# Postinfectional Fungus Inhibitors from Plants: Fungal Oxidation of Capsidiol in Pepper Fruit

A. Stoessl, C. H. Unwin, and E. W. B. Ward

Agricultural Research Institute, Canada Department of Agriculture University Sub Post Office, London, Ontario, N6A 3KO.

Accepted for publication 19 March 1973.

ABSTRACT

Capsidiol, the antifungal sesquiterpene induced in pepper fruit by several fungi, was rapidly oxidized in shake cultures of *Botrytis cinerea* and *Fusarium oxysporum* f. *vasinfectum* to the less toxic ketone, capsenone. This was further degraded by *B. cinerea* to undetermined minor products. In pepper fruit, four of six *Fusarium* spp. oxidized capsidiol to capsenone. Increases in capsidiol levels occurred between 6 and 12 hr after inoculation with *F. oxysporum* f. *pisi* or *F. oxysporum* f. *vasinfectum*. Capsidiol was oxidized by the latter almost as rapidly as it was formed. The extent of the capsidiol-capsenone conversion by *Fusarium* spp. was sufficient to eliminate inhibition of spore germination but not of mycelial growth. The ability to perform the oxidation does not appear to be specifically associated with the pathogenicity of the *Fusaria* for pepper fruit.

Phytopathology 63:1225-1231

It is well known that some pathogenic fungi can degrade or otherwise modify antifungal compounds they encounter in host plants. Both pre- and postinfectional inhibitors of a variety of structural types and biogenetic origins, are subject to such modification. These include the acetylene, wyerone acid (4); the benzophenanthridine alkaloid, sanguinarine (8); several triterpenoidal and steroidal glycosides (14, 15); several pterocarpans (3, 5, 6, 7, 11, 12, 20); and the stilbene, pinosylvin, and its methyl ether (10). Mention must also be made of the fungal inactivation of the sesquiterpene, ipomeamarone (17), although the role of this compound as a defense agent is now regarded as uncertain (9), and of the breakdown of the aromatized sesquiterpene dimer, gossypol, which has been studied in relation to reduced toxicity to animals (2). In most cases, the structures of the products, and hence also the chemical character of the reactions which lead to them, have not been elucidated. Exceptions are wyerone acid, which is converted into a fully characterized, nontoxic derivative by reduction (4), the glycosides whose detoxification is effected by partial hydrolyses (14, 15), and the reduction of sanguinarine (8). Evidently, therefore, detoxification reactions and hence also the fungal enzymes which mediate them, are varied in kind.

In several of the instances cited it has been suggested that the detoxification of inhibitory compounds is an essential element in pathogenicity. Despite their persuasiveness, arguments to this effect are not entirely conclusive. For example, the possibility cannot be ruled out that some of the detoxifications may be a consequence and not a prerequisite of pathogenicity. Thus, Christenson concluded that the degradation of pisatin is of only limited importance in the pathogenicity of different clones of *Fusarium solani* (3). Similarly, Sakuma & Millar (12) appear to have encountered a situation in which there was incomplete correlation between pathogenicity and the fungal degradation of medicarpin. It is thus obvious that detoxification reactions present several aspects which require further exploration.

Our own studies have led to the isolation and

characterization of the sesquiterpene, capsidiol, a postinfectional inhibitor and potential source of disease resistance in fruit of sweet peppers (16). We also discovered (19) that, of 10 fungi tested for their capacity to induce the formation of this compound, *Fusarium oxysporum* f. *vasinfectum* and *Botrytis cinerea* oxidized capsidiol (Fig. 1-a) to the ketone, capsenone (Fig. 1-b), which was appreciably less fungitoxic. Although not primarily pathogens of pepper fruit, both fungi invaded pericarp tissue after inoculation, differing in this respect from seven of the 10 species tested. Thus, it appeared that infection was perhaps facilitated by the detoxification of capsidiol. However, to establish its significance for pathogenesis it is essential to know at least whether the process is sufficiently rapid and extensive, and whether it operates in vivo. The results reported here bear on these questions. In addition, comparisons between a number of *Fusaria* were made to determine whether the ability to oxidize capsidiol is associated specifically with pathogenicity.

MATERIALS AND METHODS.—*General.*—The fungi used were *Botrytis cinerea* Pers. ex Fr., *Fusarium oxysporum* Schlecht. f. *conglutinans* (Wr.) Snyd. & Hans., *F. oxysporum* Schlecht. f. *lycopersici* Sacc., *F. oxysporum* Schlecht. f. *pisi* Linford race 1, *F. oxysporum* Schlecht. f. *vasinfectum* (Atk) Snyd. & Hans., *F. poae* (Pk.) Wr., *F. solani* (M) Appel & Wr., f. *pisi* (F. R. Jones) Snyd. & Hans. Stock cultures were maintained on potato-dextrose agar slants at 15 C. For spore production subcultures of these were grown on V-8 juice agar at 25 C in petri dishes or milk dilution bottles (used horizontally). Still cultures of *B. cinerea* (inoculated with 5-mm diam plugs from petri dish cultures) were grown on 25 ml of malt extract medium (Difco malt extract 5 g, Difco yeast extract 5 g, D-glucose 15 g in 1,000 ml distilled water) in 200-ml Erlenmeyer flasks at 15 C in the dark for four days. A synthetic medium used for shake cultures of *B. cinerea* and *F. oxysporum* f. *vasinfectum*, was composed as follows: 2.36 g L-asparagine, 15 g D-glucose, 1 g $KH_2PO_4$, 0.5 g $MgSO_4 \cdot 7H_2O$, 100 $\mu$g thiamine-HCl, 100 $\mu$g pyridoxine-HCl, trace amounts of salts of Fe, Zn, Co, Mn, Cu, Ca, and 1,000 ml distilled water. N KOH was used to adjust the pH to 6.0. It was dispensed in 50 ml aliquots in 200-ml Erlenmeyer flasks. All media were steam sterilized by autoclaving for 15 min at 1.05 kg-force/cm$^2$ (15 psi) and 121 C.

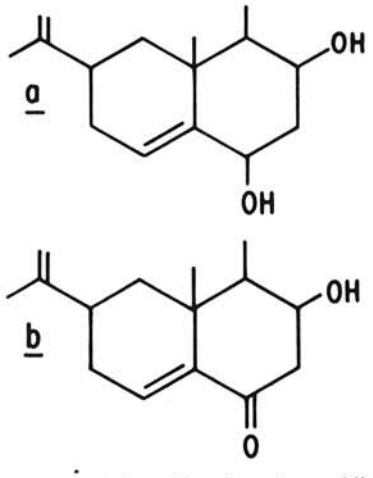


**Fig. 1.** Structural formulae for **a)** capsidiol, and **b)** capsenone.

Fruit of sweet peppers (*Capsicum frutescens* L., 'Keystone Resistant Giant') was grown in the greenhouse and harvested when partially ripe (green, streaked with red).

Pure capsidiol and capsenone were obtained previously (16, 19). Stock solutions were made up in absolute ehtanol; dilutions therefrom were made with sterile distilled water and handled aseptically.

*Assays of capsidiol and capsenone for fungitoxicity.*—A standard spore germination assay was used (1). Mycelial growth inhibition was determined on a range of concentrations of the compounds incorporated into V-8 juice agar dispensed into 35 X 10 mm plastic petri dishes (1 ml per dish) in triplicate. Inoculum consisted of a 5-mm diam plug cut from the periphery of a culture on the same medium. Growth (colony diam) was measured after 48-hr incubation at room temperature (ca. 21 C). Results are expressed as percent inhibition (control = 0).

*Fungal oxidation of capsidiol in pure culture.*—Shake cultures were established by inoculating the synthetic medium with either a spore suspension of *F. oxysporum* f. *vasinfectum* (1 ml, 1 X $10^{10}$ spores) or a suspension of washed blended mycelium of *B. cinerea* (1 ml, 7.5 mg dry weight, obtained from still cultures). These procedures gave cultures of sufficient homogeneity that reasonably uniform samples could be withdrawn with a syringe. After incubation for 40 hr at 25 C, 1 ml 5 X $10^{-3}$ M capsidiol in ethanol was added to each flask. (The final ethanol concentration, 2%, was not injurious). Aliquots (2.5 ml) were withdrawn from each of 10 flasks immediately and again at intervals extending over the next 48 hr. Without removing the mycelium, the combined 10 aliquots in each group were extracted without delay with three equal volumes of ether. The combined ether extracts were washed with 10 ml water, dried over sodium sulphate, filtered, evaporated under reduced pressure and similarly re-evaporated from 1 ml ethanol to remove remaining traces of moisture. For gas chromatography, the residue was dissolved in 0.25 - 2.0 ml ethanol and held at 0 C during the determination to minimize evaporation losses.

*Oxidation of capsidiol in pepper fruit by Fusarium (spp.).*—(1) After harvesting, the peppers were inoculated with the Fusaria, six fruit being used for each fungus, by aseptically injecting 5-10 ml of suspensions containing 5 X $10^5$ spores/ml into the fruit cavities using a hypodermic syringe. Further details have been given previously (16). After incubation 40 hr at room temperature in the dark, the fruit were cut open and the diffusates collected, extracted and prepared for analysis as described above.

(2) For the time-course study, procedures were similar except that only *F. oxysporum* f. *pisi* and *F. oxysporum* f. *vasinfectum* were used. For each fungus, diffusates from six fruit at a time were collected at intervals between 6 and 72 hr after injection. After opening, each fruit was rinsed with 5 ml distilled water which was combined with the diffusate and analyzed as previously. Recovery data are expressed as micromoles capsidiol or capsenone per fruit.

*Gas chromatographic determinations.*—Gas chromatography was done on duplicate aliquots (2 $\mu$l each) in a Hewlett-Packard Model 5750 instrument fitted with a glass column 1.83 m (6 feet) long, 3.5 mm i.d.) containing gas-chrom Q (80- to 120-mesh) coated with 3% SE 30 (Applied Science Lab., Inc.). The column was maintained at 162 C, the injector at 192 C and flame ionization detector at 230 C. Carrier gas was nitrogen at 2.81 kg-force/cm$^2$ (40 psi) inlet pressure, rotameter setting was 2.5 corresponding to a flow rate of approximately 40 ml per min. Retention times were 10.1 and 11.6 min for capsidiol and capsenone, respectively. Concentrations of compounds were determined by weighing peak areas cut from the chromatograms. Calibration curves were constructed with values obtained over a suitable range of concentrations of solutions of capsidiol and capsenone. Identity and approximate concentration of capsidiol and capsenone in the test solutions were confirmed by thin-layer chromatography (tlc) (19). As an additional check on the procedure, in some instances the capsenone produced was isolated by tlc and quantitated by spectrophotometry at $\lambda_{max}$=239 nm.

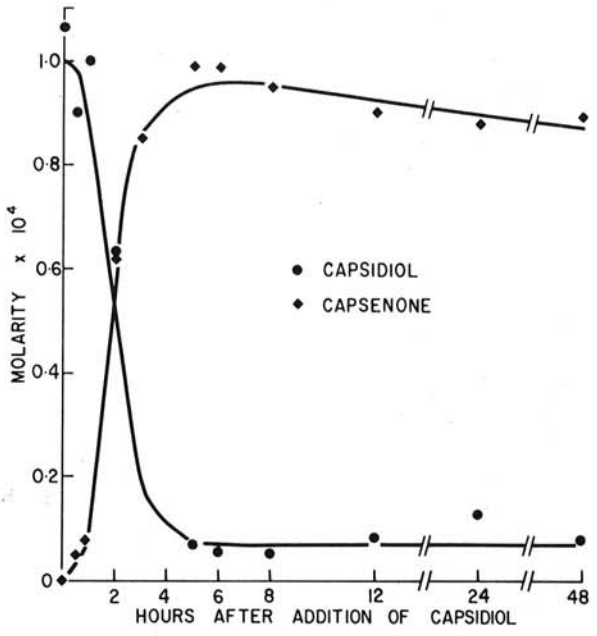


**Fig. 2.** Oxidation of capsidiol to capsenone by *Fusarium oxysporum* f. *vasinfectum* in shake culture over a 48-hr period. Culture was grown for 40 hr before addition of capsidiol.

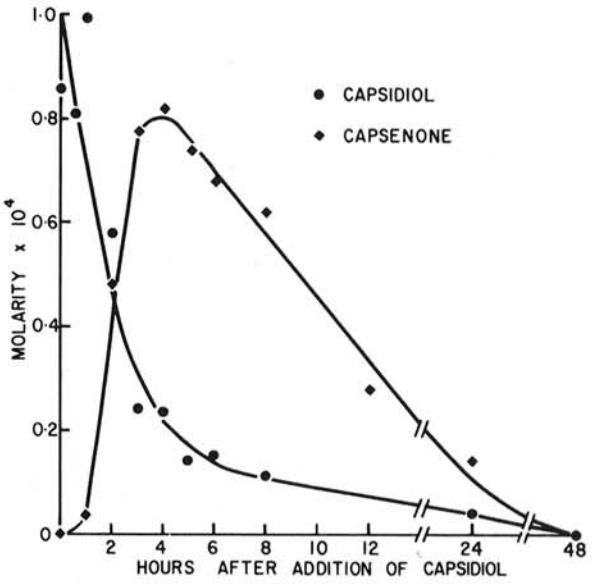


**Fig. 3.** Oxidation of capsidiol to capsenone by *Botrytis cinerea* in shake culture, and subsequent degradation of capsenone over a 48-hr period. Culture was grown for 40 hr before addition of capsidiol.

RESULTS.—*Fungal oxidation of capsidiol in pure culture.*—Oxidation of capsidiol to capsenone by shake cultures of *F. oxysporum* f. *vasinfectum* was rapid after an initial lag period, reaching a maximum value of approximately 90% after 5 hr (Fig. 2). Thereafter, the capsidiol concentration remained essentially constant and that of capsenone decreased very slightly during the 48-hr incubation period. *B. cinerea* oxidized capsidiol at a comparable rate (Fig. 3), but the reaction continued until all the capsidiol had been used up. The generated capsenone was itself destroyed after accumulating in 5 hr in 80% yield. The rate of capsenone destruction was distinctly slower than was capsidiol oxidation; by 12 hr two-thirds had been destroyed and by 48 hr the process was complete. No major degradation products of capsenone were identifiable under our conditions.

*Induction and oxidation of capsidiol in pepper fruit by Fusarium spp.*—The diffusates obtained from pepper fruit injected with spore suspensions of any of the six *Fusarium* spp. tested contained capsidiol (Table 1) and in four cases, very much higher levels of capsenone. Only trace amounts of capsenone were detected in diffusates obtained with *F. oxysporum* f. *pisi* and *F. poae*.

All species were less sensitive to capsenone than to capsidiol (Tables 2 and 3). This is more obvious for spore germination than for growth, against which capsenone has appreciable activity at higher concentrations. Differences between the fungi in their sensitivity to capsenone were small but *F. oxysporum* f. *pisi* and *F. poae* were distinctly more sensitive to capsidiol than the other four species.

An estimate of the extent of mycelial growth inhibition due to the capsidiol and capsenone

TABLE 1. Concentrations of capsidiol and capsenone in diffusates from pepper fruit injected with spore suspensions of *Fusarium* spp.

| | Concentration M × $10^4$ | | |
|---|---|---|---|
| | Capsidiol | Capsenone | Total |
| *F. oxysporum* f. *conglutinans* | 1.03 | 4.9 | 5.93 |
| *F. oxysporum* f. *lycopersici* | 0.65 | 3.3 | 3.95 |
| *F. oxysporum* f. *pisi* | 5.6 | 0 (trace) | 5.6 |
| *F. oxysporum* f. *vasinfectum* | 0.83 | 4.44 | 5.27 |
| *F. poae* | 1.7 | 0 (trace) | 1.7 |
| *F. solani* f. *pisi* | 1.27 | 4.55 | 5.82 |

TABLE 2. Inhibition of spore germination of *Fusarium* spp. by capsidiol and capsenone

| | | % Inhibition | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concentrations of capsidiol or capsenone M × $10^4$ | | | | | |
| | | 10 | 7.5 | 5.0 | 2.5 | 1.0 | 0.5 |
| *F. oxysporum* f. *conglutinans* | capsidiol | 100 | 99 | 74 | 1 | 0 | 0 |
| | capsenone | 14 | 0 | 0 | 0 | 0 | 0 |
| *F. oxysporum* f. *lycopersici* | capsidiol | 100 | 99 | 56 | 0 | 0 | 0 |
| | capsenone | 14 | 14 | 10 | 5 | 1 | 0 |
| *F. oxysporum* f. *pisi* | capsidiol | 100 | 98 | 98 | 76 | 5 | 0 |
| | capsenone | 14 | 0 | 0 | 0 | 0 | 0 |
| *F. oxysporum* f. *vasinfectum* | capsidiol | 100 | 99 | 72 | 1 | 0 | 0 |
| | capsenone | 0 | 0 | 0 | 0 | 0 | 0 |
| *F. poae* | capsidiol | 100 | 100 | 100 | 99 | 32 | 6 |
| | capsenone | 14 | 4 | 0 | 0 | 0 | 0 |
| *F. solani* f. *pisi* | capsidiol | 100 | 99 | 38 | 0 | 0 | 0 |
| | capsenone | 0 | 0 | 0 | 0 | 0 | 0 |

concentrations actually recovered in diffusates is provided by the data of Table 4. These were obtained by first drawing curves for growth inhibition of each fungus against capsidiol or capsenone concentration, using the data of Table 3. From these curves the percentage inhibition for the concentration of capsidiol or capsenone found in each diffusate was then determined by interpolation. A measure of the degree of detoxification due to conversion of capsidiol to capsenone is given by a comparison of the sum of the inhibition values for the two compounds in any one diffusate with the estimated inhibition for capsidiol alone at equivalent concentration. Unpublished experiments have shown that inhibition due to capsidiol and capsenone in mixtures is strictly additive.

*Time-course of capsidiol and capsenone production in pepper fruit.*—This was followed in fruit injected with *F. oxysporum* f. *vasinfectum* or with *F. oxysporum* f. *pisi*. Diffusates from the interaction of fruit with *F. oxysporum* f. *vasinfectum* contained a little capsidiol (ca. $4.2 \times 10^{-5}$ micromoles, 0.01 mg) as early as 6 hr after injection together with even smaller amounts of capsenone (ca. $2.5 \times 10^{-5}$ micromoles, 0.006 mg). After 12 hr the amounts were roughly equal (capsidiol $2.4 \times 10^{-4}$ micromoles, capsenone $2.9 \times 10^{-4}$ micromoles). Thereafter, the capsenone concentration increased rapidly (Fig. 4) while the capsidiol remained low and essentially constant as in the shake culture experiments. With *F. oxysporum* f. *pisi* low levels of capsidiol were produced by 6 and 12 hr ($2.1 \times 10^{-5}$ and $4.2 \times 10^{-4}$ micromoles, respectively). During the next 36 hr, the capsidiol level increased at a rate similar to that for capsenone in the *F. oxysporum* f. *vasinfectum* interaction. The decrease in capsidiol concentration during the final 24 hr remains unexplained since it cannot be accounted for by the very low levels of capsenone that were detected after 48 hr.

DISCUSSION.—Oxidation of capsidiol to the less fungitoxic capsenone by *B. cinerea* and *F. oxysporum*

TABLE 3. Inhibition of mycelial growth of *Fusarium* spp. by capsidiol and capsenone

| | | % Inhibition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Concentrations[b] of capsidiol or capsenone M × $10^4$ | | | | | | | |
| | | 10 | 7.5 | 5.0 | 2.5 | 1.0 | 0.5 | 0.1 | 0.05 |
| *F. oxysporum* f. *conglutinans* | capsidiol | 87 | 89 | 71 | 38 | 43 | 24 | 19 | 19 |
| | capsenone | 67 | 59 | 39 | 24 | 7 | 11 | 14 | 14 |
| *F. oxysporum* f. *lycopersici* | capsidiol | 96 | 94 | 95 | 76 | 45 | 42 | 26 | 19 |
| | capsenone | 78 | 67 | 48 | 32 | 2 | 4 | 3 | 7 |
| *F. oxysporum* f. *pisi* | capsidiol | 100 | 88 | 62 | 48 | 24 | 22 | 29 | 14 |
| | capsenone | 75 | 52 | 13 | 2 | 2 | 2 | 3 | 2 |
| *F. oxysporum* f. *vasinfectum* | capsidiol | 88 | 79 | 81 | 57 | 42 | 38 | 36 | 25 |
| | capsenone | 50 | 30 | 24 | 3 | 0 | 0 | 0 | 0 |
| *F. poae* | capsidiol | 100 | 95 | 87 | 87 | 72 | 63 | 55 | 31 |
| | capsenone | 42 | 38 | 28 | 17 | 26 | 13 | 15 | 8 |
| *F. solani* f. *pisi* | capsidiol | 82 | 83 | 61 | 36 | 16 | 10 | 6 | 5 |
| | capsenone | 59 | 43 | 25 | 19 | 6 | 2 | 6 | 4 |

[a] Control = 0, % inhibition calculated from measurements of diameters of triplicate colonies.
[b] Concentrations of capsidiol or capsenone in V-8 juice agar.

TABLE 4. Estimated inhibition of growth of six *Fusarium* spp. by the concentrations of capsidiol or capsenone induced by them in pepper fruit and the theoretical detoxification resulting from the capsidiol-capsenone conversion

| | % Growth inhibition | | | | |
|---|---|---|---|---|---|
| | Capsidiol[a] | Capsenone[a] | Capsidiol plus[b] capsenone | Equivalent[c] capsidiol inhibition | Decreased[d] in growth inhibition |
| *F. oxysporum* f. *conglutinans* | 28 | 38 | 66 | 78 | 12 |
| *F. oxysporum* f. *lycopersici* | 38 | 17 | 55 | 86 | 31 |
| *F. oxysporum* f. *pisi* | 66 | | 66 | 66 | |
| *F. oxysporum* f. *vasinfectum* | 40 | 18 | 58 | 80 | 22 |
| *F. poae* | 80 | | 80 | 80 | |
| *F. solani* f. *pisi* | 20 | 23 | 43 | 70 | 27 |

[a] The percentage growth inhibition estimated for the concentrations (Table 1) of capsidiol and capsenone found in diffusates from pepper fruit injected with each of six *Fusarium* spp.

[b] Sum of values in first two columns.

[c] The percentage growth inhibition calculated for a concentration of capsidiol alone, equivalent to the combined concentrations of capsidiol and capsenone recovered in diffusates from pepper fruit.

[d] Measure of detoxification due to capsidiol-capsenone conversion.

f. *vasinfectum* in vitro was rapid and efficient. Potentially, therefore, the process may be important as a mechanism for overcoming host resistance that might be based on capsidiol production. For both fungi, the oxidation rate was highest between two and five hr after addition of capsidiol. In each case there was a short but definite lag period, which may indicate a requirement for inducible enzymes. Other interpretations are possible, however, and will require more detailed investigation. The demonstration that *B. cinerea* not only converts capsidiol to capsenone, but metabolizes or degrades it further is especially interesting. It probably indicates that detoxification by *B. cinerea* is complete, but the absence of a defined detoxification product makes an analysis of the situation in vivo more complex and it is receiving separate study.

Of the six *Fusarium* spp. tested by injection into pepper fruit, four evidently induced the formation of capsidiol but oxidized most of it to capsenone in the 48 hr during which the interaction was allowed to proceed undisturbed. The two other species also stimulated capsidiol production but its oxidation by them was negligible. The final molar concentrations of capsidiol and capsenone taken together were similar in all six interactions with the exception of *F. poae*. The primary response of pepper fruit to contact with the fungi appears to be not only qualitatively the same, but generally similar quantitatively. For a study of the dynamics of the process, *F. oxysporum* f. *vasinfectum* and *F. oxysporum* f. *pisi* were used as representatives of the two types of interaction.

In contrast to the 19 hr lag period observed by Sato et al. (13) for rishitin production in potato tissue, a significant increase in capsidiol levels in pepper diffusates occurred between 6 and 12 hr after inoculation with either fungus. Capsenone was also

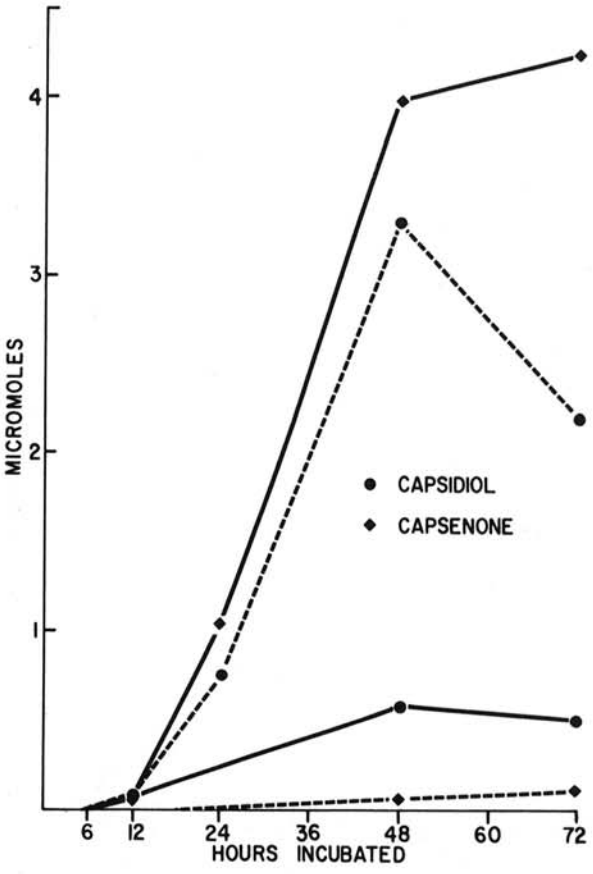


Fig. 4. Induction of capsidiol and oxidation to capsenone by *Fusarium oxysporum* f. *vasinfectum* (solid line) and *F. oxysporum* f. *pisi* (broken line) in pepper fruit during a 72-hr period after injection with spore suspensions of these fungi.

detected during this period in fruit injected with *F. oxysporum* f. *vasinfectum*. By far the largest amounts of the compounds accumulated between 24 and 48 hr. During this period the concentration of capsidiol induced by *F. oxysporum* f. *vasinfectum* increased only slightly whereas the slope of the curve representing capsenone concentration is steep and essentially the same as that for capsidiol induced by *F. oxysporum* f. *pisi*. Thus, it appears that capsidiol synthesis proceeds at about the same rate in both cases, but that *F. oxysporum* f. *vasinfectum* oxidizes this primary product to capsenone almost as fast as it is formed. Therefore, on the basis of the relative rates of capsidiol formation and oxidation, the latter process could indeed provide a means of overcoming host resistance. However, if an attempt is made to correlate assay data (Tables 2 and 3) with the concentrations of these compounds induced in pepper fruit (Table 1), it becomes evident that the situation is not this simple. Although the detoxification appears to be quite effective for spore germination inhibition, it is much less so for the inhibition of mycelial growth (Table 4) and it is probable that the latter has more relevance to the situation in vivo. Neither the actual concentration of capsidiol induced, nor the estimated concentration (had oxidation not occurred) would have been sufficient to completely inhibit mycelial growth of any of the six *Fusarium* spp. under study. Where capsidiol oxidation took place the reduction in the estimated inhibitory level did not exceed 31%, and was similar to the difference in levels of inhibition between the most (*F. poae* 80%) and least inhibited fungus (*F. solani* f. *pisi* 43%). Even the latter differences could be misleading for actual growth rates of the two fungi would be similar, since *F. poae* grew at about twice the rate of *F. solani* f. *pisi* on control media. Basically, difficulties in interpretation arise from the fact that inhibition is only partial and although decreased, remains partial after detoxification of capsidiol. Without more detailed information about the infection process it cannot be assumed that a change in growth rate is in itself a major factor in pathogenicity. A reduction in growth rate, for example, may not necessarily be paralleled by a reduction in the production of toxins or cell wall degrading enzymes. Therefore, a precise resolution of the significance of the processes discussed here must await a detailed investigation of the relative rates of fungal expansion and capsidiol production and degradation at the infection site. For the present, however, it seems reasonable to conclude that even though capsidiol production is insufficient to provide absolute protection against the *Fusarium* spp. tested, their ability to oxidize it would not permit them to colonize the host with complete freedom. Ability to perform this oxidation is clearly not specifically related to pathogenicity for pepper fruit, for it is possessed by species that are not pathogens under natural conditions. Microscopic examination of pericarp tissue after removal of the diffusates did not reveal any obvious differences between the six species with regard to tissue invasion and maceration, which was fairly limited and comparable to that described previously for *F. oxysporum* f. *vasinfectum* (16). Under natural conditions, other factors are presumably of more importance than capsidiol for screening out these fungi. Where infection occurs it would be expected to be of a secondary nature and this is supported by our own observations in the field and scattered reports (e.g., 18) of various species of *Fusarium* as weak pathogens of pepper fruit.

## LITERATURE CITED


1. AMERICAN PHYTOPATHOLOGICAL SOCIETY, COMMITTEE ON STANDARDIZATION OF FUNGICIDAL TESTS. 1947. Test tube dilution technique for use with slide-germination method of evaluating protectant fungicides. Phytopathology 37:354-356.
2. BAUGHER, W. L., & T. C. CAMPBELL. 1969. Gossypol detoxification by fungi. Science 164:1526-1527.
3. CHRISTENSON, J. A. 1971. Effect of pisatin on clones of Fusarium solani pathogenic and non-pathogenic to peas. Diss. Abstr. Int. B 32:2471.
4. DEVERALL, B. J. 1972. Phytoalexins and disease resistance. Proc. Roy. Soc. Lond. B 181:233-246.
5. HEATH, M. C., & V. J. HIGGINS. 1972. Degradation of phaseollin and pisatin by Stemphylium botryosum. Phytopathology 62:763 (Abstr.).
6. HEUVEL, J. VAN DEN, & H. D. VAN ETTEN. 1972. Alteration of phaseollin by Fusarium solani f. sp. phaseoli. Phytopathology 62:794-795 (Abstr.).
7. HIGGINS, V. J. 1972. Role of the phytoalexin medicarpin in three leaf spot diseases of alfalfa. Physiol. Plant Pathol. 2:289-300.
8. HOWELL, C. R., R. D. STIPANOVIC, & A. A. BELL. 1972. Dihydrosanguinarine, a product of sanguinarine detoxification by Verticillium dahliae. Pest. Biochem. Physiol. 2:364-370.
9. HYODO, H., I. URITANI, & S. AKAI. 1969. Production of furanoterpenoids and other compounds in sweet potato root tissue in response to infection by various isolates of Ceratocystis fimbriata. Phytopathol. Z. 65:332-340.
10. LOMAN, A. A. 1970. The effect of heartwood fungi of Pinus contorta var. latifolia on pinosylvin, pinosylvin monomethylether, pinobanksin, and pinocembrin. Can. J. Bot. 48:737-747.
11. NONAKA, F. 1967. Inactivation of pisatin by pathogenic fungi. Saga Daigaku Nogaku Iho, 109-121 [Chem. Abstr. 69:25276 (1968)].
12. SAKUMA, T., & R. L. MILLAR. 1972. Relative abilities of pathogens and nonpathogens of alfalfa to induce production of and degrade medicarpin. Phytopathology 62:499 (Abstr.).
13. SATO, N., K. KITAZAWA, & K. TOMIYAMA. 1971. The role of rishitin in localizing the invading hyphae of Phytophthora infestans in infection sites at the cut surface of potato tubers. Physiol. Plant Pathol. 1:289-295.
14. SCHLÖSSER, E. 1971. Cyclamin, an antifungal resistance factor in Cyclamen species. *In* Z. Király & L. Szalay-Marzso [ed.]. Biochemical and ecological aspects of plant-parasite relations. Acta Phytopathol., Acad. Sci. Hung. 6:85-95.
15. STOESSL, A. 1970. Antifungal compounds produced by higher plants. Rec. Adv. Phytochem. 3:143-180.
16. STOESSL, A., C. H. UNWIN, & E. W. B. WARD. 1972. Postinfectional inhibitors from plants. I. Capsidiol, an antifungal compound from Capsicum frutescens.

Phytopathol. Z. 74:141-152.
17. UEHARA, K., & T. KIKU. 1969. Inactivation of ipomeamarone by Corticium rolfsii. Kagoshima Daigaku Nogakubu Gakujutsu Hokoku, 73-80 [Chem. Abstr. 73:32593 (1970)].
18. UNITED STATES DEPARTMENT OF AGRICULTURE. 1960. Index of plant diseases in the United States. USDA Handbook No. 165. (See p. 446). 531 p.
19. WARD, E. W. B., & A. STOESSL. 1972. Postinfectional inhibitors from plants III. Detoxification of capsidiol, an antifungal compound from peppers. Phytopathology 62:1186-1187.
20. WIT-ELSHOVE, A. DE, & A. FUCHS. 1971. Influence of the carbohydrate source on pisatin breakdown by fungi pathogenic to pea (Pisum sativum). Physiol. Plant Pathol. 1:17-24.