Effect of elevated temperature and CO_2 on natural enemies of insect pests

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Biological control is a key component of Integrated Pest Management (IPM) programmes in many agroecosystems. Tritrophic interactions between plants, herbivorous and natural enemies result from a long co-evolutionary process specific to a particular environment and stable climatic conditions. Global climatic change has affected every aspect of life processes on earth and is also expected to impact herbivore-natural enemy interactions in several ways. Elevated global temperature, increased CO_2 and O_3 concentrations, UV radiation and changes in rainfall patterns are major climate change parameters. Among these, elevated temperature and CO_2 are significantly affecting the plant, pest and natural enemy interactions. Climate change affects species distribution, life histories, community composition, and ecosystem function. The impact of climatic changes is likely even more important in higher trophic levels that depend on the capacity of the lower trophic levels to adapt to these changes. Parasitoids and predators are thus organisms for which severe impact is expected, as its represent the third and fourth trophic level. In such scenario, assessment of the potential impacts of climate change on biological control is critical and challenging due to complex interspecific interactions.

Effect of elevated temperature on natural enemies

Temperature is major abiotic factor which has direct effect on the survival, development and population dynamics of herbivore and its natural enemies. Each population of every insect species has different optimum thermal range for survival and development. In the context of global warming scenario induced by climate change, all species will be under strong selection pressures and natural enemies are no exception.

1. Effect on host searching ability

Parasitoids can sustain a broad thermal range, although exposure to temperature extremes even for short periods is likely to influence parasitoid survival and host searching ability. Studies from 1993 to 1996 correlating climate data with egg parasitism suggest that rate of egg parasitism by *Trichogramma* spp. on European corn borer was drastically reduced to zero owing to extremely dry and hot weather experienced in May 1993 in Slovakia (Cagan et al., 1998). Similar study on Tachinid flies in relation to increased temperature suggests reduced range of parasitism up to 51%. Host location falls off sharply at temperatures above 35 ^{0}C of the egg parasitoid, *Trichogramma carverae* Oatman and Pinto (Thomson et al., 2001). In case of predators, it could be different. For example, it has been predicted that coccinellids reduce aphids more strongly in hot summers than in moderate summers.

2. Effect on reproduction and sex ratio of natural enemies

Extreme temperature events also have the detrimental effects on biological parameters. Temperature influences the fecundity and sex ratio in ichneumonid larval parasitoid, *Campoletis chloridae.* However, up to 50% reduction in fecundity is commonly reported in *T. carverae*, *T. pretiosum* and *T. bactrae* Nagaraja at 30 ^{0}C. Endosymbiotic bacteria, *Wolbachia* and *Buchnera* which influence several aspects of parasitoid reproduction can be eliminated or drastically reduced by short exposure to extreme temperatures.

3. Effect on host tracking by natural enemies

It is predicted that a 1^{o}C rise in temperature would enable species to spread 200 km northwards or 140 m upwards in altitude. Herbivore pests having greater mobility are likely to track the expansions. For example, rise in temperature will allow the pink bollworm, *Pectinophora gossypiella* (Saunders) to expand its range to non-traditional cotton growing areas that are presently non habitable (Guiterrez et al., 2008). Mobile species such as diamondback moth, *Plutella xylostella* L. and European corn borer, *Ostrinia nubilalis* (Hubner) will track the new areas faster than less mobile species. The probability of hosts escaping their specialist parasitoids will be highest as they may struggle to track the spatial shift of their host. These changes in the distribution of crops and expansion of herbivores range may lead to escape of these pests from natural enemies which may ultimately affect the pest control.

4. Phenological asynchrony between natural enemy and herbivore host

Change of phenology (the timing of biological events) is the most immediate response to climate change and has been widely documented across a range of species. Temperature is the most critical factor to affect the herbivore phenology; which alters the synchrony between herbivores and their natural enemies. Mismatched phenological asynchrony between a parasitoid and its host has been reported in several of cases. Grabenweger et al., (2007) reported lower level of parasitism in the first generation of horse chestnut leafminer, *Cameraria ohridella* Deschka & Dimic, which is might be due to emergence of hibernating parasitoids of leaf miners at a time when hosts are not available.

5. Temporal asynchrony between natural enemy and herbivore host

Irrespective of the species, speed of development of herbivores will generally increase under global warming. Multivoltine species will be able to increase the number of generations per year owing to more rapid development in higher temperatures. Fluctuations in parasitoid abundance and field parasitisation levels might get directly affected by rising temperature. Two way effect of temporal asynchrony may lead to extinction of host and/or natural enemy. Increased synchrony exposes host to intense parasitoid pressure, potentially leading to local extinction of the host which will ultimately lead to parasitoid population crash or local extinction due to unavailability of host in next generations (Hance et al., 2007). Conversely, decreased synchrony will lead to unavailability of host to emerging parasitoids, again causing their decline (Godfray et al., 1994).

Effect of elevated CO_2 on natural enemies

Global atmospheric CO_2 concentration is currently 390 ppm and would reach to 500-900 ppm by the end of the 21st century. Increasing atmospheric CO_2 concentrations will have a great effect on tritrophic interactions, which could modify plant resource allocation. It would also affect plant defense by altering C:N ratio. For example, in cotton, *Gossypium herbaceum* L., increasing CO_2 concentrations cause a corresponding elevation in concentrations of the phenolic aldehyde, gossypol, which has an antibiotic effect on the cotton aphid, *Aphis gossypii* Glover (Gao et al., 2009). This improved the fitness of coccinellid predator, *Propylaea japonica* Thunberg. In contrast, Dyer et al. (2013) showed that increased CO_2 and temperature weakened the biological control of armyworm caterpillars by parasitoids because of decrease in the nutritional quality of the lucerne plants and prolonged larval duration of armyworm. As a result, the parasitoids were unable to complete development, causing local extinction of parasitoid populations and weakened biological control.

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