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CLIMEX modelling for risk assessment of Asian fruit fly, *Bactrocera papayae* (Drew and Hancock, 1994) in India

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Abstract

Aim : Risk of establishment of Asian fruit fly, *Bactrocera papayae* (Drew and Hancock, 1994) an alien species to India was made for the present and expected climate change situations of 1 °C, 2 °C and 3 °C rise in global temperatures using CLIMEX, a bioclimatic modelling tool.

Methodology : CLIMEX, the bioclimatic model was run for 33 known geo-referenced home locations of *B. papayae* using "regional match climate" function in order to predict the areas with similar Climate Match Index, (CMI > 0.7). The model was also run with rise in temperature of 1 °C, 2 °C and 3 °C for predicting the risk areas for *B. papayae* establishment, in case gets introduced accidentally.

Results : High climatic similarity was predicted for most parts of South East Asia, Africa, South America, few parts of Australia, North Western Europe, North and Central America. In India, a climate match of >0.7 was predicted for the states of Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Orissa, Bihar, Jharkhand, West Bengal, Maharashtra, Kerala and Chhattisgarh, which could be potential hot spots for *B. papayae*, if introduced accidentally. In India, with the rise in temperatures from 1 °C to 3 °C, there was a gradual decrease in the climate similarity for the pest establishment, particularly in the coastal regions of Tamil Nadu and Andhra Pradesh. However, the climate similarity was projected to increase in the coastal parts in the states of Karnataka and Maharashtra with 3 °C rise in temperature, making the regions more suitable for pest establishment.

Interpretation : Present findings emphasises the need for close monitoring in the regions predicted to have congenial climatic conditions for *B. papayae* and needs strict quarantine measures against this pest.

Introduction

Insects are ubiquitous inhabiting extreme terrains like swamps, forests, deserts, temperate regions and as pests causes major damage to various crops resulting in high economic loss in the agricultural sector worldwide (Mohamed, 1999). In spite of numerous advances in plant protection, native and invasive insects continue to pose serious threat to agriculture. In such a challenging condition, invasions by non-indigenous species are a problem of increasing magnitude that threatens the stability of the world's agricultural ecosystems (Liebhold *et al.*, 2006). To check the entry, establishment and spread of the invasive species, usually risk maps for Pest Risk Analysis (PRA) are being generated (Robinet *et al.*, 2012). One such effective climate matching function of CLIMEX was used in the present study to evaluate the climatic similarity between the existing areas of the Asian fruit fly, *Bactrocera papayae* (Drew and Hancock, 1994) (Diptera: Tephritidae) and other locations in the world. Biological control agents from areas with similar climatic conditions are considered to be more likely to achieve effective control (Hoelmer and Kirk, 2005). Thus, climate matching can also be used to identify climatically suitable regions for selection of bioagents (Byrne *et al.*, 2002; Senaratne *et al.*, 2006 and Robertson *et al.*, 2008).

B. papayae, a member of Oriental fruit fly complex is widespread in South-East Asia with high economic impacts (Allwood *et al.*, 1999; Hancock *et al.*, 2000; Cantrell *et al.*, 2002) is a polyphagous pest having more than 193 hosts belonging to 114 genera and 50 families (Allwood *et al.*, 1999) and mainly spreads through fruits containing larvae either as part of cargo or accidentally carried by passengers. It infests a wide range of horticultural crops including banana, star fruit, guava, mango, papaya, almond *etc.* (Wee and Tan 2000; Clarke *et al.*, 2005). Infestation by fruit flies lead to loss of up to 12-60% in mango and papaya and 40-90% in guava (Allwood and Leblanc, 1997). In Thailand, the pest usually occurs during August-September and in May (Danjuma *et al.*, 2014). Its high dispersive ability, large host range and occurrence in both forest and non-forest habitats makes it a potential threat to horticultural crops (CABI, 2015). Its recent invasion to Australasian region is alarming though the pest is said to have been successfully eradicated at a cost of about AU\$35 million (Fay *et al.*, 1997; Hancock *et al.*, 2000; Sar *et al.*, 2001; Cantrell *et al.*, 2002).

The range of temperature elevation is expected to be 1.1 to 6.4 °C by the end of this century (IPCC climate change, 2007). This expected climate change might affect the distribution of insects either directly by changing survival and fecundity rate or indirectly influencing availability of food source, natural enemies and competitors (Baker and Bomford, 2009). Climate change also predicted range expansions or migrations from unsuitable regions to suitable regions particularly poleward expansion of the species that are currently limited by prevailing low temperatures

(Daniel, 2015).

CLIMEX software is widely used in predicting and mapping the potential geographic distribution of climate dependent trans-boundary pests and diseases (Sutherst and Floyd, 1999; Sutherst, 2003). Such bioclimatic models are used to predict geographic ranges of organisms as a function of climate to forecast range shifts due to climate change, to predict the eventual ranges of invasive species and infers paleoclimate from data on species occurrences (Ganeshiah *et al.*, 2003; Sutherst and Maywald, 2005; Jeschke and Strayer, 2008). Apart from CLIMEX, prediction models like BioClim, GARP and MaxEnt are also widely used to predict the potential geographical distribution of flora and fauna (Rameshprabhu and Swamy, 2015; Rajasri *et al.*, 2011; Kumar *et al.*, 2014). The aim of the present study was to predict climate suitability for Asian fruit fly, *B. papayae* infestation at global level with special reference to India through CLIMEX modelling based on the present distribution of the pest. The predictions were made for both present and future climate conditions with a rise of +1, +2 and +3 °C in temperature.

Materials and Methods

Known distribution of *B. papayae*: Asian fruit fly, *B. papayae* is wide spread in South East Asia (Fig. 1). It has been recorded from Oceania: Australia (Queensland - Torres Straits islands and Cairns areas), Papua New Guinea (Sutherst and Floyd, 1999) and is reported to have been eradicated from Queensland (CABI, 2015).

CLIMEX: Match climate function of CLIMEX ver 3.0 was used to compare the climate of home locations (known distribution) with away locations (area under investigation) to infer the preferred climate by the target pest. Climate matching consisted of selecting a location and then looking for locations elsewhere that have a similar climate enabling us to compare the meteorological data from different places and the extent of similarity. A Match Climates analysis showed whether the climate of 'away' location was similar to the 'home' locations, which would impact the preference of the locations for the establishment of the pest. In the present study, 33 home locations of known records (Fig.1) of *B. papayae* in the world were selected using the 'MetManager Location Selection' and the model was run with match climate regional application considering other locations in the world as 'away'. The resulting *Composite Match Index, CMI* (0-1) (Sutherst and Maywald, 2005) i.e., the similarity between 'home' and 'away' locations provides a probable risk of a pest establishing in a new location (country, continent) with implications for quarantine and pest risk analysis. CMI is the product of six indices viz., *ltmax*, *ltmin*, *lrain*, *ltpat*, *lhum* and *lsm*, indicating similarity in maximum/minimum temperature, total rainfall, rainfall pattern, relative humidity and soil moisture, respectively. A CMI value of 0.7 is generally accepted as the threshold for a biologically relevant climate match (Robertson *et al.*, 2008; Kriticos 2012). In

addition, a climate change scenario of elevated temperature of +1, +2 and +3°C for all the locations was included for running the model to arrive at Composite Match Index and to know about suitable locations in future when compared to the present spread of the pest. For climate data, CliMond 30 gridded data (Kriticos *et al.*, 2012) comprising of more than 68,000 locations was used for the present modelling.

Results and Discussion

The climate match map generated for the global scenario for the base year (averaged at 1975) is presented in Fig. 2 and confirms to the present distribution range of *B. papayae* in South East Asia (Fig. 1). High similarity in climate was seen in most parts of southern, central and eastern India, most parts of Bangladesh, Burma, Thailand, Cambodia, Vietnam, Taiwan, Japan, Malaysia, Singapore, Indonesia, Philippines and southern parts of Sri Lanka (Fig. 2). In Australia (northern parts of northern territory, northern Queensland, parts of southern Victoria) and North America parts of eastern US, southern part of Mexico, Guatemala, El Salvador, Belize, Honduras, Nicaragua, Panama, Bahamas, Turks and Caicos are expected to be similar. Most parts of South America (Brazil, Peru, Bolivia, Ecuador, Colombia, Venezuela, Guyana, and French Guiana) and Europe (Northern Portugal, Spain, most parts of France, Switzerland, Italy, England, Wales, Ireland, Scotland, Belgium, Netherlands, Denmark, parts of Germany, Austria) have similar climatic conditions, and hence with the availability of the host, the pest was expected to establish successfully in these regions. With most parts showing a CMI value of 0.6-0.7, China region could be less suitable for the establishment of *B. papayae*.

In India, north eastern parts of Andhra Pradesh, most parts of Telangana, southern tip of Chattisgarh, Orissa and southern Andaman had a climate match index of 0.8-0.9. High climate match (70-80%) was predicted in most parts of Orissa, central Chattisgarh, most regions of West Bengal, entire Assam, northern Arunachal Pradesh, entire Manipur, Nagaland and parts of Tripura and Mizoram with parts of Uttarakhand, Himachal Pradesh, Jammu, Andaman and Nicobar and Lakshadweep (Fig. 3). The aforesaid regions harbour numerous horticultural crops, most of which are known to be hosts of *B. papayae* in its native range (CABI, 2015). Below 0.6% CMI was observed in Kashmir, Meghalaya, Sikkim, most parts of Rajasthan, northern regions of Gujarat, few parts of Mizoram and Tripura, which might not favour the establishment of the pest. Poutsma *et al.* (2008) used CLIMEX as a strategic tool for estimating establishment potential as part of an environmental risk assessment for biological control agents like harlequin ladybird, *Harmonia axyridis*.

In future, climate change mediated elevated temperatures of +1, +2 and +3°C in Asia would result in gradual reduction of overall climatic similarity for the successful establishment of the pest (Fig. 4a-c). The per cent change in area

similar to the home locations is projected to decrease from 4.76% for the base year to 4.4% at 3°C increase in global temperature (Fig. 5). In most regions of Myanmar, Vietnam, Laos, Cambodia, Singapore, Indonesia and parts of Malaysia, the climatic similarity was expected to decrease. Similar modelling studies using CLIMEX under climate change context, future predictions on distribution of tomato leaf miner, *Tuta absoluta* indicated that the invasive nature of this pest will result in significant crop loss in certain locations, whereas some parts of Africa may witness diminution in ranges (Tonnang *et al.*, 2015).

In Australia, similarity in climate was expected to decrease from 11.78% in the base year to 9.32% at +3°C increase in temperature (Fig. 5). Similarity was projected to be very less in northern territory (Kakadu and Katherine) and northern regions of Queensland and Western Australia. Similarity was also expected to decrease in Victoria and Tasmania (Fig. 4a-c). In Europe, significant decrease in climate match was predicted in France, Spain, Portugal and Turkey with an overall decrease in suitability from 22.76% in the base year to 18.29% at +3°C rise in temperature (Fig. 5). On the other hand, presently cold regions of Norway and Sweden were expected to have slightly similar climatic conditions under climate change even at 3°C rise in temperature (Fig. 4a-c).

In South America, the climate similarity for invasive pest was expected to increase from 53.06% in the base year to 55.59% in future scenario of +3°C increase in temperature (Fig. 5). A decreasing similarity in climate was observed in Brazil, Peru, Venezuela, Guyana and Bolivia by 3°C increase in temperature. In case of southern coastal regions of Chile and Falkland Island, climatic similarity is expected to increase with increase in temperature (Fig. 4a-c). In North America, the climate similarity for the pest was expected to decrease from 8.05% in the base year to 7.56% in future scenario of +3°C increase in temperature (Fig. 5) with more or less similar climatic conditions (Fig. 4a-c).

In Africa, under projected elevated temperatures of +1, +2 and +3°C, the overall similarity in climate for successful establishment of the pest was expected to gradually increase from 25% in the base year to 28.61% at 3°C increase in temperature (Fig. 5). Increase in climatic similarity was seen in Cameroon, Central African Republic, Ethiopia, south Sudan and Zimbabwe. A decrease in similarity was observed in central and eastern Africa, Congo, Gabon and parts of South Africa (Fig. 4a-c).

In Africa and South America, climate similarity in many locations was expected to gradually increase with increase in temperature (Fig. 4c). On the other hand, in Asia, Australia, North America and Europe, regions with dissimilar climate for the establishment of pest were projected to increase leading to lesser regions of climatic similarities.

In India, with the rise in temperatures from 1 °C to 3 °C, there was a gradual decrease in the climate similarity for the pest establishment, particularly in the coastal regions of Tamil Nadu and Andhra Pradesh. However, similarity was projected to increase in the coastal parts of Karnataka and Maharashtra and in parts of Odisha at 3 °C increase in temperature. Under Indian conditions, possible change in the potential distribution of Oriental fruit fly, *B. dorsalis* (Sridhar et al., 2014a) and giant African snail, *Achatina fulica* (Sridhar et al., 2014b) in future as a consequence of predicted climate change was established through CLIMEX modelling.

Climatic envelope for *B. papayae* revealed *B. papayae* preferred an annual mean temperature range of 17 - 28 °C, with around 22 locations (out of 33) lying between 24-28 °C. The maximum, minimum temperature range and annual precipitation ranged from 24 - 33 °C, 11 - 23 °C and 1200 - 3600 mm, respectively (Fig. 6a-c)

Bioclimatic models assess the bio-physiological aspects of a species to generate the condition in which the species can ideally exist. In India, potential geographical distribution maps of many agriculture pests are generated using different modeling softwares like GARP, DIVA-GIS and MAXent for present and future climate change situations (Ganeshiah et al., 2003; Babasaheb, 2012). Although the above mentioned models are being successfully employed for predicting the spread of pest

species, for the first time in the present study CLIMEX was explored as a modelling approach to predict the potential geographical distribution of invasive pest, *B. papayae* in India and elsewhere. Climate match helps us to know the exact climatic preference of the pest which can be used in identifying the regions that are suitable for the pest. The present study was undertaken as there is a need to assess the extent of establishment risk by this quarantine pest in vulnerable regions. Most regions with similarity range of 0.7- 0.9 CMI were hot spots for agri-horticultural crops like almond, mango, guava, coffee, tomato, papaya etc. which were considered to be the major hosts of *B. papayae*. In future, invasion of *B. papayae* would worsen the pest status in these horticultural crops in future as many fruit fly species could compete for the same ecological niche due to their similar feeding habits.

Similarity in climate was seen in most parts of southern, central and eastern India, most parts of Bangladesh, Burma, Thailand, Cambodia, Vietnam, Taiwan, Japan, Malaysia, Singapore, Indonesia, Philippines and southern parts of Sri Lanka. In South America, most parts of Brazil, Peru, Bolivia, Ecuador, Colombia, Venezuela, Guyana, and French Guiana are expected to have similar climatic conditions as compared to the home locations. In Australia, northern parts of northern territory (Australia), northern Queensland, parts of southern Victoria were expected to be climatically similar. In North America most parts of eastern US was expected to have highly similar climatic

Fig. 1 : Current global distribution of *B. papayae* (CABI, 2015)

Fig. 2 : Global potential areas for *B. papayae* in terms of climate match (1961-1990)

Fig. 3 : Potential areas for *B. papayae* establishment in India with major host distribution (CMI=Composite Match Index)

Fig. 4 : Climatic similarity for *B. papayae* under climate change situations of (A) 1 °C, (B) 2 °C and (C) 3 °C rise in temperature

Fig. 5 : Per cent geographical area above 0.7 CMI for base year, and for three future scenarios of 1 °C, 2 °C and 3 °C rise in temperature for different continents

conditions with home locations, southern parts of Mexico, Guatemala, El Salvador, Belize, Honduras, Nicaragua, Panama, Bahamas, Turks and Caicos. In Europe, most of the north Western Europe was expected to have similar climatic conditions. Northern Portugal, Spain, most parts of France, Switzerland, Italy, England, Wales, Ireland, Scotland, Belgium, Netherland, Denmark, parts of Germany, Austria were expected to be climatically similar. Such closeness in climatic conditions would allow a successful establishment of the pest in this area, if it gains entry. Nevertheless, factors like host availability, presence of natural enemies *etc.* would enhance the accuracy of prediction. As biological control and quarantine measures are critical to limit the spread of invasive species, 'match climate function' used in the present study can play a significant role in understanding the distribution of invasive species. Similar observations with different pests were reported by Poutsma *et al.* (2008) and Sridhar *et al.* (2014b).

Strict quarantine measures and constant vigil in major hosts like mango, papaya, banana, guava *etc.* needs to be done to monitor the incidence of *B. papayae*. Parts of Andaman and Nicobar Islands are proximal to the South East Asia with high incidence of *B. papayae*. Hence, strict quarantine measures to check accidental entry of the pest needs to be undertaken in the entry ports and nearby islands of Andaman islands and this suitable zone needs to be closely monitored considering the frequent transport of commodities mainly exotic fruits like rambhutan, java apple, pomelo *etc.* and movement of people between the Andaman and Nicobar islands and Indian main land. Although, the climatic suitability indicates possible pest invasion and establishment, role of availability of host flora, other biotic and abiotic factors in the spread and establishment of the pest needs further investigations.

The present findings emphasises the need for close monitoring in the regions predicted to have congenial climatic conditions for *B. papayae* establishment and suggests strict

Fig. 6 : Climatic envelope for *B. papayae* obtained from DIVA GIS (a) Minimum temperature of the coldest month (11 - 23 °C), (b) maximum temperature at the warmest month (24 - 33 °C) and (c) Annual mean temperature with annual precipitation (17 - 28 °C and 1200 - 3600 mm)

quarantine measures against the entry of the pest from existing to new regions in the world, particularly to India.

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