and 24 April and were found to be 8 and 9 UTC respectively. The TEC values corresponding to the anomaly time for all 14 stations (locations) suggest that the TEC gradient decreased towards the epicentre on 11 April when negative anomaly was observed, and increased towards the epicentre on 24 April when positive anomaly was observed. This opens a new avenue for possible detection of the epicentre by establishing a large number of ground networks of GNSS. Figures 1 and 2 show TEC changes on 11 April 2015 at 8 UTC from 14 GNSS stations in Nepal. The TEC profile along *AB* shows a reduction of TEC at a distance of around 300 km from *A*, which could be the expected epicentre (Figure 2). When measured along *A* and the actual epicentre *A′*, the distance between them is found to be 307.5 km. Therefore, there is a definite pattern showing decreased TEC gradient towards the epicentre, where a negative anomaly is observed. This information can help in detecting the epicentre of impending earthquakes from a large number of GNSS observations. Thus, continuous ionospheric TEC monitoring with well-distributed GNSS observation stations may open up a new avenue towards precursor monitoring and epicentre detection of impending earthquakes.

1. Liu, J. Y., Chuo, Y. J., Shan, S. J., Tsai, Y. B., Chen, Y. I., Pulinets, S. A. and Yu, S. B., *Ann. Geophys.*, 2004, **22**, 1585–1593.
2. Sharma, G., Champatiray, P. K., Mohanty S. and Kannaujiya, S., *Quaternary Int.*, 2017, **462**, 65–74.
3. Abba, I., Abidin, W. A. W. Z., Masri, T., Ping, K. H., Muhammad, M. S. and Pai, B. V., *Niger. J. Technol.*, 2015, **34**(3), 523–529.
4. Ndeda, J. O. H. and Odera, P. O., *Appl. Phys. Res.*, 2014, **6**(1), 19–25.
5. Adewale, A. O., Oyeyemi, E. O., Adeniyi, J. O., Adeloye, A. B. and Oladipo, O. A., *Indian J. Radio Space Phys.*, 2011, **40**, 21–25.
6. Pulinets, S. A., *Terrestrial Atm. Oceanic Sci.*, 2004, **15**(3), 413–435.
7. Friedemann, F. T., Kulahci, I., Cyr, G., Ling, J., Winnick, M., Tregloan-Reed, J., and Freund, M. M., *J. Atmos. Solar-Terrestrial Phys.*, 2009, **71**, 1824–1834.

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Invasion and establishment of the solanum whitefly *Aleurothrixus trachoides* (Back) (Hemiptera: Aleyrodidae) in South India

Trade, transport and travel are the major drivers of bioinvasions and will continue to increase as a by-product of globalization[1]. Agricultural practices that simplify ecosystems by focusing on a small number of crops by eliminating predators and competitors generally make those systems more vulnerable to invasion[2]. The Neotropical solanum whitefly, *Aleurothrixus trachoides* is found to be invasive in India[3]; it is presently spreading fast in South India infesting many economically important plants of the family Solanaceae like brinjal (Figure 1 *a*), chilli (Figure 1 *b*), and tomato (Figure 1 *c*), and sandalwood (Figure 1 *d*), as well as some medicinal, ornamental (Figure 1 *e*) and weed species (Figure 1 *f*).

Whiteflies comprise the insect family Aleyrodidae and are an economically important group of small inconspicuous phytophagous insects; they are often overlooked despite their abundance on the surfaces of leaves[4]. Whiteflies rank among the most noxious insects attacking field crops and greenhouse crops around the world. The economic loss is due to their activities of sucking the plant sap, acting as vectors of viral diseases and in production of honey dew leading to the development of mould on leaves, thus adversely affecting photosynthesis[5]. So far 440 species of whiteflies under 63 genera are known from India, among which few are economically important.

Whiteflies pose a significant threat to agriculturists throughout the world. Globally over the past 25 years, exotic whiteflies have invaded several countries causing direct losses in agriculture, horticulture and forestry. A news report on 'Whiteflies destroying two-thirds of Punjab's cotton crop, resulting in 15 farmer suicides' (*Times of India*, 8 October 2015) is one such example in India. The spiralling whitefly *Aleurodicus disperses* invaded India in 1995 (ref. 6) and its spread was successful mainly due to its polyphagous nature and prolific breeding. Impact of its infestation on Indian agricultural economy is well recognized as it affects many economically important plants. The whitefly is breeding on over 320 plant species belonging to 225 genera and 73 families in India[7]. However, now its management is possible due to extensive research coupled with introduction of exotic parasitoids. The agricultural economy in India is vulnerable to the emerging threat by invasion of the solanum whitefly as brinjal, chilli, tomato, etc. are important solanaceous fruit vegetables grown in our country.

A. trachoides is a native of the Neotropical Region, but had become

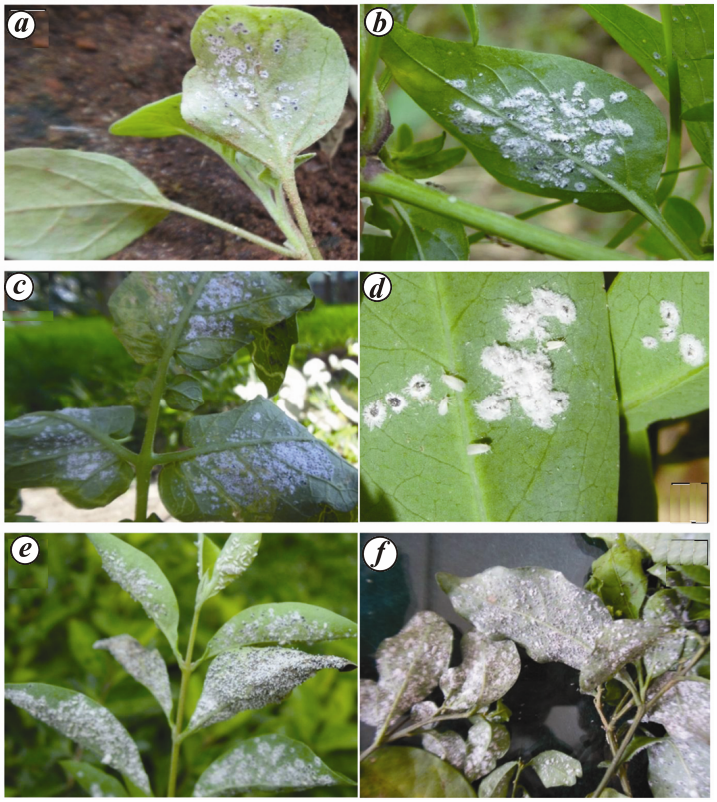

Figure 1. Infestation of *Aleurothrixus trachoides* on different host plants. ***a***, Brinjal; ***b***, chilli; ***c***, tomato; ***d***, sandalwood; ***e***, *Duranta*; ***f***, *Solanum pseudocapsicum.*

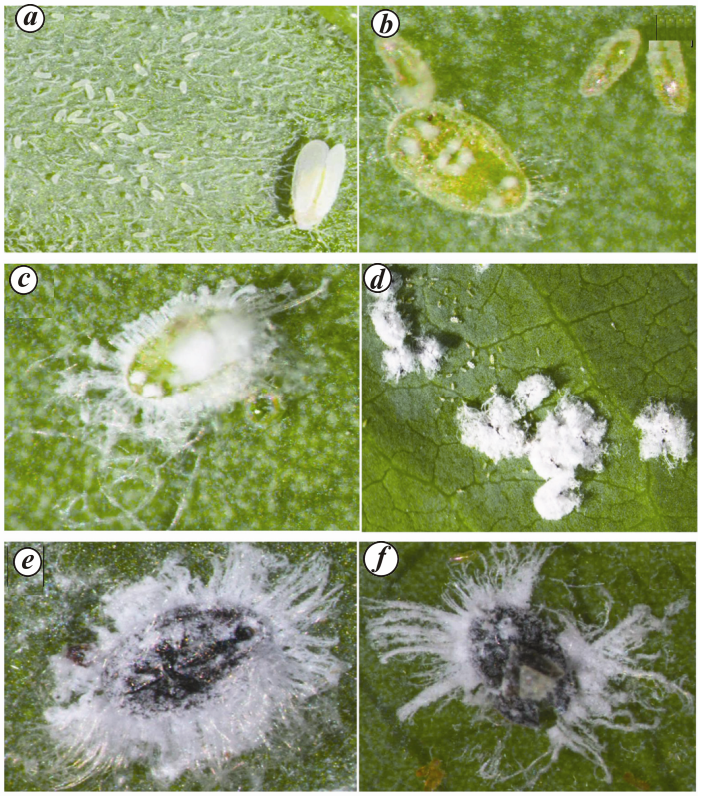

Figure 2. Developmental stages of *A. trachoides*. ***a***, Eggs and adult; ***b***, First instar nymph and eggs before hatching; ***c***, Second instar nymph; ***d***, Eggs and third instar nymphs; ***e***, Puparium; ***f***, Puparium after emergence of adult.

established in Tahiti by the 1930s (British Museum of Natural History, UK). It has become more widespread across the Pacific since the late 1970s, and is now also in Hawaii (late 1990s) and Guam (2003). Quarantine interception in England, on plant material from Gambia, indicates possible establishment in the Ethiopian Region[8], and now it occurs in North America, Pacific, West Africa and Southeast Asia[9]. In India, so far it is found breeding on 24 host plants representing 11 families (Table 1 and Figure 2 *a–f*) and observed in Karnataka, Kerala, Maharashtra and Tamil Nadu. Heavy infestations caused chlorotic spots and curling of leaves resulting in their premature shedding and in severe infestation mortality of seedlings of chilli and tomato was observed. In Bengaluru, its infestation starts from September coinciding with the waning of monsoon, reaching its peak population from January to April and declining with the onset of monsoon. The whitefly completes its life cycle in 32–38 days in summer season (Figure 2 *a–f*). Its polyphagous nature confirms the observation of Martin[10] that *A. trachoides* is called the solanum whitefly, and it does seem to favour hosts in the Solanaceae; however, it also feeds on several other plants of Araceae, Apocynaceae and Convolvulaceae. There is a warning signal that it will breed on many more host plants in India.

There is no doubt that invasive species can cause severe ecological and economic damage[11]. They may soon surpass habitat loss as the main cause of ecological disintegration globally[12] and constitute the second most serious threat to biodiversity habitat destruction[13]. The agricultural economy in India is vulnerable to threat from exotic pests/diseases, and there are 116 alien insect species[14]. Non-native species can achieve invasive pest status when they are accidentally moved to new locations if they become separated from their own natural enemy complexes and if local (indigenous) beneficial species (predators and/or parasitoids) are unable to suppress them[15]. The solanum whitefly will soon achieve invasive pest status as it is establishing on economically important fruit/vegetable crops and trees. Biologists and the public worldwide increasingly recognize the damage caused by invasive non-indigenous species and they usually assume that maintenance management is the appropriate response[14]. Hence it is of

Table 1. Establishment of *Aleurothrixus trachoides* on different host plants in India

Plant species	Family	Main use	Locality
Acalypha lanceolata	Euphorbiaceae	Medicinal	Bengaluru (Karnataka)
Alternanthera paronychioides	Amaranthaceae	Weed	Bengaluru (Karnataka)
Bidens pilosa	Asteraceae	Medicinal	Bengaluru, Tumakuru (Karnataka)
Capsicum annum	Solanaceae	Fruit/vegetable	Bengaluru, Tumakuru (Karnataka); Calicut, Thiruvananthapuram (Kerala); Andheri (Maharashtra); Dharmapuri, Hosur Kanyakumari, Salem (Tamil Nadu)
Cipadessa baccifera	Meliaceae	Medicinal	Bengaluru, Tumakuru (Karnataka)
Clerodendrum viscosum	Lamiaceae	Medicinal	Ponnempet, Tumakuru (Karnataka)
Duranta erecta	Verbenaceae	Ornamental	Bengaluru, Ponnempet, Tumakuru (Karnataka)
Duranta plumeria	Verbenaceae	Ornamental	Bengaluru, Ponnempet, Tumakuru (Karnataka)
Emilia sonchifolia	Asteraceae	Medicinal	Bengaluru (Karnataka)
Ipomoea muricata	Convolvulaceae	Vegetable	Bengaluru (Karnataka)
Ipomoea staphylina	Convolvulaceae	Medicinal	Benglauru (Karnataka)
Ipomoea tuba	Convolvulaceae	Ornamental	Bengaluru, Tumakuru (Karnataka)
Merremia aegyptia	Convolvulaceae	Ornamental/medicinal	Bengaluru (Karnataka)
Premna serratifolia	Verbenaceae	Medicinal	Bengaluru (Karnataka)
Ruellia tuberosa	Acanthaceae	Medicinal	Bengaluru, Mysuru, Tumakuru (Karnataka)
Santalum album	Santalaceae	Perfumes	Bengaluru, Mysuru, Tumakuru (Karnataka)
Solanum esculentum	Solanaceae	Fruit/vegetable	Bengaluru, Tumakuru (Karnataka); Calicut, Thiruvananthapuram (Kerala); Andheri, Thane (Maharashtra); Dharmapuri, Hosur Kanyakumari, Salem (Tamil Nadu)
Solanum melongena	Solanaceae	Fruit/vegetable	Bengaluru, Tumakuru (Karnataka); Calicut, Thiruvananthapuram (Kerala); Andheri, Thane (Maharashtra); Dharmapuri, Hosur Kanyakumari, Salem (Tamil Nadu)
Solanum pseudocapsicum	Solanaceae	Exotic weed	Bengaluru, Mysuru, Tumakuru (Karnataka)
Solanum xanthocarpum	Solanaceae	Medicinal	Bengaluru, Tumakuru (Karnataka)
Tabebuia argentea	Bignoniaceae	Avenue/ornamental	Bengaluru (Karnataka)
Tabebuia impetiginosa	Bignoniaceae	Avenue/ornamental	Bengaluru (Karnataka)
Tabebuia Rosea	Bignoniaceae	Avenue/ornamental	Bengaluru (Karnataka)
Vitex leucoxylon	Verbenaceae	Medicinal/timber	Bengaluru (Karnataka)

utmost importance that effective measures for the prevention of this alien species are to be taken on a long-term basis. Further strengthening of the plant quarantine measures by developing strict national policy is the need of hour to avoid such invasion of potential pests.

1. USDA, Nature travel and ecotourism: animal and human health concerns, US Department of Agriculture, Washington DC, USA, October 2001.
2. Perrings, C. *et al.*, *Conserv. Ecol.*, 2002. **6**(1), 1; http://www.consecol.org/vol6/iss1/art1
3. Dubey, A. K. and Sundararaj, R., *Biosystematica*, 2015, **9**(1&2), 21–26.
4. David, B. V. and Subramaniam, T. R., *Rec. Zool. Surv. India*, 1976, **70**, 133–233.
5. Sundararaj, R. and Murugesan, S., *Indian J. For.*, 1996, **19**(3), 247–248.
6. David, B. V. and Regu, K., *Pestology*, 1995, **19**(3), 5–7.
7. Sundararaj, R. and Pushpa, R., In *The Whitefly or Mealywing Bugs: Bioecology, Host Specificity and Management* (ed. David, B. V.), Lambert Academic Publishing, Germany, 2011, pp. 20–57.
8. Malumphy, C., *Entomol. Mon. Mag.*, 2005, **141**(1691/93), 94.
9. Malumphy, C. and Reid, S., UKOT Plant Pest Fact Sheet. Fera (GB), 2017; http://www.nonnativespecies.org/downloadDocument.cfm?id=1544
10. Martin, J. H., *Zootaxa*, 2005, **1098**, 1–116.
11. Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M. and Bazzaz, F. A., *Ecol. Appl.*, 2000, **10**(3), 689–710.
12. Chapin, F. S. *et al.*, *Nature*, 2000, **405**, 234–242.
13. Pimental, D., Lach, L., Zuniga, R. and Morrison, D., *Bioscience*, 2000, **50**, 53–65.
14. Mandal, F. B., *Int. J. Biodivers. Conserv.*, 2011, **3**(9), 467–473; http://www.academicjournals.org/IJBC
15. Duan, J. J., Leah, S. B., Kristopher, J. A., Michael, D. U. and Roy, G. V. D., *J. Appl. Ecol.*, 2015, **52**, 1246–1254.

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