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Weeds as alternate and alternative hosts of crop pests

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ABSTRACT

Weeds pose a perpetual menace both in cropped and non–crop areas. They provide food, shelter and reproductive sites for various pest organisms (plant pathogens, insect pests, mites, nematodes, rodents and others), and thereby play a key role to serve as alternate as well as alternative hosts. Many plant pathogens (fungi, bacteria and viruses) may also have either narrow or wide host range on which they pass at least a part of their life cycle. Alternate hosts from plant families other than the family of main (primary) host help a crop pest not only to complete its life cycle, but also support the crop pest to survive under unfavourable conditions and non–availability of main host. Alternative (collateral) hosts of similar plant family as of primary host help a crop pest to survive during the periods when main hosts are not seasonally available, and while the pests subsequently migrate back onto the main host plants. Although there are some similarities, differences between alternate and alternative hosts are aptly justified, signifying the relative importance of alternative hosts over the alternate ones. There may also have the possibilities of an elevated weed status from its indirect role as alternate and alternative hosts to directly as the main host under certain circumstances. However, eliminating harmful weeds (alternate and alternative hosts) from the margins of crop fields as well as non–crop areas at the extent possible or feasible is imperative to preventing continued infection and infestation of crop plants from different pest organisms.

INTRODUCTION

Weeds have been viewed as a perpetual menace towards successful crop production, independent of other concerns. They compete with crop plants for various growth–limiting resources like water, nutrients, sunlight, root space *etc.*, causing significant reduction in crop growth, yield and quality (Anwar *et al.* 2009, Ramachandra Prasad and Sanjay 2016). Crop losses due to weeds (33%) are more than the losses caused by pathogens (26%), insect pests (20%), storage pests (7%), rodents (6%) and others (8%) in India (Yaduraju *et al.* 2015, Yaduraju and Mishra 2018). Although competition is the primary impact that weeds have on crop production (Davis and Webster 2005, Anwar *et al.* 2009). Weeds become a part of the field ecosystem by maintaining the population levels of other pest organisms and can have other less obvious (indirect) effects such as serving as alternate and alternative hosts. Invasive weeds in natural areas may alter ecosystem processes, and exert the potential to displace the native biodiversity. They often support populations of non–native organisms, hybridize with native species and subsequently alter gene pools (Yandoc–Ables *et al.* 2006). However, weeds provide food, shelter and reproductive sites for various organisms *i.e.* plant pathogens (Gonzalez *et al.* 1991, Marley 1995, Ramappa *et al.* 1998, Singh *et al.* 2010, Rathore *et al.* 2012, Webb *et al.* 2012), insect pests (Bernays and Chapman 1994, Marshall *et al.* 2003, Penagos *et al.* 2003, Capinera 2005, Singh *et al.* 2010, Duary *et al.* 2014, Singh and Singh 2016), mites (Gupta 1985, Kreiter and Tixier 2002, Steinkraus *et al.* 2003, Nair *et al.* 2005, Mamun and Ahmed 2011, Ito *et al.* 2012, Vasquez *et al.* 2015, Chandrasena *et al.* 2016, Rathee and Dalal 2018, Mishra *et al.* 2019), nematodes (Bélair and Benoit 1996, Davidson and Townshend 1967, Tedford and Fortnum 1988, Venkatesh *et al.* 2000, Davis and Webster, 2005, Thomas *et al.* 2005, Anwar *et al.* 2008, Singh *et al.* 2010), rodents (Fulk *et al.* 1981, Parshad *et al.* 1991, Jain *et al.* 1993, Malhi and Parshad 1994, Islam 2001, Htwe *et al.* 2019) *etc.* Thus, they serve in both the ways as alternate and alternative (collateral) hosts (reservoirs) for these organisms that adversely affect crop production system (Ampong–Nyarko and De Datta 1991, Rao 2000, Bhowmick 2002, Norris and Kogan 2005, Thomas *et al.* 2005, Bhowmick *et al.* 2012, 2016, Beasley 2013, Das, 2015, Ntidi 2018, Saeed *et al.* 2015, Mishra 2018, Ramachandra Prasad and Sanjay 2016, Rao *et al.* 2018). Consequently, weed hosts have an economic impact on crop production (Bendixen 1988). In recent years, the increasing trends of certain pernicious weeds in non–crop areas jeopardize the natural environment (Ghosh *et al.* 2002, Bhowmick *et al.* 2005, Yaduraju *et al.* 2015). There is no better example to this in India than the way *Parthenium hysterophorus* has become a serious menace in vacant and uncultivated areas including roadsides, railroads, industrial sites, and airfields (Sushilkumar 2009, 2014, Duary *et al.* 2005, Sushilkumar and Varshney 2010, Mondal and Duary 2014, Sushilkumar and Duary 2015). Out of several noxious characteristics, there lies the importance of recognizing weeds both as alternate and alternative hosts. It is vital to keep them managed in the margins of crop fields as well as non–crop areas at the possible or feasible extent so as to prevent continued infection and infestation of crop plants from different pest organisms.

Importance of weeds as alternate and alternative hosts

The terms 'alternate' and 'alternative' have often been used casually and interchangeably although they have literally different uses and meanings. The term 'alternate' refers to "one that substitutes for or alternates with another", "happening, occurring or succeeding by turns" or "serving in place of another", and is used as a synonym of "substitute" or "replacement". The term 'alternative' is used for referring to "one of two or more available possibilities or options" or "an option or a choice that stands instead of the other".

An alternate host is a host that comes from a different family compared to the family of the main (or primary) host and helps a crop pest to complete its life cycle. Moreover, it supports the crop pest for survival under unfavourable conditions. Many plant pathogens (fungi, bacteria and viruses) have several alternate hosts on which they pass at least a part of their life cycle. The ubiquitous nature of the invasive weed species ascertains the continuity of infection chains for a diverse group of pathogens between weeds and crop hosts (White 1970). It will be clear from a typical example of heteroecious rust pathogen (*Puccinia graminis* var. *tritici*) which causes black or stem rust in wheat (*Triticum* spp. Poaceae family) and survives on barberry (*Barberis vulgaris*, Berberidaceae family). Two independent hosts, primary and alternate, are indispensable for completion of its (pathogen) life cycle. Wheat crop is its primary host plant where uredia, uredospores, telia and teliospores are produced. Barberry, the only other species (other than wheat) affected by the pathogen, is its alternate host plant, which is indispensable for the life cycle and survival of the pathogen. Reproductive structures like pycnia, pycniospores, aecia and aeciospores are established on the alternate hosts (barberry). Such transfer of inoculum is obligatory and essential for the survival and perpetuation of the pathogen.

Diverse weed flora plays a key role on the concept that more the diversity, more the stability holds true. Because, diverse system may provide alternate hosts as source of food, over wintering sites, refuges *etc*. However, weed flora varies from season to season, year to year and/or location to location in different agro–climatic regions. In a competitive environment, weeds potentially have higher proficiency to survive, compete, and reproduce (Schroeder *et al.* 2005). Under adverse growing conditions, hardy (tolerant) species of weeds are likely to predominate.

An alternative host can also be a collateral host that belongs to the same family of the primary host and helps a crop pest to survive when the main host is not available (McMaugh 2005, Nutter 2007, Sileshi *et al.* 2008). The epidemiological significance of alternative hosts of phytopathogens is that they can serve as an over–seasoning bridge from one crop growing season to a susceptible crop in next season, providing a localized source of initial inoculum for the next susceptible crop (Bendixen 1988, Clementine *et al.* 2005, Nutter 2007). They further serve as a source of initial inoculum by producing dispersal units (spores, sclerotia, viruliferous insects, *etc.*), thus aiding in the spread of infection when they come in contact with another susceptible crop or weed host species under favourable environmental conditions (Nutter 2007). Thus, collateral hosts aid to bridge the gap between two crop seasons. For example, the phytopathogenic fungi causing blast disease [*Pyricularia grisea* (Teleomorph: *Magnaporthe grisea*)] in rice (Poaceae) infects the grasses like *Brachiaria mutica*, *Digitaria marginata*, *Dinebra retroflexa*, *Echinochloa crus–galli*, *Leersia hexandra*, *Panicum repens etc.* belonging to same family, and survives on these grassy weeds in absence of rice crop. During the subsequent rice season, the conidia (inocula) gets liberated from the weed hosts, grown on bunds or adjacent areas and disseminated by wind or other media to infect the fresh crop through initiation of the disease in rice nursery and/or main field. The alternative hosts susceptible to the phytopathogens of crop plants facilitate continuous growth and multiplication/reproduction of these pathogens during non–cropping season.

Highly preferred alternative hosts can be sometimes used as trap crops to attract herbivores away from less preferred crops. Identifying the entire host range is particularly important for early detection surveys of exotic pests as well as delimiting surveys investigating the extent of a pest incursion (McMaugh 2005).Similarities of alternate and collateral hosts are that both are the secondary (not the main, primary or principal) hosts on which a parasite, insect, pathogen or other pests can survive. Both the types of weed hosts are important in maintaining and building up the initial inoculum for the next crop. They determine the course and intensity of an epidemic. But the role of alternate hosts is not as significant as that of collateral (alternative) hosts. When a pathogen has a very wide host range (*Sclerotium rolfsii, Alternaria alternata, Rhizoctonia solani, Fusarium* spp. *etc.*) and is tolerant to a wide range of environmental conditions, the alternate hosts become essential source of survival for the pathogen, aiding in completion of the life cycle of heteroecious rust pathogens. In temperate regions, barberry bush as an alternate host plant of black/stem rust pathogen for wheat is, therefore, naturally found established along with the cultivated host, wheat. In such areas, the wild host barberry is crucial for survival of the fungus. This helps in the completion of a diverse infection chain of the rust fungus. Thus, the terms ‘alternate’ (replacement for the original) and ‘alternative’ (another option to the original) hosts should rightly be used.

Weeds appear on field bunds/margins, waste lands, irrigation and drainage channels, fence lines, pastures, shelterbelts, riparian areas, *etc.* during off–season and/or in–season of crop plants. Their presence under these sites or situations is highly objectionable as they harbour a number of pest organisms which may either spread to neighbouring fields to easily infest the crop plants during cropping season (Bhowmick 2002) or maintain pest populations to cause infection to the succeeding crops (Anwar *et al.* 2009, Ntidi 2018). Thus, alternate and alternative hosts, which are often weeds, provide a means for crop pests (pathogens, insects, mites, nematodes, rodents) to survive and multiply. Complete eradication of these weed hosts (alternate and alternative) that serve as potential sources of inoculum in field sites, is an important principle of disease and insects management as well (Nutter 2007). Because, removal and destruction of these hosts along with volunteer plants and crop residues (field sanitation) help either in the life cycle completion of pest organisms under adverse condition (Schroeder *et al.* 2005) or reducing their carry–over from one season to another (Levins and Miranda 2007, Singh *et al.* 2009). For example, white flies in cotton crop can be controlled by eradicating their alternate weed hosts like common Indian shrub (*Abutilon indicum*), suryavarti (*Chrozophora rottleri*), black nightshade (*Solanum nigrum*) and white wild musk mallow (*Hibiscus ficulneus*) from the fields and neighbouring areas to maintain field sanitation and avoid pest infestation. Weeds like heartleaf hempvine (*Mikania cordata*), yellow flowered blackjack (*Bidens biternata*), red tassel flower (*Emilia sonchifolia*), Chinese knotweed (*Polygonum chinense*) and common lantana (*Lantana camara*) offer excellent hiding places and serve as alternate hosts for the tea mosquito bug (*Helopeltis theivora*) in tea. Growth of these weeds and wild host plants in and around tea fields can be controlled to reduce the growth of tea mosquito bug population (TBI 2019).

However, the presence of low levels of pest populations *vis–a–vis* alternate and alternative hosts may sometimes be necessary to keep the natural enemies available in a particular area or location (Levins and Miranda 2007, Naveed *et al.* 2007, Saeed *et al.* 2015). Weed hosts like coat buttons (*Tridax procumbens*), goat weed (*Ageratum* sp.,) joyweed (*Alternanthera* sp.) *etc.* act as nectar source for natural enemies when primary hosts like wheat are not available (GoI 2014). Thus, alternate and alternative host plants in the vicinity of crop fields provide both advantages and disadvantages across agro–ecosystems.

Weed host–pathogen relationship

A disease generally develops from an interaction of three components; the host, the pathogen, and the environment. Plant diseases are caused by plant pathogens including bacteria, mollicutes, viruses, viroids, fungi, *etc.* These plant pathogens form an intimate relationship with their host plants in gaining access to host resources through a process called pathogenesis which involves infection, colonization, reproduction and spread. As a result, they prevent plants from performing to their maximum potential and can have devastating ecological, economic and social consequences globally (Velásquez *et al.* 2018). A plant disease may be endemic or sporadic, and may assume an epidemic or epiphytotic form under special circumstances which are governed by nature of host, nature of pathogen, and environment. Abundance of susceptible hosts in a particular area is one of the major causes for the spread of infection, leading to epidemics under favourable environmental conditions. Plant pathogens are often hardy and have evolved to survive for a prolonged period under unfavourable weather condition. They are capable of continual evolution through mutation leading to novel and dangerous strains enabling them to shift or expand host or emerge as a more virulent and resistant to abiotic stresses and environmental changes. Plant diseases are persistent threat to food and cash crops critical for global food security contributing to widespread poverty, hunger and malnutrition (Records *et al.* 2020). For example, potato late blight in Ireland in 1846 was caused by *Phytophthora infestans*, and it had an enormous socio–economic impact on the country with millions of people dead or emigrated (Nelson and Ristaino 2011). The phytopathogenic fungus *Cochliobolus miyabeanus* (formerly known as *Helminthosporium oryzae*) was largely responsible for the Bengal famine in 1943 (Padmanabhan 1973). It was reported to cause about 50–90% yield losses in rice production in the region.

In tropical regions where year–round cropping of plant species such as rice and root crops (cassava, sweet potato, taro and yams) are a common practice, the continuous presence of host plants enables parasites to survive by continuously infecting new hosts. In temperate regions, it is not uncommon for self–sown, volunteer crop plants to grow along roadsides, fence lines and irrigation channels and as weeds in paddocks during periods when the main crop is absent. These self–sown plants enable pathogens to survive during intercrop periods and serve as sources of inoculum when the main crop is grown. Black rot bacterium of Brassicaceae plants (*Xanthomonas campestris* pv. *campestris*) is known to survive on related weed species such a wild radish (Brown 1997).

Phytopathogens are not always host–specific. Most of them have the ability to infect a wide range of plants over same or different family (Linde *et al.* 2016). Weeds associated with crops often come from same family as the crop, thus sharing several botanical similarities possibly making them susceptible to the same pathogen(s). Weeds are likely to be more genetically diverse than their cultivated counterparts, and thus, become less susceptible to diseases themselves. But many weed species in addition to being pests themselves, have been reported as reservoirs or obligate hosts of many plant pathogens associated with crops (Wisler and Norris 2005, Singh *et al.* 2010). Unlike crops, weeds being hardy can survive throughout the year, and hence, often act as over–summering or overwintering hosts for a range of plant pathogens and their carrier arthropods (Webb *et al.* 2012). Thus, weeds can act as source to serve initiation of epidemics in crops and can elevate the existing problems of disease management. Presence of phytopathogens on weed hosts may not be always obvious, and it is possible that the symptoms normally associated with the disease may remain asymptomatic, making disease management in crop more challenging (Shrestha *et al.* 2016). For example, common dicotyledonous weeds in soybean fields can serve as asymptomatic hosts of the blight pathogen (*Fusarium oxysporum*), which retains pathogenicity for soybean (Helbig and Carroll 1984). Linde *et al.* (2016) suggested that pathogen population from a genetically diverse host could be more virulent than those from a monoculture crop that weedy or wild relative could play a major role in pathogen evolution. Hence, management of diseases on crops must include the management of weedy hosts or wild relatives, which might harbour disproportionate supplies of virulent pathogen strains (Linde *et al.* 2016). Further, weeds are prolific seed producers. Seeds may act as passive carriers of pathogens across vast distances and may even be responsible for the emergence of diseases in new areas (Darrasse *et al.* 2010).

Phytopathogenic bacteria and weed association: A diverse range of bacteria are associated with many wild hosts and weeds, and their presence increases the risk of infecting many cultivated crops (Kyrkou *et al.* 2018). Banana wilt (*Xanthomonas campestris* pv. *musacearum*) is known to severely affect the production of banana (*Musa* spp.). Studies showed that few weeds and crops associated with banana can significantly influence the *Xanthomonas* wilt dynamics either through spread and survival of the pathogen or supporting pathogen survival and perpetuation of the disease (Ocimati *et al.* 2018). *Xylella fastidiosa* causes pierce's disease (PD) of grapevines. Bermuda grass has been reported as a favoured host of the main PD vectors (Hopkins and Purcell 2002). Important vascular wilt pathogen in the tropics is *Pseudomonas solanacearum* which causes bacterial wilt in a wide range of crops and has been isolated from several weed species belonging to Solanaceae and Asteraceae families, being relatively susceptible and often displaying visible symptoms.

Phytopathogenic fungi and weed association: Several grasses are collateral hosts of *Sclerospora sacchari*, *S. philippinensis* (downy mildews), *Pyricularia oryzae* (rice blast) and *Ustilago scitaminea* (sugarcane smut), which can produce abundant inoculum, leading to epidemics. Such outbreak of heteroecious blister rust of pine (*Cronartium ribicola*) in Europe and the U.S.A took place due to import or introduction of eastern white pine (*Pinus strobus*) from the USA. de Oliveira *et al.* (2018) evaluated health of some weed seeds and the pathogenicity of fungi associated with economically important crop plants. They observed a positive correlation between their ability to carry several species of phytopathogenic fungi with potential to cause disease on cultivated plants. Evans (1971) reported a fungus *Verticillium dahliae* that was probably introduced along with weed seed, and then increased on natural dicotyledonous weeds, from which it spread to the introduced crops such as cotton. The fungus was isolated from stems and roots of twenty–six weed species of the region out of which several of weeds were not reported as hosts of the pathogen from other weed infested areas. Weedy barley grass with high genetic diversity and population size is a well–known carrier of phytopathogenic fungus, *Rhynchosporium commune* which causes leaf blotch on cultivated barley (King *et al.* 2013). Soybean rust caused by *Phakopsora pachyrhizi* is an exceptionally aggressive global concern for soybean worldwide causing yield losses up to 80% in susceptible cultivars (Chander *et al.* 2019). The pathogen is known to overwinter on kudzu, a noxious weed, in the southern United States, thus keeping it alive under unfavourable conditions (Ward *et al.*, 2012). A part of life cycle of wheat rust is completed on wild ber (*Zizyphus rotundifolia*) when the wheat crop is not in the field (Bhowmick *et al.* 2016). Southern cutgrass, locally known as nylon grass (*Leersia hexandra*), is a potential source of *Bipolaris oryzae* causing brown spot disease in rice. *Phytophthora capsici* is known to successfully survive on weeds, making it a difficult–to–control pathogen that can utilize weed as a host in absence of a host crop, making it difficult to utilize cultural control measures for this serious vegetable pathogen. Many rust pathogens also overwinter on reservoir hosts. Pathogens of various diseases rest on *Trianthema* spp. of ice plant family (Aizoaceae). The spores of *Alternaria* blight of Indian mustard survive on scarlet pimpernel (*Anagallis arvensis*) of Primulaceae family, field bindweed (*Convolvulus arvensis*) of Convolvulaceae and lambsquarters (*Chenopodium album*) of Chenopodiaceae (Rathore *et al.* 2012).

Phytopathogenic viruses and weed association: Several authors (Aguiar *et al.* 2018, Mouhanna *et al.* 2008, Papayiannis *et al.* 2011, Wisler and Norris 2005) reported weeds as alternate hosts and sources of inoculum for a wide range of plant pathogenic viruses of crops. The plant viruses that can not be directly transmitted from an infected plant to another plant of the same species must alternate between two completely unrelated biological species. They can only be transmitted through a vector, often an insect. The phytopathogenic viruses live either in collateral hosts or arthropod vectors in absence of suitable crop hosts. These viruses are secondarily spread by insect vectors feeding generally on both cultivated plant and associated weeds. Thus, weeds also act as alternate or intermediate hosts of vectors of viral diseases (Shrestha *et al.* 2016). Wisler and Norris (2005) observed that weeds inspite of being reservoirs of plant viruses often do not show disease symptoms, making management efforts even more challenging. Many weeds serve as alternative hosts for the beet necrotic yellow vein virus (BNYVV), beet soil–borne virus (BSBV), and their common vector a plasmodiophorid, *Polymyxa betae* (Mouhanna *et al.* 2008). The host–pathogen relationships were confirmed using enzyme–linked immunosorbent assay (ELISA), internal transcribed spacer (ITS) sequence and northern blot analysis, and also positive spread of the viruses by their vector from infected weed roots to sugar beet crops. Squash vein yellowing virus (SqVYV), disseminated by the whitefly Middle East–Asia Minor 1 (MEAM1) [formerly *Bemisia tabaci* biotype B] causes devastating disease on Florida watermelon, *Citrullus lanatus* (Webb *et al.* 2012). In few transmission experiments (Adkins *et al.* 2008, Shrestha *et al.* 2016), common cucurbit weeds including smell melon (*Cucumis melo* var. *dudaim*) and wild bitter melon (*Momordica charantia*) were distinguished as natural hosts of the virus. Shrestha *et al.* (2016) further observed egg–laying preference of the whitefly on uninfected plants and on virus infected ones raising the possibilities of rapid spread of the virus in the agro–ecosystem.

Different wild grasses, crops and grassy weeds are known to host wheat streak mosaic virus (WSMV) and its vector, the wheat curl mite (Ito *et al.* 2012). In India, the chilli mosaic has been found to be due to a number of different viruses, each of which may have different host range (Dasgupta 1988), indicating practical difficulty in implementing such measures. Wild and weedy rice are the important hosts of Rice Yellow Mottle Virus in Africa (Johnson *et al.* 1999, Rodenburg and Johnson 2009). Though many examples can be cited, all those discussed so far indicates how weeds aid in propagating plant pathogens, which they render more destructive and more difficult–to–control. An understanding of the mechanisms involved in the different steps of plant disease epidemiology is essential to develop new control strategies (Darrasse *et al.* 2010). Cropping techniques are crucial in diminishing the plant disease risks. There is a need to undertake integrated management of weeds and crop pathogens in order to get rid of the source. Papayiannis *et al.* (2011) suggested new weed control strategies to be introduced focusing on the control of alternate pathogen/ pest hosts during the growing and non–growing seasons of crops.

Weeds often as a pest itself, vector or reservoir of a pathogen, can significantly influence disease incidence (Wisler and Norris 2005). The role of alternate hosts is especially more important where the pathogen has a wide host range and rotation is the main cultural method of disease management. Even crop rotation with non–host plants is the first general agronomic rule to avoid soil–borne diseases, and certain recommended rotations have been designed as decision support tools (Rouxel *et al.* 1991, Ratnadass *et al.* 2012). Alternative weed hosts among the weed flora then need to be removed if rotation with a non–host (immune) crop is to be fully effective as a control measure. Grasses such as mouse barley grass (*Hordeum leporinum*) and common wheat grass (*Agropyron scabrum*) can serve as alternative hosts to various special forms of the rust fungus *Puccinia graminis*. A similar infection chain occurs with other pathogens of wheat. Many plant pathogens survive intercrop periods by infecting alternative hosts. For example, the black rot bacterium (*Xanthomonas campestris* pv. *campestris*) of crucifers can survive on related weed species such as horse radish (Vicente and Holub 2013). Eradication of over–wintering hosts breaks the chain in the completion of the life cycle of the pathogen (Bhowmick *et al.* 2012). For example, barberry eradication in temperate countries helps to control the black or stem rust of wheat. There may have certain scope in reducing the incidence of viral diseases by eradicating their weed (reservoir) hosts and symptom–less carriers. Even weeds in non–crop areas assume profuse growth owing to their prolific seed producing ability, easy sprouting and/or regenerating ability through underground rhizomes, tubers or runners with roots at each node. Some others may have definite perennating mechanisms. All these call for a thorough study and better understanding about the host–pathogen relationship before taking any attempts for the management of weeds in both cropped and non–crop areas.

Weed host–insect pest relationship

The relationship between insects and host plants varies largely from very specialized to generalized feeding behaviours (Capinera 2005). Phytophagous insect species locate their host plants from mixed vegetation when they face the dangers of annihilation by various abiotic and biotic agents. Hence, the damage caused by insects is quite limited in natural ecosystem. In contrast, natural regulating factors play only a limited role in agro–ecosystem, and insect pest outbreaks are quite frequent (Sharma *et al.* 2017). However, there is a continuous spectrum between insect species that feed only on one plant species and others that feed on a very wide range of plants under a number of families. Weeds in particular harbour many insect pests during crop season as well as off–season. Many insects feed exclusively, or nearly so, on weeds. Depending on their host–plant ranges and feeding behaviour, the insects are categorized as: monophagous, oligophagous and polyphagous although there are certain alternative terms of occasional use as stenophagous insects with a restricted host–plant range and euryphagous insects with a broad host–plant range.

Monophagous insects: Monophagous insects generally feed on only one plant species and also include the species feeding on plants within a single genus. Some examples are spotted alfalfa aphid (*Therioaphis maculata*) feeding only on alfalfa (*Medicago sativa*), and brown planthopper (*Nilaparvata lugens*) feeding on rice throughout south and South-east Asia. Klamath weed beetle (*Chrysolina quadrigemina*) is another example which is a monophagous insect herbivore used for the selective biological control of Klamath weed (*Hypericum perforatum*) in California. Only hosts of the European spruce sawfly (*Diprion hercyniae*) are spruce trees in north–temperate regions of Europe and America (Bernays and Chapman, 1994). Such insects possibly diapause during non–availability of their host plant.

Oligophagous insects: Oligophagous insects feed on a number of plants, usually in different genera within a plant family (Bernays and Chapman 1994, Capinera 2005). Sometimes an insect may be associated with a small number of plant species from different families. For example, Colorado potato beetle (*Leptinotarsa decemlineata*) feeds mostly on about 14 plants in the genus *Solanum* under the Solanaceae family. The reddish potato beetle (*Leptinotarsa rubiginosa*) is more restricted in feeding on solanaceous plants, including only on two species of *Physalis* and two of *Solanum*. However, many grasshoppers like migratory locust (*Locusta migratoria*) feed on different grasses with common features (Bernays and Chapman 1994). So weeds and wild plants from same genera or family act as alternative hosts for these insects in absence of the preferred host plant.

Polyphagous insects: Polyphagous insects feed on a relatively large number of plants from different families (Bernays and Chapman 1994). Even they often have a well–defined preferential hierarchy, feeding on alternative host only when preferred hosts are unavailable (Capinera 2005). A number of aphid species, including green peach aphid (*Myzus persicae*) and potato aphid (*M. euphorbiae*), are known to colonize potato plants. These aphids are typically polyphagous as they feed on hundreds of host plants in multiple plant families, including both cultivated and alternate weed hosts (Singh and Singh 2016). Cotton leaf hopper (*Amrasca devastans*) is the most devastating major insect pest of cotton and a well–known polyphagous herbivore on wide range of plant species, that remains active throughout the year due to uninterrupted availability of alternative host plants (Saeed *et al*. 2015). Common vetch (*Vicia sativa*) in chickpea provides shelter to *Helicoverpa armigera*, a major pest of chickpea (Chauhan *et al*. 1991). The weed *Amaranthus* gives shelter to many caterpillars (Rathore *et al.* 2012) which are highly polyphagous in nature. Tropical armyworm (*Spodoptera litura*) is a serious polyphagous pest as it prefers to consume the leaves of weed hosts like *Alternanthera philoxeroides*, *Euphorbia hirta*, *Eichhornia crassipes*, *Trianthema portulacastrum*, *P. hysterophorus*, *Cichorium intybus*, *Rumex obtusifolius* and *Ipomoea fistulosa* (*Ipomoea carnea*). Of these, weed species, *T. portulacastrum* has been found to be the most suitable food plant (Sushilkumar and Ray 2007). Grassy weeds like *Brachiaria ramosa*, *Cynodon dactylon*, *Echinochloa colona*, *Digitaria sanguinalis* and *Leptochloa chinensis* of Poaceae family provide alternate shelter to rice mealybugs for their survival and multiplication during off–season (Mishra *et al.* 2019).

In agricultural systems, weeds directly serve as important food sources or provide other ecosystem resources for herbivorous arthropods, and indirectly serve carnivorous (beneficial) arthropods by providing food and shelter to their prey. Weeds can serve as potential alternative hosts for insect pests and beneficial arthropods when their preferred crop host is absent (Capinera 2005, Norris and Kogan 2005). For example, black–jack (*Bidens pilosa*) is an alternative host to common bean insect pests during the off–season (Laizer *et al*. 2019). Wild and weedy rice are the only alternative hosts of African rice gall midge in rice (Johnson *et al.* 1999, Rodenburg and Johnson 2009). Weeds may also impact the propensity of dispersing insects to locate crop plants (Capinera 2005). Like many other natural enemies, predaceous ground beetles do not disperse far from their overwintering sites due to an easy access to permanent habitat near or within the field that gives them a jump–start on early pest populations. Weeds that are closely related to crops are explicitly predominant in harbouring insects that attack those crops. Thus, there are some weeds which may distract beneficial insects such as pollinators during the flowering stage (Laizer *et al*. 2019) and certain others which attract. Alternate hosts have also been reported to serve as trap crops. Insects may use these plants as alternate habitat until an appropriate crop occurs in a nearby field. Napier grass (*Pennisetum purpureum*) is an example that can defend itself against the pest onslaught. Once attacked by a borer larva, it secretes sticky substance that physically traps the pest and effectively limits its damage. When insects have a broad host range (oligophagous to highly polyphagous), they may move from weeds to crop plants and cause crop damage. Then, it may be advisable to keep weed populations at check, not only within the crop field, but also in the adjacent areas like irrigation channels, field bunds, fence rows, *etc.* as a common source in view of either reducing the level of crop damage or maintaining natural enemies of crop pests. Thus, taxonomic similarity between weeds and crop plants are essential in forecasting possible damage to crops by weed–feeding insects (Capinera 2005). Farmers should also be careful in assessing the potential threat from insect pests before weeding out or removing any plants.

Weeds not only harbour insect pests that cause insect damage to crop plants, they sometimes also play a key role by harbouring insect vectors responsible for causing crop diseases and thereby, subjecting the crop plants to serious damage with conjoint or multiple attack of crop enemies. The American palm cixiid (*Myndus crudus*) is the most abundant potential vector on coconut palms. Populations of leaf hoppers (*Cicadellidae*) and plant hoppers (*Flugoroidea*) also become much higher in areas of high lethal yellowing incidence than disease–free areas in West Africa. Guinea grass (*Panicum maximum*), a perennial tufted grass, is the most abundant host of these vector insects responsible for causing lethal yellowing disease in coconut palms (Eziashi *et al.* 2013).

In India, carrot weed or congress grass (*Parthenium hysterophorus*) has already been reported as an alternate host of striped mealybug (*Ferrisia virgata*) in the states of Punjab and Haryana and cerembycid borer (*Nupserha* sp.) at Jabalpur and Vindhyanagar in Madhya Pradesh (Sushilkumar 2009). Many other insects like aphids, cotton bollworm (*H. armigera*), bagworm (*Clania crameri*), hairy caterpillar (*Dicrasia oblique*), mealybugs and grasshoppers have also been reported feeding on *P. hysterophorus* (Sushilkumar 2009). Besides, *P. hysterophorus* has been reported as the most preferred host for both the grubs and adults of host–specific leaf–feeding Mexican beetle, *Zygogramma bicolorata* (Sushilkumar and Bhan 1998, Sushilkumar *et al.* 1995 and 1997) while the wasteland weed (*Xanthium strumarium*) acts as an alternate host of *Z. bicolorata* (Sushilkumar and Bhan 1996). Considering the huge importance of *P. hysterophorus* for the survival and multiplication of *Z. bicolorata*, the Mexican beetle is often referred to as the parthenium beetle. As a weed of international importance, *P. hysterophorus* is, thus, an important example to cite and elevate the status of weeds from their indirect role as alternate and alternative hosts to the direct role as main host.

Weed host–mite relationship

Among phytophagous mites belonging to the families of Tetranychidae, Tuckerellidae, Tenuipalpidae, Nalepellidae, Eriophyidae, Rhyncaphytoptidae and Tarsonemidae, eriophyoid mites are host–specific (Gupta 1985, Vásquez *et al.* 2015), whereas those belonging to Tetranychidae, Tenuipalpidae and Tarsonemidae are not host–specific (Gupta 1985). Some polyphagous mites may occur on a wide variety of plants (Gupta 1985).

Mites under the families of Eriophyiidae and Tetranychidae have emerged as major pests of bean, brinjal, cotton, cucurbits, okra, apple, ber, citrus and mango in Northern India (Rathee and Dalal 2018). Eriophyoid mites (gall mites) are characterized by an intimate relationship with their host plants and restricted range of plants upon which they reproduce (Vásquez *et al.* 2015). Among the tetranychids, some are quite specific as to the type of host (Gupta 1985). *Schizotetranychus* species mostly occur on monocotyledons with the exception of *S. baltazari* which is an injurious pest of citrus (Gupta 1985). *Platytetranychus* species generally occurs on conifers, whereas *Oligonychus*, *Eotetranychus* and *Tetranychus* occur on a diverse group of plants (Gupta 1985). Even mites may have a certain level of preference for a particular type of microhabitat within a particular host plant (Gupta 1985). For example, mango spider mite (*Oligonychus mangiferus*) occurs only on the upper leaf surface of grape vine while lower surface of same leaf may be infested by *Eotetranychus truncatus* (Gupta 1985). Sugarcane and sorghum are the alternate hosts of *Oligonychus indicus* while *Dicanthium annulatum* is the primary host as the mite occurs on that host even during the rainy season (Khan and Murthy 1956). Alternate hosts of date palm mite (*Oligonychus afrasiaticus*) belong only to the families of Arecaceae and Poaceae, and include *Hyphaene thebaica*, *Phoenix canariensis* (Arecaceae), *Cenchrus ciliaris*, *Dichanthium annulatum*, *Hilaria* sp., *Hyparrhenia hirta*, *Pennisetum ciliarae*, *P. divisum*, *Pennisetum* sp. and *Aeluropus littoralis* (Poaceae) in Saudi Arabia (Alatawi 2020). Two phytophagous mites, *Eutetranychus orientalis* and *E. palmatus* (Tetranychidae), and the predatory mite, *Spinibdella cronini* (Bdellidae) remain associated with the date palm mite on date fruits, whereas the phytoseiid mite, *Cydnoseius negevi* remains on the grasses growing under the trees (Alatawi 2020).

Under field conditions, air–borne adults of tomato russet mite (*Aculops lycopersici*) may begin to infest tomatoes from perennial alternate hosts shortly after transplanting. When the primary host dies, some of the mites get dispersed by the wind to nearby alternative hosts, where they can form overwintering aggregations (FAO 2017). Removal of alternate hosts like shaggy button weed (*Borreria hispida*), goat weed (*Scoparia dulcis*), chocolate weed (*Melochia corchorifolia*) and Fussiala (*Fussiala suffruticosa*) in and around plantations gives a good control of red spider mite (*Oligonychus coffeae*) in tea (TBI 2019).

Spider mites always cause sporadic problems in Midsouth cotton. Most important species of these mites on cotton are two spotted spider mite (*Tetranychus urticae*), desert spider mite (*T. desertorum*), strawberry spider mite (*T. turkestani*) and carmine spider mite (*T. cinnabarinus*). Spider mite outbreaks in cotton are related to the population levels on other host plants including weeds where they overwinter and develop during May–June. Infestations often begin in cotton adjacent to field borders or uncultivated areas. Thereafter, spider mites move from these alternate hosts to cotton by crawling over the soil or from plant to plant, carried by wind, human or equipment, or by animal movements. Palmer amaranth (*Amaranthus palmeri*) and pitted morning–glory (*Ipomoea lacunosa*) are reported as the major weeds in the field borders which serve as the sources of spider mite infestations in cotton fields in Arkansas (Steinkraus *et al.* 2003).

Coconut eriopyhid mite (*Aceria guerreronis*) is an invasive pest of coconut since its host range is very narrow, being coconut (*Cocos nucifera*) and palmyra palm (*Borassus flabellifer*) in India (Nair *et al.* 2005). The eriophyid mite (*Aceria solstitialis*) remains alive on yellow star thistle (*Centaurea solstitialis*), *Centaurea cyanus*, *Centaurea diffusa*, *Carthamus tinctorius*, and *Cynara scolymus* in Turkey (Vásquez *et al.* 2015).

Among the predatory plant mites (Cheyletidae, Stigmaeidae, Tydeidae, Bdellidae, Cunaxidae, Erythraeidae, Ameroseiidae, Ascidae and Phytoseiidae), no specificity has been observed though one species may occur only on a particular plant while another species may occur on a wide range of plants (Gupta 1985). Kreiter and Tixier (2002) explained the role of host plants in providing substrates for colonization, liquid and pollen foods, and pilosity and domatia either for pollen trapping or protection, which are important for phytoseiid mites (potential predators of the citrus rust mite and the broad mite in Guadeloupean citrus orchards). These mites live mostly on leaf undersurfaces having raised veins, dense hairs, tunnelled margins and cave–like structures in the vein axils (domatia).

Although Gupta (1985) made an enormous task in preparing a detailed list of plant–mite catalogue, still there is a need to have sufficient knowledge about true host ranges and mechanisms of host specificity in understanding mite–host interactions, potential mite–host coevolution, and species diversity (Skoracka *et al.* 2010).

Weed host–nematode relationship

Weeds have been recognized for their ability to serve as potential alternate hosts (Beasley 2013) as well as alternative hosts (Thomas *et al.* 2005) of plant–parasitic nematodes. Weed species enable plant–parasitic nematodes to survive in absence as well as presence of a crop, and thereby providing a nematode inoculum source for the subsequent crop season (Rich *et al.* 2008). The importance of a particular nematode as the damaging pest depends on its host range (Anwar *et al.* 2009, Dixit 2019), whereas the major role of weeds is to support the nematodes in their (nematodes) reproduction and survival under field condition. Such a relationship between weeds and nematodes may be a normal adaptation due to limited mobility of both the groups of organisms and obligate parasitism of phytophagous nematodes (Thomas *et al.* 2005). Most of the genera excepting the cyst nematodes (*Heterodera* spp. and *Globodera* spp.) do not survive for a long–term in absence of suitable host plants (Schmitt and Sipes 2000, Thomas *et al.* 2005). The role of weeds as alternate and alternative hosts depends largely on the feeding behaviour of nematode as determined by the level of host specialization needed for the parasite to successfully feed (Thomas *et al.* 2005, Anwar *et al.* 2009, Mitiku 2018). There are several other factors like type of plant and tissues invaded, soil types, nematode density, effective survival and dissemination mechanisms adopted by the nematode, *etc.* (Anwar *et al.* 2009, Dixit 2019). Based on the requirement of host specialization, different taxa of plant–parasitic nematodes are, however, broadly grouped into three feeding categories: sedentary endoparasites, migratory endoparasites, and ectoparasites (Ferris and Ferris 1998, Sijmons *et al.* 1994). Tiwari *et al.* (1994) recorded several plant parasitic nematode species with weed flora of Kymore Plateau and Satpula hills of Madhya Pradesh. Tiwari and Singh also (1995) found spiral nematode *Helicotylenchus* spp. as root parasite in 30 weed spices in Madhya Pradesh. *Helicotylenchus elegans* was recorded as a predominant species on more than 19 weeds whereas *T. dihystera* was observed common species in the state. Tiwari and Sushilkumar (1996) recorded root-rot nematode *Hirschmanniella oryzae* on the weed species *Cyperus rotundus* (pre-dominant), *C. difformis*, *C. iria* and *C. platystlis* in addition to root-knot nematode *Meloidogyne incognita* on *C. iria* from Madhya Pradesh and *C. compressus* from Chhattisgarh.

Sedentary endoparasites: Sedentary endoparasites require the highest level of host specialization at the time of feeding. Juveniles (pre–reproductive) females do not remain within the soil, and they rather enter into the plant roots and induce host transformations through some secretions, resulting in the formation of certain specialized feeding sites (giant cells, syncytia, nurse cells) which serve as the permanent sources of nutrients for growth and reproduction of nematode parasites and enable them to feed in a particular location throughout their life cycle for a long period of time (Thomas *et al.* 2005). Among the plant–parasitic nematodes, root–knot nematodes

(*Meloidogyne* spp.), cyst nematodes (*Heterodera* spp. and *Globodera* spp.), reniform nematode (*Rotylenchulus reniformis*), false root–knot nematodes (*Nacobbus* spp.) and citrus nematode (*Tylenchulus semipenetrans*) are the most important crop pests (Thomas *et al.* 2005, Anwar *et al.* 2009, Ntidi 2018). Their host ranges are more restricted than for other feeding behaviours (Thomas *et al.* 2005). Crops that are not affected by nematode secretions may be effective for crop rotation to suppress the nematode population. Simultaneously, weeds can serve as reservoirs for these nematodes in susceptible crops with increased proportions of early–season crop infection and more population of nematodes to affect subsequent crops (Schroeder *et al.* 1993, 1994, Bird and Hogger 1973, Davis and Webster 2005, Anwar *et al.* 2009, Singh *et al.* 2010). Weeds grown in the irrigation ditches or channels can help a lot in the maintenance and dissemination of false root–knot nematode (*Nacobbus aberrans*) into the non–infested fields through irrigation water (Inserra *et al.* 1985).

Most common species of root–knot nematodes in the tropics are *M. incognita* (southern root–knot) and *M. javanica* (Javanese root–knot) whereas other species occur less frequently (Schmitt and Sipes, 2000). These nematodes feed and mature inside the roots of plants. From the on–farm as well as pot experiments, Singh *et al.* (2010) identified slender amaranth (*Amaranthus viridis*), diamond–flower (*Oldenlandia corymbosa*), tropic ageratum (*Ageratum conyzoides*), sicklepod (*Senna obtusifolia*), wild bittermelon (*Momordica charantia*), purple bush–bean (*Macroptilium atropurpureum*), little ironweed (*Cyanthillium cinereum*), ivy gourd (*Coccinia grandis*) and cutleaf groundcherry (*Physalis angulata*) as the potential reservoir hosts commonly infected by root–knot nematodes (*Meloidogyne*). Singh *et al.* (2010) observed the presence of egg masses of root–knot nematode on these weed hosts which indicates their ability to sustain the nematode populations. *M. incognita* was reported to reproduce on the largest number of weeds with over 138 weedy plant hosts throughout the world, indicating weeds as the major reservoir of root–knot nematodes (Rich *et al.* 2008). Although witchweed (*Striga hermonthica*) is a parasitic weed of cereals, it also serves as a good alternate host of root–knot nematodes, which attack agroforestry species such as the Egyptian riverhemp (*Sesbania sesban*) and fish–poison–bean (*Tephrosia vogelii*) in Western Kenya (Desaeger *et al.* 2004).

Migratory endoparasites: Although migratory endoparasitic nematodes invade the roots of host plants, they generally do not induce specialized feeding sites. They typically use their stylets to pierce and feed upon cortical cells, which often subsequently die and collapse since these nematodes migrate through root tissue, causing an extensive damage (Thomas *et al.* 2005). The wounded roots of crops may also be infected by the fungal pathogens, leading to a complex of diseases (Abawi and Chen 1998, Rowe *et al.* 1985). Host pathogenicity in association with feeding behaviour of migratory endoparasites like lesion nematodes (*Pratylenchus* spp.), stem nematodes (*Ditylenchus* spp.), burrowing nematodes (*Radopholus* spp.), and rice root nematode (*Hirschmanniella oryzae*) tends to be less severe than for sedentary endoparasites, but greater than the damage caused due to most ectoparasites (Thomas *et al.* 2005). Here, crop rotation and host–plant resistance are less effective against certain migratory endoparasites which are less dependent on host specialization with respect to their feeding and reproduction (Thomas *et al.* 2005). Since weeds as alternative hosts may contribute substantially to the maintenance and population build–up of migratory endoparasites under fallow conditions, their deleterious effect on crop rotations and resistant crops is less likely than with sedentary endoparasites (Thomas *et al.* 2005).

In a study of Anwar *et al.* (2008), rice root nematode (*Hirschmanniella oryzae*) was reported to occur in roots of 11 rice cultivars and 10 weed species belonging to 7 families. Of the weed species, *Echinochloa colona*, *E. glabrescens* (Poaceae), *Chenopodium album* (Chenopodiaceae), *Cyperus difformis*, *Rumex dentatus* (Polygonaceae) and *Scripus maritimus* (Cyperaceae) were found to support the nematodes at levels similar to that recovered from roots of rice plants grown in and around the fields during and after the cropping season as well (Anwar *et al.* 2009). Some weed species like *Coronopus didymus* (Brassicaceae), *Marsilea minuta* (Marsileaceae), *Paspalum distichum* (Poaceae) and *Sphenoclea zeylanica* (Campanulaceae) were frequently infected by the nematode but at lower levels from those found in rice roots (Anwar *et al.* 2009).

The northern root–lesion nematode (*Pratylenchus penetrans*) has a wide host range including crops including cereals, cotton, pulses, pastures and oilseeds along with a number of weed genotypes. The nematode can penetrate and reproduce more easily in perennial weeds with soft–textured roots than in annual weeds with hard–textured roots. These act as reservoirs for the overwintering *P. penetrans*, posing substantial threat to any succeeding crop(s) susceptible to this nematode (Anwar *et al.* 2009). The winter–active annual groundsel (*Senecio vulgaris*) serves as an important winter reservoir for *P. penetrans* (Townshend and Davidson 1960). Furthermore, the life span of weeds plays a key role in keeping the nematode population alive throughout the year (Anwar *et al.* 2009). The noxious nut grass (*Cyperus* sp.) maintains harmful populations of several nematodes (Hogger and Bird 1976, Rhoades 1964).

Ectoparasites: Ectoparasitic nematodes live freely in the soil near the host, move closely or on the root surface, and feed intermittently on the epidermis and root hairs near the root tip. They only penetrate the plant roots with their stylets and feed on tissues from outside the plant. They have a wide host range and need a little or no host specialization for feeding (Thomas *et al.* 2005). Although some genera like ring nematodes (*Criconemella* spp.) may feed at the same location on a root for an extended period of time, most of them browse on epidermal and cortical tissues at different locations along roots (Thomas *et al.* 2005). Some examples of other ectoparasites are lance nematodes (*Hoplolaimus* spp.), spiral nematodes (*Helicotylenchus* spp.), sting nematodes (*Belonolaimus* spp.), stubby–root nematodes (*Trichodorus* spp.) and stunt nematodes (*Tylenchorhynchus* spp.). Crop damage occurs due to direct injury into the cells at the time of feeding, depending on the number of nematodes present, their size, rate of population growth, and specific host sensitivity (Thomas *et al.* 2005). Management of these nematodes is limited to non–specific strategies such as weed–free clean fallowing or using nematicides because of their presence in a wide host range during fallow period (Thomas *et al.* 2005).

However, weed hosts can be classified as good (susceptible), moderate, and weak or poor (resistant) host to nematodes, depending on their reproductive size (Rich *et al.* 2008, Anwar *et al.* 2009). The impact of each category varies with the interaction between the crop and the specific nematode (Anwar *et al.* 2008). Weed species resistant to nematodes have low potential to maintain a high level of nematode population, whereas susceptible weeds can maintain a high level of nematode population in the weed infested fields (Davis and Webster 2005, Anwar *et al.* 2009).

As the most economically important soybean pathogen in the United States, soybean cyst nematode (*Heterodera glycines*) has been reported to parasitize a wide range of host plants, covering about 100 legume genera of Fabaceae family and about 50 non–legume genera of 22 plant families (Johnson *et al.* 2008). Of these, the major ones are common winter annual weeds of soybean, and include purple deadnettle (*Lamium purpureum*) and henbit (*Lamium amplexicaule*) as strong hosts, field pennycress (*Thlaspi arvense*) as a moderate host, and shepherd's purse (*Capsella bursa–pastoris*) as a weak host (Johnson *et al.* 2008). There are some more instances. Wild marigold (*Tagetes minuta*) is generally considered as a poor host for a variety of nematode pests (Dixit 2018). Wandering Jew (*Commelina benghalensis*) and pigweeds (*Amaranthus* spp.) have been reported as good weed hosts for the root–knot nematode (*M. incognita*) based on their reproductive potential (Singh *et al.* 2010). Thus, there is an urgent need for a thorough study on the host–nematode relationships so as to design effective management strategies for weeds and nematodes both.

Weed host–rodent relationship

Weeds have been reported to form an important component in the diet of rodents (Fulk *et al.* 1981, Malhi and Parshad 1994), and also act as hiding niche (Jain *et al.* 1993). In India, about eighteen species of rodents are considered as pests in agriculture and allied sectors (Parshad, 1999). Of these, the lesser bandicoot rat (*Bandicota bengalensis*) is the most predominant and widespread pest of agriculture in wet and irrigated crop fields as well as grassland almost throughout the country excepting a few specified areas (Parshad 1999). Other species which are widespread in both irrigated and dry farming systems in the country are Indian gerbil (*Tatera indica*), soft–furred field rat (*Rattus meltada*) and house mouse (*Mus musculus*). Almost all field crops are affected by rodents from sowing to harvesting and even up to the storage areas (Parshad 1999). However, both the weeds and rodents are major concerns to rice farmers in the tropics (Htwe *et al.* 2019). Because, rodents selectively invade and cause more damage in weedy than in weed–free rice crop (Drost and Moody 1982). In temperate cereal systems, high protein seeds of grass weeds can be an important food source for rodents (Htwe *et al.* 2019). Weed infestations in and around rice crop fields provide important refuge areas for rodent pests (Htwe *et al.* 2019). The study of Htwe *et al.* (2019) under lowland irrigated rice agro–ecosystem in Myanmar revealed *B. bengalensis* as the dominant rodent species in transplanted rice during both wet and dry seasons. In dry season, *Cyperus difformis* was found dominant at the tillering stage, whereas *Echinochloa crus–galli* was the dominant weed species at the booting stage. *E. crusgalli* was the dominant weed throughout the wet season. Damage by rodents was higher in dry season as evidenced from larger economic benefits for best weed management and effective rodent control in the dry season than in the wet season (Htwe *et al.* 2019). Cutting weeds from the areas bordering rice crop and removing weeds from the rice field reduces potential nesting sites and shelters for rats and others (Islam 2001). But the presence of an alternative food source reduces the performance of other control techniques such as trapping and poison baiting (Parshad *et al.* 1991). Hence, concurrent control of weeds in and around rice fields combined with coordinated community trapping of rodents during the early tillering stage and ripening stage of rice are recommended management options (Htwe *et al.* 2019). In recent years, increasing trend of farm mechanization is expected to reduce the wastelands and wild vegetation on crop field boundaries which otherwise provide harbourage to rodents. A clean environment through harbourage reduction can discourage rodents from their establishment in an area (Parshad 1999).

Conclusion

Weeds are very much affiliated to different pest organisms like diseases, insects, mites, nematodes and rodents for their growth, multiplication, perpetuation, reproduction and/or survival. Individually, each one of these is responsible for a considerable loss by itself. But if weeds remain disregarded, it gives rise to the infestation of the other (s). Weeds play a key role by serving as the alternate and alternative hosts of various pest organisms. It is very much necessary to understand, circumvent and manage the weeds in time for an efficient management of other crop pests. Regular removal of weeds is a type of preventive control as it minimizes competition of nutrients, prevents hibernating pests, as well as, facilitates proper aeration and application of pesticides. The key behind the success of insect pests, diseases and other pests is significantly related to the weeds and their need–based management. Each of these problems and infestations need specific approach towards prevention and control. Eradicating and treating sources of inocula in the field are important preventive measures. Concerted efforts are very much needed to have an in–depth study over the relationship between weed hosts and other pests. This is imperative for updating the host range or host profile of different pest organisms, because the direct role as documented for *P. hysterophorus* as main host of Mexican beetle is not uncommon. An integrated approach would be more effective to obviate the weeds or wild plants for minimizing the carryover of crop pests on the cultivated hosts.

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