한국식물병리학회지 3(1) : 43-53 (1987)
Korean J. Plant Pathol. 3(1) : 43-53 (1987)

Recent Advances in Studies of Host-Specific Toxins
— with Special Reference to *Alternaria* Toxins*—

Keisuke Kohmoto

Faculty of Agriculture, Tottori University, Tottori 680, Japan

植物病原菌의 寄主選擇性毒素에 대한 最近의 硏究動向
— *Alternaria* 毒素를 中心으로—

甲 元 啓 介

鳥取大學 農學部, 日本

INTRODUCTION

The toxin concept in plant pathology has changed greatly during the past two decades since researchers directed their attention to host-specific toxin (host-selective toxin, HST). The term "host-specific toxin" was coined in 1964 by Pringle and Scheffer(35). A little later, Nishimura and Scheffer (27) and Yoder and Scheffer (44) added two important requisites for HST. Now, it is most likely reasonable and persuasive that the following four conditions must be satisfied at least before calling a candidate toxin a HST: a) Correlation between toxin productivity and pathogenicity of the fungus. All strains of the fungus that produce HST are pathogenic. All strain that fail to produce the HST are non-pathogenic to the specific host. b) Correlation between toxin sensitivity and susceptibility to the fungus in plants. Plants that are susceptible to the fungus are sensitive to its toxin. c) Toxin is released on germination at the site of initial invasion (27). d) Toxin is involved in initial colonization of the fungus (44). Toxin can induce the susceptibility to fungal invasion only in host cells. A serious need for such HST study was shown in the statement by Wood at the 1971 Long Ashton Symposium on Fungal Pathogenicity and the Plant's Response: "The microorganism X (but not others) produce substance Y which damages plant or plant group A but not others, and only A is parasitized (41). Until now, about fourteen examples of such HST were reported mainly with the so-called "saprophytic pathogens" such as *Alternaria* and *Helminthosporium* (Table 1). At present, it is no doubt that HST is the primary determinant for pathogenicity and the host-recognition factor. Because pathological and epidemiological studies with HSTs have accumulated many lines of the evidence that HSTs are integral factors in plant pathogenesis and can act as reliable surrogates for the pathogens that produce them (30,31,32).

This paper comprises an overview of some limited facets of HSTs from *Alternaria* pathogens. Previous reviews (29,32,39) and chapters (28,30,31) have dealt with *Alternaria* toxins. Research advances in HST problems also have been critically discussed by other reviewers (1,2,4,20,36,45).

* Supported in part by Research Grant (No. 61480047) from the Ministry of Education, Science and Culture of Japan and by a grant from JSPS.

Table 1. Demonstration of host-specific toxins

Date	Disease name	Pathogen (Previous name)	Toxin	Susceptible plant
1933	Black spot	*Alternaria alternata* Japanese pear pathotype (*A. kikuchiana*)	AK-toxin	Japanese pear cv. Nijisseiki
1947	Victoria blight	*Helminthosporium victoriae*	HV-toxin	Oat cv. Victoria
1961	Milo	*Periconia circinata*	PC-toxin	Grain sorghum
1965	Northern leaf spot	*Helminthosporium carbonum*	HC-toxin	Corn
1966	Leaf blotch	*Alternaria alternata* apple pathotype (*A. mali*)	AM-toxin	Apple cv. Starking
1966	Brown spot	*Alternaria alternata* tangerine pathotype (*A. citri*)	ACT-toxin	Dancy tangerine, Emperor mandarin
1970	Leaf blight	*Helminthosporium maydis* race T	HMT-toxin	Corn Texas cytoplasma
1971	Eye spot	*Helminthosporium sacchari*	HS-toxin	Sugarcane
1973	Yellow leaf blight	*Phyllosticta maydis*	PM-toxin	Corn Texas cytoplasma
1975	Target leaf spot	*Corynespora cassiicola*		Tomato cv. Ife
1976	Stem canker	*Alternaria alternata* tomato pathotype (*A. a.* f.sp. *lycopersici*)	AL-toxin	Tomato cv. First cv. Earlypak 7
1979	Brown spot	*Alternaria alternata* rough lemon pathotype (*A. citri*)	ACR-toxin	Rough lemon
1979	Black spot	*Alternaria alternata* strawberry pathotype	AF-toxin	Strawberry
1980	Brown spot	*Alternaria alternata* tobacco pathotype (*A. longipes*)	AT-toxin	Tobacco

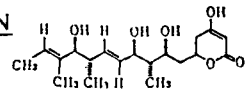
STRUCTURAL ASPECT OF HST

Recent advances in analytical instruments, isolation and bioassay techniques for natural products chemistry have resulted in a kind of "quantum leap" in our knowledge of chemical aspects of HSTs. During the last five years the structures of most HSTs known to date have been reasonably elucidated with well documentations (2,20,32). More recently, new structures have been compiled in a growing toxin list (Fig. 1).

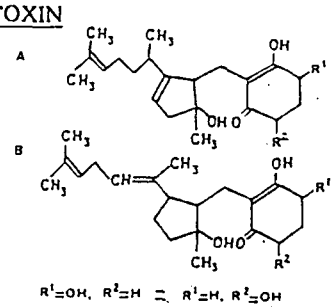
With ACR-toxin from rough lemon pathotype of *A. alternata*, Nakatsuka *et al.* (24) purified the major toxin and determined its chemical structure to be a 4-hydroxy-5,6-dihydro-2-pyrone derivative (designated as ACR-toxin I). Independently, Gardner *et al.* (3) also came to the same structural conclusion with their major toxin (ACRL-toxin I). Furthermore, they characterized other five minor α-pyrone analogues having less toxicity than ACRL-toxin I (16).

With HSTs from tangerine pathotype of *A. alternata*, Kono and Gardner group (17) most recently proposed the structures of major toxins and named ACTG-toxin A and B. However, an open

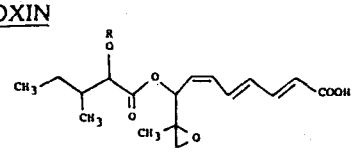
ACR-TOXIN



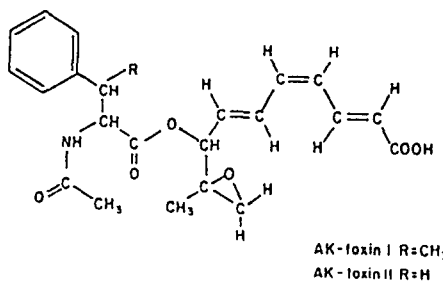
ACTG-TOXIN



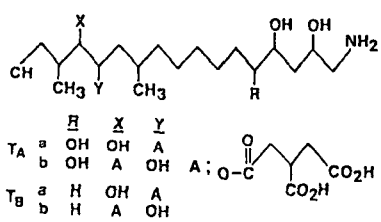
AF-TOXIN



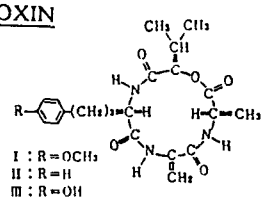
AK-TOXIN



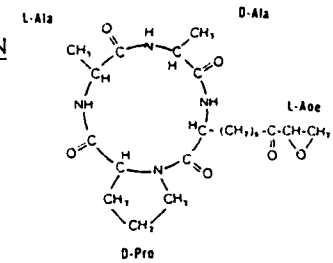
AL-TOXIN



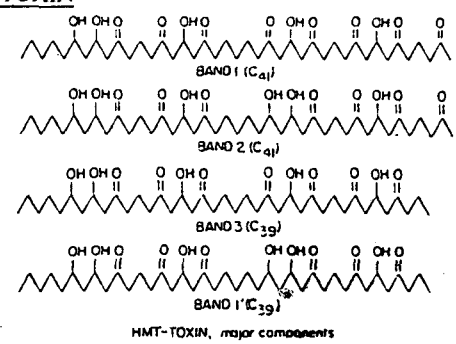
AM-TOXIN



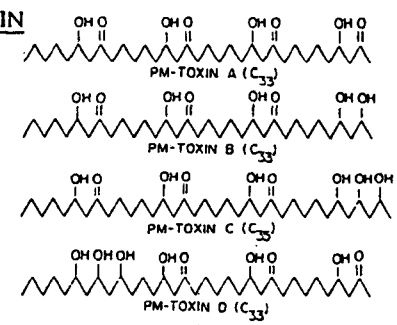
HC-TOXIN



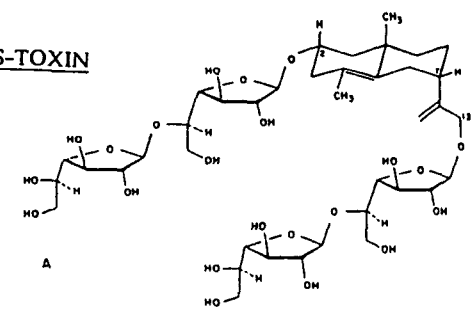
HMT-TOXIN



PM-TOXIN



HS-TOXIN



HV-TOXIN

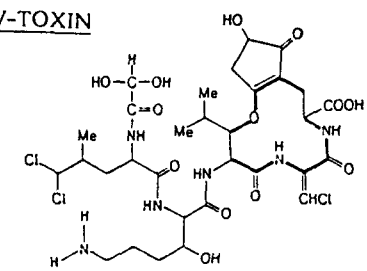


Fig. 1. Structures of host-specific toxins (HSTs) elucidated until 1986.

question whether their toxins are identical with our ACT-toxins is still remained.

Nakatsuka *et al.* (23,25) elucidated in 1985 the structures of AF-toxins I, II and III from strawberry pathotype of *A. alternata*. The toxins have in common a 9, 10-epoxy-9-methyl-decac-(2*E*, 4*E*, 6*Z*)-trienoic acid in structure, while AK-toxin has a different configuration of the same acid (2*E*, 4*Z*, 6*E*)(22). There is a very interesting relation between the structures of these HSTs and the host specificity that each HST determined. Several isomers of AF-toxins also were detectable in culture filtrates or in the course of toxin isolation. Could they be called as multiple toxins in a pathological sense? This reminds us the importance of "release toxin on germination" (27).

In 1985 summer, Macko's group (40) presented the structure of HV-toxin (victorin C) from *Helminthosporium victoriae* affecting oats. It is a great success in the plant toxin field about 40 years after Meehan and Murphy's first report of toxin involvement in Victoria blight disease of oats. The toxin appears very unique structurally with the presence of 3 chlorine atmos in the molecule.

MODE OF ACTION OF HST

The *Alternaria* HSTs mentioned above are now becoming available in pure state and useful for precise studies at the molecular level of their act and role in pathogenesis.

Generally speaking, there are at least two w in mode-of-action studies of HSTs. One is bioch ical and physiological approach, and the o pathological one. Both approaches, of cou should not be understood separately. Howe much attention has been paid so far only on mechanism of physiological and biochemical act of HST, and unfortunately, little attention paid on their pathological significance.

Table 2 gives a brief summary, without ente into details, on the primary action sites for *Al naria* HSTs suggested to date. ACR-toxins (13, and AT-toxin (11) appear to have initial effects mitochondria in susceptible cells. ACT-toxin (1 AF-toxin (21) and AK-toxin (34) have effects plasma membrane function, while AM-toxin (affects chloroplasts in addition to plasma m branes. AL-toxin is very unique. According Gilchrist (4,5), it may have the target enzyme, asp tate carbamoyltransferase. It may act as a pot synergist for the regulatory inhibition by urid monophosphate. Thus, the primary action site HST in susceptible genotypes greatly vary with H species involving in combination of host and pa site.

Table 2. A tentative list of the primary action sites of *Alternaria alternata* HSTs

HST	Plant	Ultrastructural change			
		Plasma membrane	Chloroplast	Mitochondrion	Ion loss
ACR-toxin I	Rough lemon	-	-	+	+
ACT-toxin A	Dancy tangerine	+	-	-	+
ACT-toxin B	Japanese pear	+	-	-	+
AF-toxin I	Strawberry	+	-	-	+
	Japanese pear	+	-	-	+
AK-toxin I	Japanese pear	+	-	-	+
AL-toxin	Tomato	-	-	-	-
AM-toxin I	Apple	+	+	-	+
	Japanese pear	+	+	-	+
AT-toxin	Tobacco			+	-

PATHOLOGICAL ROLE OF HST

From the pathological viewpoint, HSTs appear) play, in common, the same key role as an initiaon factor for successful plant infection, though ıey are diverse in chemical category as well as in hysiological primary effect on respective host. ig. 2 shows our basic model for illustrating the role f HST in pathogenesis. The model has been contructed, based on experimental results with several ombinations of Japanese pear and AK-toxin, of ıpple and AM-toxin, of citrus plants and ACR- & ACT-toxins, and of strawberry and AF-toxin 7, 42, unpublished).

Plant cells, susceptible, resistant or nonhost, ;ommonly possess general and potential defense mechanisms against attempted fungal invasion. The defense mechanisms appear to be triggered by the ınducer or activator released from germinating spores, regardless of their pathogenicity. It takes at least several hours for the completion in the induction of defense reaction.

On the other hand, susceptible cells carry HST-specific binding sites or HST receptors, but resistant and nonhost cells lack such receptors. Pathogenic spores release HST on germination, and the released toxin affects instantaneously susceptible cells but not resistant and nonhost cells at all. Hence, due to the presence of a trace amount of HST, the induction of defense reaction has to be abolished only in susceptible genotypes but not in resistant and nonhost ones. "Release toxin" from germinating spores acts as a telepathogenic factor, prior but not posterior to penetration. HST is capable of predisposing the susceptible condition for fungal invasion selecting the toxin-sensitive cells, where general and potential defense mechanisms may be suppressed through several steps of toxin action.

A goal of the mode-of-action study is to elucidate the chains of events leading from the toxin binding on primary site to the suppression of defense, the induction of accessibility, and the eventual cell death. Recently, we (6, 33) could partially characterized the nature of some components involved in the sequence of events triggered by AK-toxin by careful use of certain counteractive reagents against toxin action. Studies showed

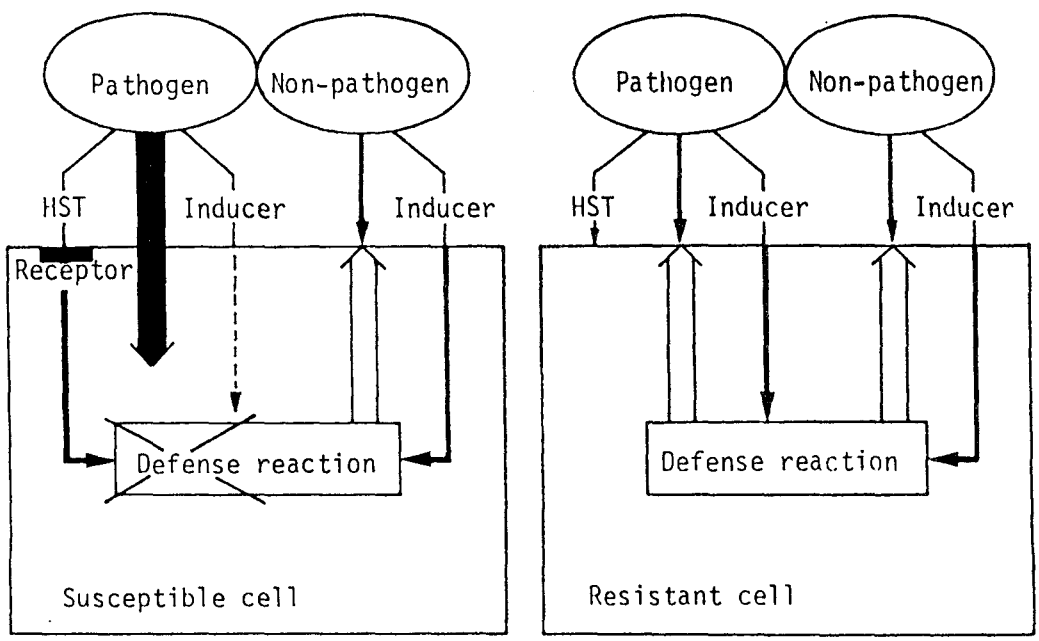


Fig. 2. A basic model for illustrating a telepathogenic role of host-specific toxin in interactions between plant and fungal pathogen.

that AK-toxin have pleiotropic effects on susceptible cells after specific binding to the primary site. A branched series of events may amplified with time just like a cascade structure (Fig. 3).

Toxin action may begin to start as follows: a) AK-toxin, released from virulent spores during germination, may bind to a hypothetical toxin receptor or specific sensitive site carrying sulfhydryl radical in susceptible pear cells. b) A signal of toxin recognition at the receptor site then may be transmitted to an oxygen-dependent process. This process will complete within 30 min after toxin exposure. Via the oxygen-dependent process, a channel may be switched on to suppress the inducing resistance in pear tissues as indicated by dotted line in the Fig. 3. This channel is now a bla box, but the very important target for pathologic role study of toxin in the near future. c) T oxygen-dependent process may induce a modul tion in permeability, and electrolyte loss will occu d) The modulation may be taken over by an adc tional process leading to veinal necrosis. Th process consists of at least two stages. The first o probably induce *de novo* synthesis of protei within 5 hr after toxin exposure. The second ma associate with copper- and iron-containing protei within 10 hr after toxin exposure. e) Eventuall vein necrosis become visible 12-18 hr after toxi exposure. Thus, the accessibility of the pear cel to the invader appears to be induced through

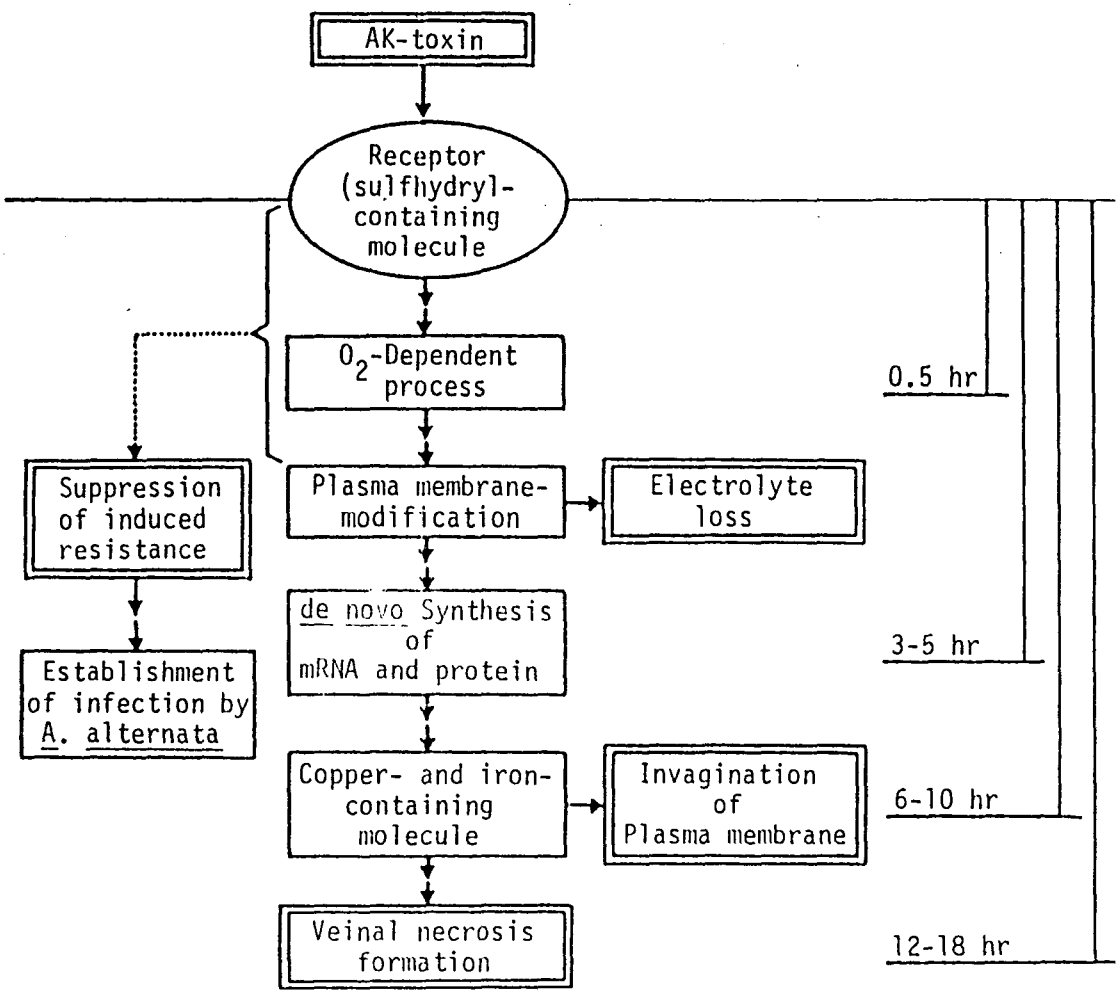


Fig. 3. A scheme for the mechanism of action of AK-toxin in susceptible pear cells.

fferent process branched from very early stages the process of toxin-induced leaf necrosis. The ey role of HST in pathogenesis is not the killing ost cells, but definitely the inducing such accessiility.

With respect to this point, evidence supporting ie same conclusion has come more recently from study of light effect on the action process of M-toxin of apple leaf blotch disease. When AMoxin-treated leaf tissues of susceptible apple cv. a concentration of 10^{-8} M were covered with or ithout aluminum foil and were kept under daylored fluorecent light at 2300 lux, necrosis ccurred only on the foil-covered area of the tissues 37). This result indicates that light suppress a stage n the action process of AM-toxin-induced necrosis. Time-course study suggests that its critical period hould be between 3-8 hr after toxin treatment. Yellow and near red lights had an inhibitory effect on the AM-toxin action, and red, green, blue and near UV lights had no effect (38). However, active light had affected neither on the loss of electrolytes from AM-toxin-treated leaves nor on the infection by pathogenic spores and saprophytic spores with a trace amount of AM-toxin (37). Now, we can say again that the host-selective induction by HST of the susceptible condition to fungal invasion and initial colonization of the pathogen are throughly independent events from toxin-induced necrosis and cell death themselves. The process of host recognition in fungal parasitism appears to be achieved without occurrence of necrotic cell death.

The use of chemically defined samples of HSTs may lead to opening another new door toward mode-of-action studies relating to host specificity at the molecular basis. Action of AF-toxin I and fungal infection on strawberry leaves were markedly protected by pre-treating the leaves with a toxoid (AF-toxin II) (26). A similar protection of toxin action was already reported with HS-toxin and its analogues from *Helminthosporium sacchari* causing eye spot disease of sugarcane leaves(19). These agonist-antagonist-competition studies strongly suggest not only the probable existence of toxin

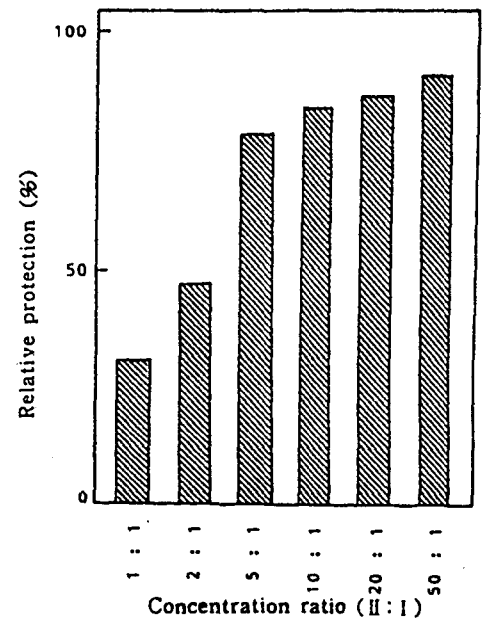


Fig. 4. Protection by a toxoid (AF-toxin II) of the formation of AF-toxin I-induced vein necrosis on susceptible strawberry leaves. Detached leaves were exposed to AF-toxin II (2.6×10^{-5} M) for 18 hr, and then treated with AF-toxin I solutions adjusted at 1, 1/2, 1/5, 1/10, 1/20 and 1/50 of AF-toxin II (2.6×10^{-5} M) to give 1:1, 2:1, 5:1, 10:1, 20:1 and 50:1 ratio.

receptor or binding site in susceptible cells in basic research field, but also a new strategy for disease control without employing antifungal agents or fungicides in applied field.

AGRICULTURAL USE OF HST

HST can be effectively employed for the quantitative analysis of a genetic background for disease susceptibility. A recent study with black spot disease of strawberry revealed that the susceptibility to the pathogen and the sensitivity to AF-toxin I are both inherited as a single locus with two alleles expressing incomplete dominance when heterozygous (43). Susceptible cv. Morioka-16 was found to be susceptible heterozygote, while resistant cv. Hokowase recessive homozygote.

Another practical contribution to agriculture come from the application of HST to a conventional

breeding program as a selection agent for disease resistance. Cultivar First and its relates have very good taste and commercially high quality. People like this cultivar very much. However, the cultivar became suffered seriously from tomato pathotype of *Alternaria alternata* as the cultivar was exclusively used for intensive cultivation in greenhouses in Japan during last decade. Nishimura's group at Nagoya University planed to detect a single gene mutant for the disease reaction, without loosing the other superior characteristics (8, 9, 10). They found that cv. Mie-First carry a single dominant gene pair for the susceptibility to the stem canker pathogen and also the sensitivity to AL-toxin produced by the pathogen. By treating many seeds of the cultivar with AL-toxin solution, a very few seeds, that were expected to be slightly tolerant against the toxin, were found alive, rescued and raised to thier maturity. Two plants seemed to be heterozygous mutant in toxin sensitivity. After selfing, 179 progenies in S_1 were obtained, and were found to separate: 45 toxin-sensitive, 95 toxin-tolerant and 39 toxin-insensitive (9, 10). This segregation ratio fits susceptibility-dominant homozygote SS: heterozygote Ss: recessive homozygote ss, 1 : 2 : 1. Cultivar characteristics of the recessive homozygote was proved to be identical with those of the superior parent cv. Mie-First except the immune response against the *Alternaria* stem canker disease, and was named the cultivar "AL-First" after AL-toxin (10). This is the first success worldwide at commercial level in breeding disease-immune crop using HST.

CONCLUSION

Although only a few, limited topics were shortly introduced and discussed, it is clear that HST studies in both basic and applied fields should be truly exciting, interesting and challenging. New pathological approaches armed with molecular biology and genetic engineering (18) in addition to the present research activities might again result in a "quantum leap" in our understanding for the molecular basis of host-parasite interactions.

REFERENCES

1. DALY, J. M. & KNOCHE, H. W. (1982). Th chemistry and biology of pathotoxins exhibi ing host-selectivity. In *Advances in Plan Pathology* vol. 1, Ed. by D. S. Ingram an P. H. Williams, pp. 83-138. Academic Pres New York.
2. DURBIN, R. D. (1981). *Toxins in Plant Disease* 515p. Academic Press, New York.
3. GARDNER, J. M., KONO, Y., TATUM, J. H. SUZUKI, Y. & TAKEUCHI, S. (1985). Plan pathotoxins from *Alternaria citri:* The majo toxin specific for rough lemon plants. *Phyto chemistry* 24: 2861-2867.
4. GILCHRIST, D. G. (1983). Molecular mode of action. In *Toxins and Plant Pathogenesis* Ed. by J. M. Daly and B. J. Deverall, pp 81-136. Academic Press, Sydney.
5. GILCHRIST, D. G., McFARLAND, B., SILER D., CLOUSE, S. & MARTENSEN, A. (1985) Genetic control of pathotoxin-induced stres in plants. In *Cellular and Molecular Biology o Plant Stress*, Ed. by J. L. Key and T. Kosuge pp. 367-380. Alan R. Liss, New York.
6. HARAMOTO, M., OTANI, H., KOHMOTO, K & NISHIMURA, S. (1985). Involvement of *de novo* protein synthesis in development of hos cell damages induced by AK-toxin of *Alternaria alternata* Japanese pear pathotype. *J. Fac Agric. Tottori Univ.* 21: 10-14.
7. HAYAMI, C., OTANI, H., NISHIMURA, S & KOHMOTO, K. (1982). Induced resistanc in pear leaves by spore germination fluids o nonpathogens to *Alternaria alternata* Japanes pear pathotype and suppression of the induc tion by AK-toxin. *J. Fac. Agric. Tottori Univ* 17: 9-18.
8. IEDA, T., NISHIMURA, S., YAMAMOTO T. & TAGAMI, M. (1985). Analysis by usin AL-toxin of the gene for susceptibility t Alternaria stem canker of tomato and selectio

of toxin-tolerant seeds. *Ann. Phytopath. Soc. Japan* 51: 379-380. (Abstr. in Japanese)

9. IEDA, T., NISHIMURA, S. & SUMIDA, A. (1986). Selection with AL-toxin of resistant mutant seeds of tomato against stem canker and survey of the pedigree of the susceptibility gene. *Ann. Phytopath. Soc. Japan* 52: 134. (Abstr. in Japanese)
10. IEDA, T., NISHIMURA, S., SUMIDA, A., YAMAMOTO, T. & TAGAMI, M. (1986). Characteristics of a new tomato cultivar "AL-First" selected with AL-toxin as a stem-canker-immune genotype. *Ann. Phytopath. Soc. Japan* 52: 528. (Abstr. in Japanese)
11. KODAMA, M., PARK, P., TSUJIMOTO, T., NISHIMURA, S. & KOHMOTO, K. (1985). Ultrastructural changes in host cells caused by host-specific toxin (AT-toxin) from tobacco brown spot pathogen. *Ann. Phytopath. Soc. Japan* 51: 379. (Abstr. in Japanese)
12. KOHMOTO, K., NISHIMURA, S. & OTANI, H. (1982). Action sites for AM-toxins produced by the apple pathotype of *Alternaria alternata*. In *Plant Infection: The Physiological and Biological Basis*, Ed. Y. Asada, W. R. Bushnell, S. Ouchi and C. P. Vance, pp. 199-214. Japan Scientific Societies Press, Tokyo.
13. KOHMOTO, K., KONDOH, Y., KOHGUCHI, T., OTANI, H., NISHIMURA, S. & SCHEFFER, R. P. (1984). Ultrastructural changes in host cell caused by host-selective toxin of *Alternaria alternata* from rough lemon. *Can. J. Bot.* 62: 2485-2492.
14. KOHMOTO, K., KOHGUCHI, T., KONDOH, Y., OTANI, H., NISHIMURA, S., NAKATSUKA, S. & GOTO, T. (1985). The mitochondrion: the prime site for a host-selective toxin (ACR-toxin I) produced by *Alternaria alternata* pathogenic to rough lemon. *Proc. Japan Acad.* 61B: 269-272.
15. KONDOH, Y., KOHGUCHI, T., OTANI, H., KOHMOTO, K. & NISHIMURA, S. (1984). Ultrastructural changes in susceptible tangerine cells caused by ACT-toxin from *Alternaria alternata* tangerine pathotype. *Ann. Phytopath. Soc. Japan* 50: 407. (Abstr. in Japanese)
16. KONO, Y., GARDNER, J. M., SUZUKI, Y. & TAKEUCHI, S. (1985). Plant pathotoxins from *Alternaria citri:* The minor ACRL-toxins. *Phytochemistry* 24: 2869-2874.
17. KONO, Y., GARDNER, J. M. & TAKEUCHI, S. (1986). Structure of the host-selective toxins produced by a pathotype of *Alternaria citri* causing brown spot disease of mandarins. *Agric. Biol. Chem.* 50: 801-804.
18. KOSUGE, T. & NESTER, E. W. (1984). *Plant-Microbe Interactions. Molecular and Genetic Perspectives.* 444p. Macmillan, New York.
19. LIVINGSTON, R. S. & SCHEFFER, R. P. (1984). Toxic and protective effects of analogues of *Helminthosporium sacchari* toxin on sugarcane tissues. *Physiol. Plant Pathol.* 24: 133-142.
20. MACKO, V. (1983). Structural aspects of toxins. In *Toxins and Plant Pathogenesis*, Ed. by J. M. Daly and B. J. Deverall, pp. 41-80. Academic Press, Sydney.
21. MAEKAWA, N., YAMAMOTO, M., NISHIMURA, S., KOHMOTO, K., KUWATA, M. & WATANABE, Y. (1984). Studies on host-specific AF-toxins produced by *Alternaria alternata* strawberry pathotype causing Alternaria black spot of strawberry (1) Production of host-specific toxins and their biological activities. *Ann. Phytopath. Soc. Japan* 50: 600-609.
22. NAKASHIMA, T., UENO, T., FUKAMI, H., TAGA, T., MASUDA, H., OSAKI, K., OTANI, H., KOHMOTO, K. & NISHIMURA, S. (1985). Isolation and structures of AK-toxin I and II, host-specific phytotoxic metabolites produced by *Alternaria alternata* Japanese pear pathotype. *Agric. Biol. Chem.* 49: 807-815.
23. NAKATSUKA, S., UEDA, S., GOTO, T., YAMAMOTO, M., NISHIMURA, S. & KOHMOTO, K. (1985). Presented at The 3rd International Kyoto Conference on New Aspects of Organic Chemistry (Kyoto, Japan) (Abstr.).

24. NAKATSUKA, S., GOTO, T., KOHMOTO, K. & NISHIMURA, S. (1986). Host specific phytotoxins. In *Natural Products and Biological Activities*, Ed. by H. Imura, T. Goto, T. Murachi and T. Nakajima, pp. 11-18. University of Tokyo Press, Tokyo.

25. NAKATSUKA, S., UEDA, K., GOTO, T., YAMAMOTO, M., NISHIMURA, S. & KOHMOTO, K. (1986). Structure of AF-toxin II, one of the host-specific toxins produced by *Alternaria alternata* Strawberry pathotype. *Tetrahedron Lett.* 27: 2753-2756.

26. NAMIKI, F., YAMAMOTO, M., NISHIMURA, S., NAKATSUKA, S., GOTO, T., KOHMOTO, K. & OTANI, H. (1986). Studies on host-specific AF-toxins produced by *Alternaria alternata* strawberry pathotype causing Alternaria black spot of strawberry (4) Protective effect of AF-toxin II on AF-toxin I-induced toxic action and fungal infection. *Ann. Phytopath. Soc. Japan* 52: 428-436.

27. NISHIMURA, S. & SCHEFFER, R. P. (1965). Interactions between *Helminthosporium victoriae* spores and oat tissue. *Phytopathology* 55: 629-634.

28. NISHIMURA, S., KOHMOTO, K. & OTANI, H. (1979). The role of host-specific toxins in saprophytic pathogens. In *Recognition and Specificity in Plant Host-Parasite Interactions*, Ed. by J. M. Daly and I. Uritani, pp. 133-146. Japan Scientific Societies Press, Tokyo.

29. NISHIMURA, S. (1980). Host-specific toxins from *Alternaria alternata*. Problems and prospects. *Proc. Japan Acad.* 56B: 362-366.

30. NISHIMURA, S., KOHMOTO, K., OTANI, H., RAMACHANDRAN, P. & TAMURA, F. (1982). Pathological and epidemiological aspects of *Alternaria alternata* infection depending on a host-specific toxin. In *Plant Infection: The Physiological and Biochemical Basis*, Ed. by Y. Asada, W. R. Bushnell, S. Ouchi and C. P. Vance, pp. 199-214. Japan Scientific Societies Press, Tokyo.

31. NISHIMURA, S., & KOHMOTO, K. (1983). Roles of toxins in pathogenesis. In *Toxins ar Plant Pathogenesis*, Ed. by J. M. Daly ar B. J. Deverall, pp. 137-157. Academic Pres Sydney.

32. NISHIMURA, S. & KOHMOTO, K. (1983 Host-specific toxins and chemical structur from *Alternaria* species. *Ann. Rev. Phytop thol.* 21: 87-116.

33. OTANI, H., HARAMOTO, M., KOHMOTO, I & NISHIMURA, S. (1985). Two differe phases in host cell damages induced by Al toxin of *Alternaria alternata* Japanese pe pathotype. *J. Fac. Agric. Tottori Univ.* 2(8-17.

34. OTANI, H., KOHMOTO, K., NISHIMUR S., NAKASHIMA, T., UENO, T. & FUKAM H. (1985). Biological activities of AK-toxi I and II, host-specific toxins from *Alternar alternata* Japanese pear pathotype. *Ann. Phyt pth. Soc. Japan* 51: 285-293.

35. PRINGLE, R. B. & SCHEFFER, R.P. (1964 Host-specific plant toxins. *Ann. Rev. Phytopathol.* 2: 133-156.

36. SCHEFFER, R. P. & LIVINGSTON, R. S. (1984). Host-selective toxins and their role in plant diseases. *Science* 223: 17-21.

37. TABIRA, H., KAGEI, M., OTANI, H., KOHMOTO, K. & NISHIMURA, S. (1986). Effect of light on AM-toxin-induced necrosis of apple leaves. *Ann. Phytopath. Soc. Japan* 52: 132-133. (Abstr. in Japanese)

38. TABIRA, H., OTANI, H., KOHMOTO, K. & NISHIMURA, S. (1986). Effect of light on AM-toxin-induced necrosis of apple leaves (supplementary). *Ann. Phytopath. Soc. Japan* 52: 526. (Abstr. in Japanese)

39. TSUGE, T. & NISHIMURA, S. (1986). Recent advances in research of *Alternaria alternata* host-specific toxins. *Shokubutsu boeki (Plant Protection)* 40: 395-402. (in Japanese)

40. WOLPERT, T. J., MACKO, V., ACKLIN, W, JAUN, B., SEIBL, J., MEILI, J. & ARIGONI, D. (1985). Structure of victorin C, the major host-selective toxin from *Cochlio-*

bolus victoriae. *Experientia* 41: 1524-1529.

1. WOOD, R. K. S. (1973). Specificity in plant diseases. In *Fungal Pathogenicity and the Plant's Response*, Ed. by R. J. W. Byrde and C. V. Cutting, pp. 1-16. Academic Press, New York.
2. YAMAMOTO, M., NISHIMURA, S., KOHMOTO, K. & OTANI, H. (1984). Studies on host-specific AF-toxins produced by *Alternaria alternata* strawberry pathotype causing Alternaria black spot of strawberry (2) Role of toxins in pathogenesis. *Ann. Phytopath. Soc. Japan* 50: 610-619.

43. YAMAMOTO, M., NAMIKI, F., NISHIMURA, S. & KOHMOTO, K. (1985). Studies on host-specific AF-toxins produced by *Alternaria alternata* strawberry pathotype causing Alternaria black spot of strawberry (3) Use of toxin for determining inheritence of disease reaction in strawberry cultivar Morioka-16. *Ann. Phytopath. Soc. Japan* 51: 530-535.
44. YODER, O. C. & SCHEFFER, R. P. (1969). Role of toxin in early interactions of *Helminthosporium victoriae* with susceptible and resistant oat tissues. *Phytopathology* 59: 1954-1959.
45. YODER, O. C. (1980). Toxins in pathogenesis. *Ann. Rev. Phytopathol.* 18: 103-129.