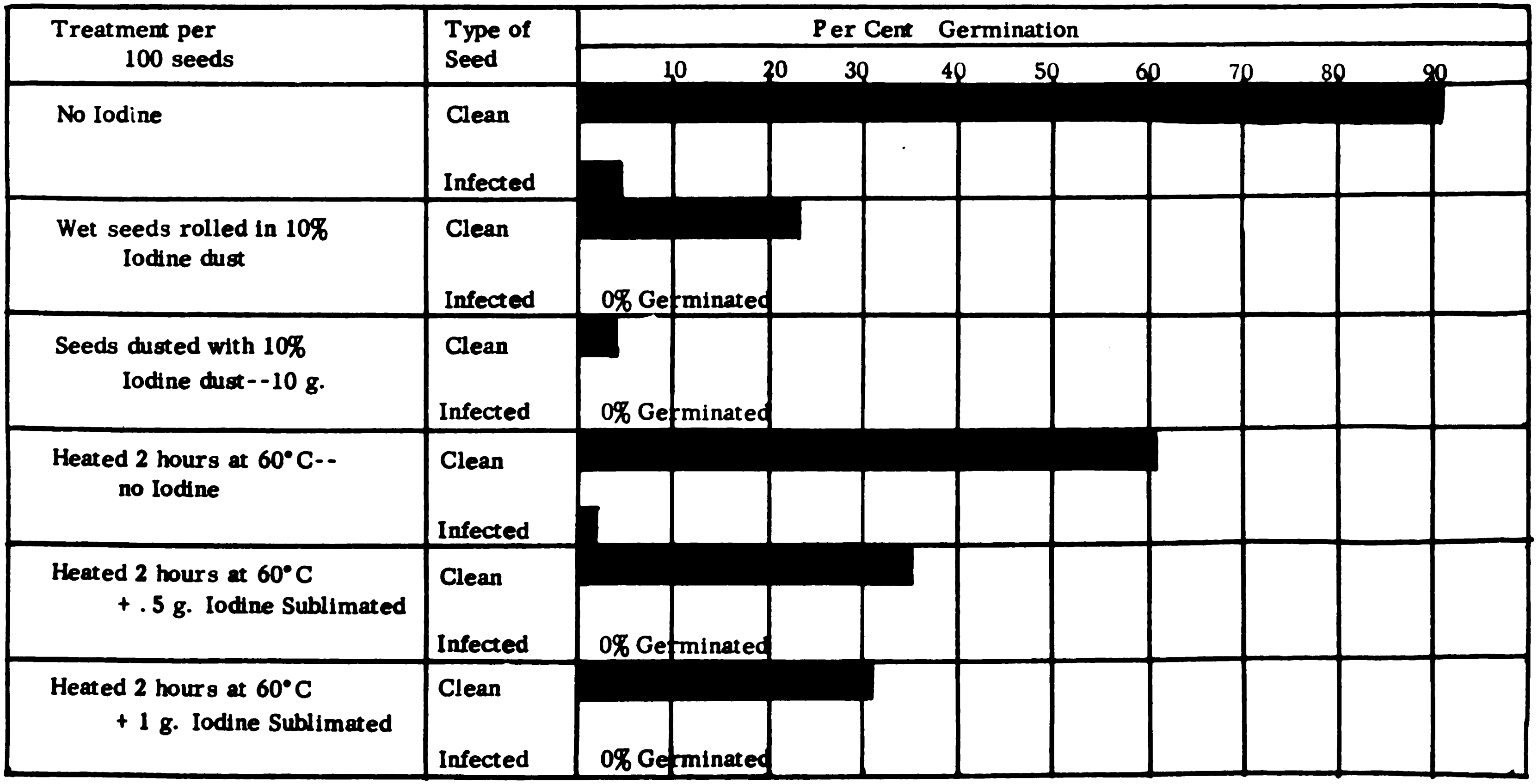


Figure 15. The per cent germination of clean and infected bean seeds using various methods of applying iodine to eradicate bacterial blight of beans.

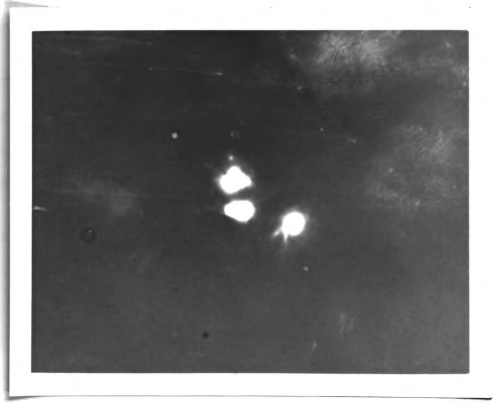


Figure 16. An autoradiogram of a Cameo chrysanthemum which had been treated with I^{131}. Three drops of the I^{131}-2, 000 ppm colloidal iodine treatment solution was applied to a mature leaf eight leaves below the apex of the plant. The three drops contained a total of 1. 2147 microcuries of I^{131}. Note, according to the results obtained, that the iodine applied to the foliage was not translocated to other parts of the plant.

Figure 17. An autoradiogram of a Cameo chrysanthemum which had been soil drenched with 25 ml. of I^{131}-2, 000 ppm. colloidal iodine solution. 5. 666 microcuries of I^{131} was present in each treatment solution per single plant. Note the distribution of iodine throughout the plant with a greater concentration at the apex. The concentration of iodine present on the bottom leaf was not typical, but this print was the clearest of all plants treated this way.

Figure 18. An autoradiogram of a Cameo chrysanthemum which had been treated by adding 25 ml. of I^{131} - 2, 000 ppm. colloidal iodine treatment solution to 450 ml. of distilled water in which the plant had been placed. Note the distribution of iodine throughout the plant with concentrations appearing at the shoot apex, and roots.

DISCUSSION

The fungicidal and bactericidal properties of colloidal iodine have been demonstrated by culture tests. This work is substantiated by the general or recognized fact that iodine has good germicidal activity. Anson and Stanley (2), in addition, found iodine effective as a tobacco mosaic viricide. Therefore, one may conclude that iodine possesses eradicative possibilities in relation to plant pathogens.

Phytotoxic properties of iodine were demonstrated on many plant species. Regardless of the method used, iodine applications resulted in a wide tolerance variation among plants treated. Inherent salt, or halophytic tolerances, and anatomical features of certain plant species appeared responsible for the degree of tolerance to iodine. Bean plants and seeds were very intolerant to iodine as they are to even moderate applications of fertilizers which indicates low tolerance to soluble chemicals. Begonias appeared to be the extreme opposite of beans, and tolerated iodine at relatively higher concentrations. Thick cutinous coverings of the leaves, and tolerance of high salts probably contributed greatly to the iodine tolerance of begonias.

The method of application appears to be an important factor in the use of iodine materials on plants. Radioactive I^{131} - colloidal iodine treatments of chrysanthemums by foliar application demonstrated that iodine is not translocated within the plant. Probably the iodine applied was held as the result of some reaction between chemically reactive organic substances present in the leaves and the iodine itself. The mature, lower leaves of some sprayed plants (bean, tomato, cucumber, and chrysanthemum) exhibited greater injury than younger, immature leaves toward the apex of the plants. This may be accounted for by the fact that the iodine applied was held in greater quantities by chemically reactive substances which would be in greater concentration in the more mature portions of a plant.

A different situation appears likely in connection with iodine uptake by application to roots. Water cultures and soil drenches of iodine using I^{131} demonstrated that iodine was taken up by roots and distributed throughout the plant. Apparently little or none of the materials responsible for holding or tying-up iodine must inhibit its path upwards in the plant. Iodine probably is taken into the plant by root hairs, then through the xylem system, finally reaching its destination in the plant's foliage. While the iodine is in the roots and xylem, little material capable of tying-up the iodine would be present, and if some were present it would be greatly diluted by water and other simple chemical substances taken-up by the plant in addition to iodine. However, when the iodine reaches its destination in the foliage, it is held or tied up because reactive substances are present in more concentrated quantities.

Characteristics of a plant pathogen and its relation to the host are other important factors connected with the use of iodine for eradication of plant diseases. Deeply embedded pathogens, such as vascular disorders may not be affected by iodine applications, while pathogens inhabiting the surface ornear the surface of a host may be easily eradicated using iodine materials.

From the previous discussion, one would conclude that the interaction between the plant treated, the method of treatment, and the pathogen involved all must be considered in order to determine the feasibility of using iodine to eradicate a specific plant pathogen.

Verticillium of chrysanthemum and fusarium of radish were not controlled because foliage applications of iodine could not penetrate the infected plant tissues in sufficient quantity to kill the pathogen. Soil drenches of iodine were not used because of severe toxicity to the host plants. The nature of the pathogen, and the degree iodine tolerance of the host plants made eradication difficult.

Control of bacterial blight of beans was not feasible by iodine treatment of infected seeds because of extremely low tolerance and the many complex carbohydrates which may inactivate the iodine applied.

The amount of iodine applied must be so great in order to control the disease that the metabolism of the seeds was upset resulting in injury and eventual death.

Rhizoctonia damp-off of seedlings was not effectively controlled by iodine soil drenches because soil components successfully compete for the iodine added. If sufficient iodine were added to control the pathogen, the metabolism of soil organisms and nutrient interactions would be greatly disturbed. Possibly better results would be realized if a chemically less active medium, such as sand, was used in place of soil.

Mildew of cucumber was effectively controlled because the plant could tolerate iodine in concentrations lethal to the disease pathogen, the disease inhabited the surface or was close to the surface, and sufficient quantities of iodine could be easily applied as a spray. In addition to being on the surface of the host plant, the milder mycelium appeared to have a physical or chemical affinity for iodine. Iodine sprays easily wetted the areas infected and appeared to concentrate on the patches of mildew present on the leaves.

The results of bean seed soaks (Figure 12) are difficult to explain. Perhaps alteration of the physical or chemical properties of colloidal iodine changes with dilution, thus causing differential absorption or reaction rates on various components of the bean seeds.

From the results and conclusions of this work, it might be feasible to treat cuttings of some plants in an effort to eradicate certain diseases. The theory that certain chemically reactive substances within the plant may be responsible for inactivation of iodine, hence producing injury to the plant, suggests that storage of the plant in the dark may reduce appreciably the amounts of these substances. If these reactive substances could be reduced, the quantity of iodine applied may also be reduced, causing less phytotoxic damage. Therefore, some vegetatively reproduced plants could be stored for a short period of time and then set-in or dipped-in iodine solutions. The iodine could be taken-up by the vascular system and into the cutting's foliage to attack pathogens present in an effort to obtain disease free propagation stock.

The use of wrappers impregnated with iodine to prevent spoilage of fruits and vegetables (9, 10, 11, 12, 29, 30, 31, 44, 45, 46, 47) in storage has resulted in various degrees of success. Some fruits are severely damaged, and others are not damaged using iodized wrappers. It would seem likely that consideration of the anatomical features of the fruit treated would be or prime importance. Oranges, with their thick outer skin, probably could be shipped in iodized wrape, while peaches, with their thin, easily injured outer skin, probably would react with the iodine causing discoloration and bad taste to the exocarp and mesocarp if shipped in iodized wraps.

Conclusions of this discussion would indicate that colloidal iodine, and other forms of elemental iodine are phytotoxic to many species, lethal to many plant pathogens, and ineffective in treating diseased hosts in an effort to eradicate the infecting pathogen. However, some observations, such as the control of powdery mildew of cucumber, indicate iodine is effective when employed in specific cases where the host plant is tolerant to iodine treatment, and characteristics of the pathogen allow for its control.

Iodine crystals or colloidal iodine solutions possess characteristics which must be considered in their use. Volatilization of iodine from the crystalline form and colloidal iodine solutions should be realized in the storage of iodine materials and in connection with fine sprays in which much of the iodine used may be lost to the atmosphere before reaching the object to be sprayed. If the iodine applied does not penetrate the surface on which it was placed, a large portion may volatilize and not be useful for treatment. On the other hand, very little, if any residue results from foliar applications of colloidal iodine which is an important consideration in connection with some crops. In the event of war, iodine may be a useful replacement for some copper and mercury compounds used in connection with plants.

SUMMARY

This investigation consisted of a number of experiments which were grouped into four major categories. The phytotoxic range of iodine for many plant species, the lethal range of iodine on four plant pathogens in culture, the effectiveness of iodine in the control of infected plant material, and radioactive I^{131} used to study the movement of iodine applied to plants comprised the four major sections of this experiment.

Phytotoxicity Studies:

Plant response to foliar spray applications of colloidal iodine using concentrations from 0 - 4,000 ppm. iodine showed plant species differ in their tolerance to iodine. The order of tolerance ranged from the least tolerant to the most tolerant in the following order: beans, cucumbers, chrysanthemums, radishes, tomatoes, begonias and snapdragons.

Plant response to soil drench applications of colloidal iodine using concentrations from 0 - 4,000 ppm. iodine showed most plant species treated could not tolerate iodine applied in this manner. In the concentration ranges used, beans and cucumbers were killed, and all other species treated were severely injured with the exception of begonias, which exhibited moderate tolerance. Root injury resulted on many plant species from soil drench treatments.

Plant responses to sublimation of crystalline iodine at the rate of one or two grams per 1,500 cubic feet indicated injury to some plant species used. The one-gram sublimation gave results similar to those obtained by spraying the same species with the intermediate spray concentrations, while the two-gram sublimation was comparable to the most concentrated sprays used. Begonias and snapdragons were not injured by this treatment.

Bean seeds soaked in 100 ml. of colloidal iodine per 100 seeds for either 1/2 or 1 hour, using concentrations from 0 - 4,000 ppm. iodine responded with reductions of 13 to 48 per cent germination.

Culture Studies:

Pathogens grown in culture were treated with 2 ml. of colloidal iodine per Petri plate using concentrations from 0 - 4,000 ppm. iodine. The lethal range of colloidal iodine was 1,500 - 4,000 ppm. iodine for *Fusarium oxysporum* f. *conglutinous* and *Xanthomonas phaseoli*, and 500 - 4,000 ppm. iodine for *Verticillium dahliae* and *Xanthomonas campestris*.

Infected Plant Material:

Spray treatments of plants infected with fusarium of radish, verticillium of chrysanthemum, and powdery mildew of cucumber resulted in control of the mildew only. Complete mildew control was accomplished using colloidal iodine spray concentrations of 1, 500, 2, 000, 2, 500 and 3, 000 ppm. iodine.

Bean seeds infected with Xanthomonas phaseoli were treated with a 10 per cent iodine dust and sublimated iodine. The infected seeds failed to germinate when treated with iodine by either method, therefore no degree of control could be established.

Rhizoctonia infested soils were drenched with colloidal iodine using concentrations of 0 - 4, 000 ppm. iodine to prevent seedling damp-off. None of the treatments controlled the pathogen, but iodine did contribute to the injury and reduced germination of seeds planted in the treated soils.

Radioactive Iodine Study:

Foliar application of I^{131} - colloidal iodine solutions revealed that iodine is not translocated from a single leaf or the shoot apex to other parts of the plant.

Root application of I^{131} - colloidal iodine solutions revealed that iodine is taken up by plants. Iodine was present throughout the entire plant, and concentrations appeared in the terminal meristematic region and in the plant roots.

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