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Diseases Vectored by Whiteflies: Etiology, Ecology, Geographical Distribution and Possible Control Measures

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Abstract

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The whitefly-transmitted viruses produce a wide and divergent group of diseases, most of which have not been characterized. The agents are transmitted by at least three whitefly species in the nonpersistent, semipersistent, persistent and by biological mechanisms. The viruses cause significant losses throughout the world and are responsible for some 70 important diseases in the tropical and sub-tropical areas. Recent years have shown an increase in losses in wide areas north and south of the tropics, approaching areas of intensive agricultural production. The whitefly-transmitted diseases have been characterized in general on the basis of their transmission by whiteflies and the activity of the agents on host plants, such as symptoms and host range. A compilation of available data on the viruses themselves would suggest at least seven groups of viruses differing in type of virus particle, symptom type, and vector relationships. The two major groups of whitefly-transmitted viruses of worldwide importance (the geminiviruses and closteroviruses) are differently transmitted by biotypes of *Bemisia*. This vector specificity impacts virus distribution and epidemiology. Transmission systems may be valuable to trace origins of viruses and their vectors.

Key words: Insect transmission, *Bemisia tabaci*, geminiviruses, closteroviruses, epidemiology.

Bemisia tabaci (Gennadius), the sweetpotato whitefly (SPW), is a rapidly increasing worldwide pest of cotton, cultivated food and ornamental crops. The magnitude of the problem, with increases in whitefly population densities and the occurrence of whitefly-borne viruses in the tropics and in wide areas of the subtropics, including areas of intensive agricultural production such as the Mediterranean region and southern United States, is largely unexplained. The intensified losses have been attributed to the widespread use of synthetic organic insecticides, resistance to pesticides, enhancement by pesticides, changing climatic conditions, intensified agricultural practices, and the international transport of plant materials with contaminant populations of *Bemisia* (24).

Whitefly transmitted disease agents cause significant losses throughout the world. They are responsible for the natural spread of a large number of economically important diseases in tropical and subtropical areas. Recent years have shown an increase in losses in wide areas north and south of the tropics, approaching areas of intensive agricultural production such as the southern

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United States, Jordan, Israel, (11, 13, 16, 25) and even southern Europe (19). These areas are now within the steadily increasing range of *Bemisia tabaci*, the most intensively studied whitefly vector. Recent years have shown, if not an absolute increase, at least an increase in the awareness of disease losses caused by two other whitefly species, *Trialeurodes vaporariorum* (Westwood) and *T. abutilonea* (Hald.), in temperate areas of the United States, Europe, Australasia, and Asia (21, 22, 31, 34, 38, 40).

The importance of the whitefly-transmitted agents becomes apparent when the crops affected by the diseases induced by them are reviewed. Serious losses are induced on cassava, cotton, cowpea, bean, tobacco, soybean, tomato, squash, melon, watermelon, lettuce, sugar beet, carrot, peppers, sweetpotato, cucumber, and papaya (1, 2, 3, 4, 5, 10, 14, 16, 17, 20, 25, 39). Some 70 or more diseases have been reported to be induced by the feeding of infectious whiteflies. The relationships between these diseases, often poorly described, are not well established and in many instances probably represent diseases induced by the same agent or strains of that agent.

The earliest investigations of whitefly transmission of cotton leaf curl, tobacco leaf curl, and cassava mosaic (all transmitted in a persistent manner) gave the impression that whitefly-transmitted disease agents were somehow different, with greater vector dependence than viruses transmitted by other vectors (37).

A compilation of data on whitefly-transmitted viruses at this point suggests the involvement of at least seven distinct groups of viruses differing in type of virus particle, symptom type, type of transmission and vector relationships. These include geminiviruses, and viruses similar to the closteroviruses, carlaviruses, potyviruses, nepoviruses, luteoviruses and a DNA-containing rod-shaped virus. Since the data on the 70 or so diseases reported to be transmitted by whiteflies are so limited, the number of viral groups involved is undoubtedly much larger (23).

At the present time, the two most important virus groups transmitted by whiteflies appear to be the geminiviruses and the closterolike viruses.

Only one of the established groups of plant viruses, the geminiviruses, has been reported and described as being transmitted by whiteflies. The group also has important members transmitted by leafhoppers. Since the natural method of transmission is one of the eight criteria used in virus classification by the Subcommittee on Virus Nomenclature, it is difficult to place newly described whitefly-transmitted viruses in the "older" virus groups until more is known of their comparative vector relationships, purification, serology, and biochemistry.

Definitive members of the geminivirus group by particle morphology or serology all cause symptoms of the variegation or leaf curl type on susceptible plants and are persistent in their vectors.

Many of the whitefly transmitted geminiviruses are also mechanically transmitted. It is rare among the insect-transmitted viruses to be persistent in the vector and to be mechanically transmitted. Persistence in the vector usually is associated with viruses with high tissue specificity involving the phloem and these viruses generally do not involve epidermal or mesophyll tissues. The bright yellow variegated symptoms associated with the mechanically transmitted geminiviruses are unique in appearance and the distribution of virus. The apparent landing behavior of whiteflies, attraction to yellow color, short-sightedness, and passive landing behavior seem to be especially adaptive to vectoring by whiteflies (8).

Members of the geminivirus group and possible members, where tested, have fairly similar transmission characteristics, except perhaps for persistence. The viruses are acquired by whiteflies in as short a period as 10 min. but efficiency of transmission increases with feeding periods up to 24 hr. Inoculation periods as short as 10 min are adequate for infection, but transmission efficiency increases with longer inoculation periods. Latent periods between acquisition of virus and the ability of the insects to infect plants varied from 4 to 21 hr, but these differences may reflect transmission efficiency differences rather than real differences between the viruses. Where adequately tested, *Euphorbia* mosaic, bean golden mosaic, tobacco leaf curl, squash leaf curl, and other whitefly-transmitted geminiviruses were retained by the vectors for 20 or more days. Several of the viruses in the group have been shown to be acquired in the nymphal stages and to transmit the virus to healthy plants as they emerge as adult whiteflies from their pupal cases.

There is no direct evidence for the multiplication of the circulative viruses in the whitefly. However, there are some indications that the pathway of these viruses is not passive. For instance, tomato yellow leaf curl virus (TYLCV) (12) triggers an antiviral mechanism in *Bemisia tabaci* (Genn.). Two factors were found in homogenates of whiteflies carrying TYLCV. The introduction of these materials into the whiteflies before or after TYLCV acquisition resulted in reduced ability of the insects to acquire and transmit the virus. These factors apparently are responsible for the phenomenon of "periodic acquisition" of the virus (6, 7, 9, 10, 35, 36). A similar phenomenon was observed with tomato yellow mosaic in India (39). A high frequency of transmission following the latent period, associated with apparent harmful effects of the virus on the vector suggested that SLCV may multiply in the vectors (14).

Whitefly-transmitted yellowing viruses are causing severe economic losses throughout the world. The viruses responsible for these losses are in the closterovirus group. Seven whitefly-transmitted viruses have some characteristics similar to the aphid-transmitted closteroviruses, including Abutilon yellows (AYV) (23), beet pseudo yellows (BPYV) (21), cucurbit yellow stunting disorder (CYSDV) (27, 30), lettuce chlorosis (LCV) (28), lettuce infectious yellows (LIYV) (26), sweetpotato virus disease-associated closterovirus (SPVD-AC), and tomato infectious chlorosis (TICV) (29). The characteristics of this group of viruses include symptoms of the yellowing type, interveinal yellowing, and brittleness of affected leaves, and/or vein yellowing symptoms. Virus particles are long, flexuous rods 1000-2000 nm long and none have been transmitted mechanically. The viruses of the group are transmitted by three distinct species of whitefly, *Trialeurodes vaporariorum, T. abutilonea,* and *Bemisia tabaci*, all in a semipersistent manner. Each virus seems to be transmitted by only one whitefly species. Cytopathological examinations of diseased plants of those diseases studied revealed the presence of flexuous, rod-shaped particles in the cytoplasm of phloem parenchyma cells and sieve elements. The particles were associated with membranous vesicles containing fibrils.

Those viruses studied can be acquired by nonviruliferous whiteflies in a period as short as 10 min. There is a positive correlation between the length of the acquisition feeding period and the duration of the inoculation feeding period and the probability of virus transmission. The viruses are retained by the whiteflies for periods of days, ranging from 3 days for LIYV to 8 days for CYSDV. Four of the known whitefly transmitted closteroviruses are causing economic losses throughout the world. Three distinct whitefly transmitted viruses have been distinguished on cucurbits--beet pseudo yellows (BPYV), lettuce infectious yellows (LIYV), and cucurbit yellow stunting disorder virus (CYSDV). BPYV virus has caused severe losses in greenhouse grown cucurbit crops throughout North America, Europe, and Asia. It has been reported from France, The Netherlands, Japan, Italy, Spain, England, Australia, and Bulgaria. Since 1982, the incidence in melon crops under protected environments and outdoors on the Mediterranean coast of Spain has continually increased inducing considerable economic losses.The virus has a wide host range of important crop, weed and ornamental hosts. BPYV is transmitted by *Trialeurodes vaporariorum* in a semipersistent manner and is retained by the insect for 6 days. Purified preparations contained long, flexuous particles 1500 nm long. The virus has been termed cucumber yellows, muskmelon yellows, melon yellows, and cucumber chlorotic spot virus, but these isolates have not been shown to be distinct from BPYV. A distinct whitefly transmitted virus, LIYV, was reported from the desert regions of California and Arizona in 1981. The virus, transmitted specifically by the "A" biotype of *Bemisia tabaci*, has a wide host range of important crop hosts. LIYV has long filamentous particles 1800 nm long which are retained by *Bemisia* for 3 days. The virus has been also found in Texas and Mexico. In the early 1980's a yellowing and stunting disorder of cucurbits was noticed in the Middle East. The disease has been found in Jordan, Israel, UAE and Turkey. The virus, cucurbit yellow stunting disorder virus, CYSDV, has a narrow host range, mainly in the Cucurbitaceae. CYSDV is transmitted specifically by the "B" biotype of *B. tabaci* and is retained by the vector for 8 days. Purified preparations contained long, flexuous particles 1200 nm long.

A newly described virus of tomato, tomato infectious chlorosis virus (TICV), was recently found in California (29). Affected tomato plants exhibited interveinal yellowing, necrosis and severe yield losses. The disease affected virtually 100% of the crop in the Irvine hills and valley region. The outbreak was associated with the occurrence of high populations of the greenhouse whitefly, *Trialeurodes vaporariorum*. Leaf dips showed flexuous filamentous particles of variable length similar to closteroviruses. The virus was transmitted by *T. vaporariorum* but not by either the "A" or "B" biotypes of *Bemisia tabaci*.

TICV may be distinguished from other diseases of tomato by the transmission by *Trialeurodes* and from BPYV (the only other *Trialeurodes* transmitted closterovirus) by serology, ds RNA analysis and vector relationships.

Recent changes in the populations of SPW in Florida, Texas, Arizona, and California have been shown to be caused by the introduction of a new biotype into the United States (15, 18). The new biotype population "B" differs in several ways from the previously occurring population "A", including its ability to induce silverleaf of squash, host preferences, larval development, virus transmission and isozyme banding patterns. The biotypes can not be distinguished morphologically. Isozyme analysis of *Bemisia* from California (A & B), Florida, Texas, Nigeria and Israel indicates that these populations have the range of isozyme patterns representative of the variations or segregates of the A & B population (32, 33).

A very important characteristic of the different whitefly biotypes is their differential transmission of plant viruses. Lettuce infectious yellows virus (LIYV), a closterovirus, is transmitted 100 fold more efficiently by the "A" biotype, and squash leaf curl virus was transmitted twice as efficiently and retained for twice as long by the "A" biotype (Duffus and Cohen, *unpublished*). Conversely, preliminary studies indicate that a recently discovered clostero-like virus of cucurbits in Israel (cucurbit yellow stunting disorder virus) is transmitted specifically by the "B" biotype and may be widespread in the Mediterranean region (27). These biotypes differ significantly in their abilities to transmit several geminiviruses; they also differ significantly in their abilities to transmit closteroviruses. The isolation and/or characterization of the components or mechanisms responsible for these major differences in vector efficiency and specificity could provide basic data crucial to devising strategies for controlling these viruses.

الملخص

دوفوس، جيمس. الأمراض المنقولة مع الذباب الأبيض: مسبباتها، بيئياتها، توزعها الجغرافي والطرائق الممكنة للمكافحة. مجلة وقاية النبات العربية: 12 (2): 143-148.

تسبب الفيروسات المنقولة مع الذباب الأبيض مجموعة واسعة ومتباعدة من الأمراض، لم يتم توصيف معظمها بعد. وتنتقل العوامل المسببة لهذه الأمراض، بالطريقة غير الباقية، نصف الباقية، الباقية، والحيوية في ثلاثة أنواع من الذباب الأبيض على الأقل. وتسبب هذه الفيروسات خسائر كبيرة في كل أصقاع العالم. وهي مسئولة عن 70 مرض هام في المناطق المدارية وشبه المدارية. وتزايدت، في السنوات القليلة الماضية، الخسائر في مناطق واسعة شمال وجنوب المناطق المدارية مقتربة من مناطق الزراعة المكثفة. وقد تم توصيف الأمراض المنقولة مع الذباب الأبيض بالإستناد الى مدى انتقالها مع هذه الحشرات، ونشاط العوامل على النباتات العائلة كالأعراض والمدى العائلي. ويدعو تجميع البيانات المتاحة عن الفيروسات أنفسها الى الإفتراض بوجود سبع مجموعات من الفيروسات تختلف في نمط الجسيمات الفيروسية، والأعراض، والعلاقات مع الناقل. وتنقل المجموعتين الرئيستين من الفيروسات المنقولة مع الذباب الأبيض ذات الأهمية العالمية (الفيروسات التوأمية وفيروسات مجموعة كلوسترو) بطرق مختلفة، بوساطة أنماط حيوية من حشرة *Bemisia*. ويؤثر التخصص الناقلي هذا في توزيع الفيروس ووبائيته. وقد يكون لأنظمة النقل قيمة هامة في اقتفاء مصادر الفيروسات ونواقلها.

كلمات مفتاحية: النقل الحشري، *Bemisia tabaci*، الفيروسات التوأمية، الفيروسات الخيطية، وبائيات.

References

1. Ahmed, M. 1978. Whitefly (*Bemisia tabaci*) transmission of a yellow mosaic disease of cowpea, Vigna unguiculata. Plant Dis. Rep. 62: 224-226.

2. Allen, R.M., H. Tucker and R.A. Nelson. 1960. Leaf crumple disease of cotton in Arizona. Plant Dis. Rep. 44: 246-250.

3. Andrews F.W. 1936. The effect of leaf curl disease on the yield of the cotton plant. Emp. Cotton Grow. Rev. 13: 287-293.

4. Chant, S.R. 1958. Studies on the transmission of cassava mosaic virus by *Bemisia* spp. (Aleyrodidae). Ann. Appl. Biol. 46: 210-215.

5. Clerk, G.C. 1960. A vein-clearing virus of sweet potato in Ghana. Plant Dis. Rep. 44: 931-933.

6. Cohen, S. 1967. The occurrence in the body of *Bemisia tabaci* of a factor apparently related to the phenomenon of "periodic acquisition" of tomato yellow leaf curl virus. Virology 31: 180-183.

7. Cohen, S. 1969. In vivo effects in whiteflies of a possible antiviral factor. Virology 37: 448-454.

8. Cohen, S. 1982. Control of whitefly vectors of viruses by colour mulches, *in* K.H. Harris and K. Maramorosch (eds.), Pathogens, Vectors, and Plant Diseases, Approaches to Control. Academic Press, New York, pp. 45-56.

9. Cohen, S. and I. Harpaz. 1964. Periodic, rather than continual, acquisition of a new tomato virus by its vector, the tobacco whitefly (*Bemisia tabaci* Genn.). Entomol. Exp. Appl. 7: 155-166.

10. Cohen, S. and S. Marco. 1970. Periodic occurrence of an anti-TMV factor in the body of whiteflies carrying the tomato yellow leaf curl virus (TYLCV). Virology 40: 363-368.

11. Cohen, S., V. Melamed-Makjar and J. Hameiri. 1974. Prevention of the spread of tomato yellow leaf curl virus transmitted by *Bemisia tabaci* Genn. (Homoptera, Aleyrodiadae) in Israel. Bull. Entomol. Res. 64: 193-197.

12. Cohen, S. and F.E. Nitzany. 1960. Transmission and host range of tomato yellow leaf curl virus. Phytopathology 56: 1127-1131.

13. Cohen, S. and F.E. Nitzany. 1966. A whitefly transmitted virus of cucurbits in Israel. Phytopathol. Medit. 1: 44-46.

14. Cohen, S., J.E. Duffus, R.C. Larsen, H.Y. Liu and R.A. Flock. 1983. Purification, serology, and vector relationships of squash leaf curl virus, a whitefly-transmitted geminivirus. Phytopathology 743: 1669-1673.

15. Cohen, S., J.E. Duffus and H.Y. Liu. 1992. A new *Bemisia tabaci* (Gennadius) biotype in southwestern United States and its role in silverleaf of squash and transmission of lettuce infectious yellows virus. Phytopathology 82: 86-90.

16. Costa, A.S. 1965. Three whitefly-transmitted virus diseases of beans in Sao Paulo, Brazil. Plant Protect. Bull. FAO 13: 121-130.

17. Costa, A.S. 1975. Increase in the populational density of *Bemisia tabaci*, a threat of widespread virus infection of legume crops in Brazil, p. 27-49. In. J. Bird and K. Maramorosch (eds.). Tropical Disease of Legumes. Academic Press, New York.

18. Costa, H.S. and J.K. Brown. 1991. Variation in biological characteristics and esterase patterns among populations of *Bemisia tabaci*, and the association of one population with silverleaf symptom induction. Entomol. Exp. Appl. 61: 211-219.

19. Credi, R., L. Betti and A. Canova. 1989. Association of a geminivirus with a severe disease of tomato in Sicily. Phytopathol. Medit. 28: 223-226.

20. Dhanraj, K.S. and M.L. Seth. 1968. Enations in *Capsicum annum* (Chilli) caused by a new strain of leaf curl virus. Ind. J. Hortic. 25: 70-71.

21. Duffus, J.E. 1965. Beet pseudo-yellows virus, transmitted by the greenhouse whitefly *Trialeurodes vaporariorum*. Phytopathology 55: 450-453.

22. Duffus, J.E. 1975. A new type of whitefly-transmitted disease. A link to the aphid-transmitted viruses, p. 79-88. In: J. Bird and K. Maramorosch (eds.). Tropical Diseases of Legumes. Academic Press, New York.

23. Duffus, J.E. 1987. Whitefly transmission of plant viruses, p. 73-91. In Current Topics in Vector Research. Springer-Verlag, New York.

24. Duffus, J.E. 1992. Whitefly vectors: Increasing threat to world agriculture. Proc. XIX International Congress of Entomology, pg. 352.

25. Duffus, J.E. and R.A. Flock. 1982. Whitefly-transmitted disease complex of the desert southwest. Calif. Agric. 36: 4-6.

26. Duffus, J.E., R.C. Larsen and H.Y. Liu. 1986. Lettuce infectious yellows virus--A new type of whitefly transmitted virus. Phytopathology 76: 97-100.

27. Duffus, J.E., H.Y. Liu and S. Cohen. 1994. Partial characterization of a new closterovirus, the causal agent of cucurbit yellow stunting disorder. Pg. 49 *in* Sweetpotato Whitefly: 1994 Supplement to the Five Year Plan, U.S. Dept. Agr. ARS No. 112.

28. Duffus, J.E., H.Y. Liu and G.C. Wisler. 1994. Lettuce chlorosis virus -- A new whitefly-transmitted closterovirus in the southwest. Phytopathology 84: 1168.

29. Duffus, J.E., H.Y. Liu and G.C. Wisler. 1994. A new closterovirus of tomato in southern California transmitted by the greenhouse whitefly (*Trialeurodes vaporariorum*). Phytopathology 84: 1072-73.

30. Hassan, A.A. and J.E. Duffus. 1991. A review of a yellowing and stunting disorder of cucurbits in the United Arab Emirates. Emir. J. Agr. Sci. 2: 1-16.

31. Larsen, R.C. and K.S. Kim. 1985. Ultrastructure of *Diodia virginiana* infected with a whitefly-transmitted virus-like disease agent. Phytopathology 75: 1324.

32. Liu, H.Y., S. Cohen and J.E. Duffus. 1992. The use of isozyme patterns to distinguish sweetpotato whitefly (*Bemisia tabaci*) biotypes. Phytoparasitica 20: 187-194.

33. Liu, H.Y., J.E. Duffus and S. Cohen. 1993. Intra-biotype mating with A and B biotypes of the sweetpotato whitefly. Pg. 35 *in* Sweetpotato Whitefly: 1993 Supplement to the Five-year National Research and Action Plan, U.S. Dept. Agr. ARS No. 112.

34. Lot, H., J.C. Onillon and H. Lecoq. 1980. Une nouvelle maladie a virus de la laitue de serre: La jaunisse transmise par la mouche blanche. Rev. Hortic. 209: 31-34.

35. Marco, S., S. Cohen, I. Harpaz and Birk, Y. 1972. In vivo suppression of plant virus transmissibility by an anti-TMV factor occurring in an inoculative vector's body. Virology 47: 761-766.

36. Marco, S., S. Cohen, I. Harpaz and Y. Birk. 1975. An anti-TMV factor in the tobacco whitefly after acquisition of tomato yellow leaf curl virus. J. Insect Physiol. 21: 1821-1826.

37. Sylvester, E.S. 1956. Aphid transmission of plant viruses, in: Proceedings of the 10th International Congress of Entomology Vol. 3, pp. 195-200.

38. VanDorst, H.J.M., N. Huijberts and L. Bos. 1980. A whitefly transmitted disease of glasshouse vegetables, a novelty for Europe. Neth. J. Plant Pathol. 85: 311-313.

39. Verma, H.N., K.M. Srivastava and A.K. Mathur. 1975. A whitefly-transmitted yellow mosaic disease of tomato from India. Plant Dis. Rep. 59: 494-498.

40. Yamashita, S., Y. Doi, K. Yora and M. Yoshino. 1979. Cucumber yellows virus: Its transmission by the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and the yellowing disease of cucumber and muskmelon caused by the virus. Ann. Phytopathol. Soc. Japan 45: 484-496.