2023

Insect and Pest Management for Sustaining Crop Production Under Changing Climatic Patterns of Drylands

Ruchika Kashyap
University of California, Davis, rkashyap@ucdavis.edu

Sajjan Grover
University of Nebraska - Lincoln, sgrover2@unl.edu

Heena Puri
University of Nebraska-Lincoln, fheena2@huskers.unl.edu

Sandeep Kaur
Punjab Agricultural University

Jagmohan Singh
Guru Angad Dev Veterinary and Animal Sciences University

See next page for additional authors

Authors
Ruchika Kashyap, Sajjan Grover, Heena Puri, Sandeep Kaur, Jagmohan Singh, Karansher S. Sandhu, Gagandeep Kaur, Hinal Kharva, Shivreet Kaur, and Balwinder Kaur

Insect and Pest Management for Sustaining Crop Production Under Changing Climatic Patterns of Drylands

Ruchika Kashyap,[1] Sajjan Grover,[2] Heena Puri,[2] Sandeep Kaur,[3] Jagmohan Singh,[4] Karansher S. Sandhu,[5] Gagandeep Kaur,[6] Hinal Kharva,[7] Shivreet Kaur,[8] and Balwinder Kaur[9]

1 Department of Plant Pathology, University of California, Davis, CA, USA; e-mail: rkashyap@ucdavis.edu
2 Department of Entomology, University of Nebraska-Lincoln, Lincoln, NE, USA; e-mail: sajjan.grover@huskers.unl.edu
3 Department of Entomology, Punjab Agricultural University, Ludhiana, Punjab, India
4 Krishi Vigyan Kendra, Handiaya, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India; Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, New Delhi, Delhi, India
5 Department of Crop and Soil Sciences, Washington State University, Pullman, WA, USA; e-mail: k.sandhu@wsu.edu
6 Gulf Coast Research and Education Center, University of Florida (UF), Institute of Food and Agricultural Sciences (IFAS), Gainesville, FL, USA; e-mail: gkaur2@ufl.edu
7 Naturalist-Inspired Chemical Ecology Lab, National Centre for Biological Sciences, Tata Institute of Fundamental Research, Bangalore, Karnataka, India; School of Life Sciences, The University of Trans-Disciplinary Health Sciences and Technology, Bangalore, Karnataka, India
8 Department of Plant Pathology, North Dakota State University, Fargo, ND, USA; e-mail: shivreet.kaur@ndsu.edu
9 Everglades Research and Education Center, University of Florida (UF), Institute of Food and Agricultural Sciences (IFAS), Belle Glade, FL, USA; *Corresponding author* — e-mail: bkaur@ufl.edu

Published in A. Naorem, D. Machiwal, eds., *Enhancing Resilience of Dryland Agriculture Under Changing Climate*, 2023
doi:10.1007/978-981-19-9159-2_21

Abstract
Climate change is alarming, particularly for agriculturists as it severely impacts the development, distribution, and survival of insects and pests, affecting crop production globally. Over time, climate change is drastically tumbling the crop productivity in all the cropping systems, whereas the dryland agriculture with existing low productivity is immensely hit. While all the existing species in drylands, including humans, are coping with extreme climate variations for millennia, future climate change predictions put dryland agriculture in a threat zone. Drylands support 38% of the world's population; therefore, climate change coupled with population growth and global food security draws the attention of scientists towards sustainable crop production under changing trends. The intermingling and intermixing of various biological, hydrological, and geographical systems plus the anthropogenic factors continuously amplify the changes in the dryland systems. All of this brings us to one challenge: developing pest management strategies suitable for changing climatic patterns. In this complex agrology framework, integrated pest management (IPM) strategies, especially those involving early monitoring of pests using prediction models, are a way to save the show. In this chapter, we will summarize the direct and indirect effects of climate change on crop production, the biology of insect pests, the changing pest scenarios, the efficacy of current pest management tactics, and the development of next-generation crop protection products. Finally, we will provide a perspective on the integration of best agronomic practices and crop protection measures to achieve the goal of sustainable crop production under changing climatic trends of drylands.

Keywords: Climate change, Dryland, Agriculture, Pest management, Production

1 Introduction

Climate change has been the talk of the hour globally due to its impact on almost all the natural and man-made ecosystems including terrestrial, hydrological, and agricultural systems (Rosenzweig et al. 2007). This led to a new discipline called "climate change biology" which studies the impacts of climate change on different biological systems (Hannah 2021). Talking about the agricultural system, climate change is one of the focal areas for agriculturists as it deeply affects the agriculture sector due to fluctuations in numerous factors including temperature, rainfall, CO2, etc. that directly or indirectly influence crop and livestock production (Adams et al. 1998). Hulme (1996) categorized these climatic conditions that affect agriculture into four major groups, namely, temperature, water runoff, carbon dioxide, and extreme conditions (Jones and Hassan 1991). The agriculture production scenario worsens in extreme calamities such as droughts, floods, and windstorms and is alarming due to the uncertainties attached to climate change (Jones and Hassan 1991). A global yield reduction of 3.8% maize and 5.5% wheat is predicted due to the changing climatic conditions (Lobell et al. 2011). There is no denying the fact that the earth is getting hotter and over the past 100 years, major warming, constituting more than half of the total, occurred in the drylands. The drylands are described in terms of aridity index (AI) which is a function of average annual precipitation (P) and potential evapotranspiration (PET) (Middleton and Thomas 1997). The P/PET ratio is less than 0.65 in these areas, suggesting the AI is high which indicates scarcity in water supply in relation to atmospheric demand (Hulme 1996). The drylands share 42% of the total lithosphere of our planet, which comprises the grasslands, forests, cultivated land, and residential area. The drylands are very crucial for the developing countries as 58% of the drylands are marked in Asian and African countries (Laban et al. 2018). Scientists predicted that climate change will lead to the expansion of drylands, estimated to increase 10% by 2100 (Middleton and Thomas 1997). Climate change is most importantly marked by an increase in greenhouse gasses, like CO2, which led to global warming. The increase in atmospheric temperature leads to the depletion of water resources in drylands, which drastically reduces agricultural productivity. The spatial and temporal variability in temperature and rainfall and complex biological, physical, and socio-economical systems accompanied by anthropogenic factors in these areas make it the worst-hit area for agriculture (Jones and Hassan 1991; IUCN 2019). The existing risks of droughts and floods in drylands will be amplified by the predicted rise in temperature (IPCC 2015; McKenzie 2009). Evidence suggests that in order to meet the yield requirements, cropland expansions occur at an approximate rate of 9% owing to yield reductions in drylands (Zaveri et al. 2020). Various crop models developed by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) to study the effects of climate change on crop growth, development, and productivity suggest that crop productivity will reduce under high-temperature regimes of drylands due to increased evapotranspiration and decreased LGP and crop duration, radiation interception, harvest index, and biomass accumulation (Jat et al. 2012).

It is predicted that the probability of strident and plausible impacts on agriculture and related species, especially the ones vulnerable, is inevitable and is thought to increase with time (IPCC 2015). Among the vulnerable species are the insect pests which are feared to be affected adversely by the changing climatic conditions of drylands leading to changes in the insect pest scenario and the onset of new pest species. Pest population dynamics including insect development, reproduction, survival, and spread along with their interaction with other pest species and natural enemies completely change with the increasing temperatures (Prakash et al. 2014). It is also thought that this rapid dynamic change in the insect population not only increases the rate of insect food consumption but also increases the risk of pesticide resistance development (Dillon et al. 2010; Matzrafi 2019; Pu et al. 2020). Consequently, many insect species have now shifted to low pest risk areas as well due to these climatic changes (Bebber et al. 2013).

2 Effects of Climate Change in Drylands

2.1 Insect Pest Biology

The vulnerability of agriculture to pest threat is increasing with the rise of temperature around the planet. It is anticipated that by the end of the twenty-first century, the global temperature would rise by at least 4 _C (Brown and Caldeira 2017). An increase in temperature, CO2 level, reduced humidity, and frequent precipitation severely affect insect biology and ultimately the extent of crop losses. Temperature plays an important role in regulating insect growth, survival, and reproduction. Insects have a greater tendency to flourish in hotter temperatures and this allows them to feed more and reproduce more. Increased temperature can have direct effects on insects like elevating the developmental rates of insects and making them more heat tolerant (Harvey et al. 2020). In dryland areas, drier conditions often lead to the reduced production of secondary metabolites which are involved in plant defenses and increase the concentration of amino acids in plants which makes the plant more nutritious for insects to feed. Therefore, some insects perform better on water-deficit plants (White 1969; Maxmen 2013). However, this performance is displayed for a shorter period. In the case of sap-sucking insects like aphids, they can feed during the dry spells, but as the plants become water-stressed, there is a decline in fluid pressure in phloem cells which negatively impacts the aphid feeding (Huberty and Denno 2004). Growing maize at higher temperatures and under wet conditions leads to detrimental effects on the performance of herbivore *Bicyclus anynana*. These conditions led to a decrease in the herbivore's body weight, fat content, storage reserves, and phenoloxidase activity. These are the indirect consequences on herbivores mediated by variation in host plant quality due to climate change (Kuczyk et al. 2021).

The potato tuber moth outbreaks are more prevalent in Peru during hotter and drier years as compared to the usual conditions. The higher temperature in combination with less rainfall does not help in washing off the moths from the leaves and stems of the potato plant. Moreover, dry conditions produce cracks in soil which allow the larvae to move into the soil to feed on tuber (Kroschel et al. 2013). It is also expected that an increase in global temperature could expand the range of pest distribution. The pests which are now restricted to tropical regions only could move to temperate regions due to temperature changes. In sub-Saharan Africa, rice is among the major crops cultivated in different countries. It is severely affected by the attack of flea beetles of *Chaetocnema pulla* species group which is also a vector of rice yellow mottle virus disease. This disease causes 80–100% yield loss. Beetles spreading the virus make the condition worse. Currently, this beetle is posing problems to rice crops in Madagascar and Western and Central-Eastern Africa. Future predictions based on climate changes concerning increasing temperature over the years suggested the faster dispersal of this beetle to some territories of Sudan, South Sudan, Cameroon, Nigeria, Zimbabwe, Democratic Republic of the Congo, and the Republic of South Africa. These examples suggest that in dryland land areas, climate change is playing a big role in increasing the risk of pest attack to different crops, expanding the range of insect population (Iannella et al. 2021).

Insects can get well adapted to their surroundings. For dryland areas also, to avoid the harsh climatic conditions and to thrive well, insects undergo physiological, morphological, and behavioral modifications. Some insects have a protective layer of hair around their body to prevent the loss of water during high heat waves and to reduce heat absorption by the body. They also spend much of their time underground in the soil or somewhere where the conditions are more favorable to live, and in such a way insects can escape the outside hotter environment. For example, in dryland areas, the dormancy of larvae of *Sesamia* occurs in the stalks of the sorghum plant in the hot summer season. However, in the case of irrigated areas, the dormancy of *Sesamia* occurs much later from the summers.

2.2 Pest Status

When insects escape their natural regulation via natural control agents, they uplift their status to pests, causing harm to humankind. Insects carried to a new region by human activities reduce the availability of particular natural enemies in the new place, thereby amplifying the pest population. Lack of natural control over pest populations helps the pest to achieve the levels where it can start causing economic damage (e.g., swarms of locusts grazing the farms). Climate change has a significant impact on the status of various agricultural insect pests. Researchers use different methods to forecast how the variation in temperature and precipitation may affect the existing status of insect pests, their abundance, and distributions. Changing climatic conditions has resulted in several pest outbreaks around the world. The warmer climate has facilitated the spread of fall armyworm *Spodoptera frugiperda* across countries attacking maize and millets including sorghum.

Another most devastating spreading pest is the desert locust, which has caused menace in the fields of African and Southeast Asian countries. Dessert locus usually lives in its solitary phase, but under certain circumstances, they change their behavior to the gregarious phase where their population becomes dense. The only single climatic factor does not result in huge outbreaks; instead a combination of rising temperature, heavy rainfalls preceded by multiple cyclones, and strong winds has provided a favorable environment for locust breeding, its development, and migration (Salih et al. 2020; Meynard et al. 2020). Desert locust consumes a variety of green vegetation including crops, shrubs, grasses, and trees. This shows the stronger impact of changing climatic conditions on pests and encourages them to thrive as major pests, thus resulting in risking food security. This not only affects the small-scale farmers and their livelihoods but also the people residing in countries where food availability is already at risk.

2.3 Invasive Insect Species

Invasive species pose a greater problem to agriculture success and can severely affect food security. These are the non-native species that are introduced to new geographical areas as a result of man-made activities. Due to increased global warming, globalization, high trade, international travel, and tourism, the introduction of invasive species to countries where they were not previously present is expected to be more. In the United States, crop loss of almost $40 billion is estimated to occur from invasive species present in the cropland and forest areas (Paini et al. 2016). As the invasive pests move from their native place to a completely new place, they avoid their regulation by their natural enemies like predators or parasitoids and attack on native plants. Recent examples of the most serious invasive pests around the world include desert locust *Schistocerca gregaria* movement from South Africa to East Asia, fall armyworm invasion in India, red turpentine beetle *Dendroctonus valens* that originated from North America and invaded China, spotted lanternfly introduction in North America native to China, and Asian tiger mosquito *Aedes albopictus* invasion in South America (Venette and Hutchison 2021).

Climate change inflicts direct effects on invasive pest biology and their behavior. The introduction of these pests, their establishment in the non-native area, distribution, and the success of their mitigation tactics are projected to be impacted by climate change. Global warming has a direct effect on plant physiology, like changes in the flowering time of temperate plant species; this facilitates the introduction of new pests to new regions and causes crop losses. Recently in 2020, the outbreak of desert locust *S. gregaria* in drylands of African countries and its movement to Southeast Asia have displayed a great example of how climate change has imposed severe threats to food security across the nations. High temperature coupled with precipitations and heavy winds provided favorable environmental conditions for its reproduction, growth, and movement. This explains that climate change played a significant part in providing conditions suitable for locust outbreaks (Karthik et al. 2021). Some insects have the ability to thermoregulate to overcome the harsh temperature and environmental conditions, increasing their possibility to invade the new geographic region. In the case of *S. gregaria*, it uses different thermoregulatory strategies like perching, stilting, and blending with vegetation to maintain their body temperature up to 40 °C to sustain the extreme temperature of 28–56 °C (Maeno et al. 2021).

Other invasive species include fall armyworm (FAW), *S. frugiperda*, which is a chewing herbivore that causes severe devouring of the host plant. This pest has previously invaded Africa, but in 2018 and 2019, it has been distributed to many countries like China, Indonesia, Australia, India, Japan, Thailand, and Myanmar. Undoubtedly, the increase in temperature has an impact on the developmental rates of pests which affects their biology, dispersal, and richness. Insects grow and develop in the defined temperature range which is suitable for their body but changes in the temperature can influence their development rates, reproduction, and life cycle and ultimately affect their subsistence. Their body metabolism increases when there is an increase in ambient temperature closer to a thermal optimum of pests (Karthik et al. 2021). Due to the multivoltine nature of FAW, it is anticipated to have more generations per year due to the effect of climate change (Sparks et al. 2007).

3 Impact on Pest Management Strategies

3.1 Chemical Control

The use of pesticides is the first choice of farmers for the control of pests and it is preferred over the other control methods due to its easy availability and quick and sure action against the target organisms. On the other hand, ill effects such as pest resistance, resurgence, secondary pest outbreak, and destruction of natural enemies may occur (Khan et al. 2011). However, the injudicious use of synthetic pesticides results in human health hazards, environmental pollution, and pest resurgence (Sharma 2014). Therefore, the choice of pesticide plays a key role in sustainable crop production in dryland areas. Based on the residue persistence of pesticides, less persistent chemicals can be used. Indiscriminate use of pesticides may interfere with plant development and help in managing crop production by killing competitive vegetation. But increased pesticide usage may affect soil quality (Arias-Estévez et al. 2008), food safety (Liu et al. 1995), human health (Nawaz et al. 2014), aquatic species (Skevas et al. 2013), and beneficial insects (Mullen et al. 1997). However, deployment of plant origin insecticides, growth regulators, attractants, and even synthetic pyrethroids can fit well in the IPM.

Due to the change in the climatic pattern of the dryland areas, there may be the occurrence of an increase in insect pest outbreaks, and it will eventually increase chemical usage which is likely to have a negative effect on the environment. Insect pests under changing climatic patterns of drylands for sustainable crop production can be managed by using suitable crop protection chemicals. However, in dryland areas, the effectiveness of crop protection chemicals could be affected due to changes in temperature, precipitation patterns, and physiological and morphological changes of crop plants (Coakley et al. 1999). Before insects establish themselves in protected feeding sites and to avoid the problem of resistance, the synchronization of the use of pesticides at the time of egg hatching and early instars of pests results in the best control. The time gap between pesticide application and weather conditions is the major cause for the loss of pesticides (Blenkinsop et al. 2008; Nolan et al. 2008). Higher temperatures in dryland areas can cause faster uptake of pesticides by the plants and ultimately increase the toxicity to pests. Pertaining to the efficacy of insecticides, there is the belief that some of the pesticides may result in greater toxicity to insect pests with the increasing temperature (Noyes and Lema 2015; Noyes et al. 2009). However, de Beeck et al. (2017) reported chlorpyrifos degradation and hydrolysis at higher temperatures that result in reduced mortality and less oxidative damage to insect pests (Hooper et al. 2013). Also, an increased temperature results in volatilization loss of pesticides (Otieno et al. 2013). Likewise, rainfall can result in increased pesticide wash-off and ultimately reduce the efficiency of pesticides to control the pest. To avoid pesticide wash-off instead of liquid, the use of granular formulations is less liable to be washed off by rainfall and also has lower drift instead of foliar spray applications.

In dryland areas, an increase in pest infestation results in the greater use of chemical pesticides. On the other hand, excess usage of pesticide could have detrimental effects on other beneficial organisms and ultimately results in the greater loss of crops due to the abundance of pests in the absence of biocontrol agents. Under changing climatic conditions, medium-range forecasting of weather can help in the prediction of rainfall patterns that will be helpful to avoid the application of pesticides under impending rainy conditions. Regular monitoring helps to undertake control interventions at the right time, thus helping in the easy and effective management of the small population of pests in dryland areas. Generally, pesticide losses are mainly affected by the time gap between extreme weather conditions and pesticide application (Blenkinsop et al. 2008; Nolan et al. 2008). Therefore, it is crucial to develop novel molecules which can balance the ill-effects of conventional chemicals and reduce the impact on natural enemies.

3.2 Cultural and Physical Control

To avoid insect pest damage in dryland areas, there is a need for suitable control tactics. Cultural methods are eco-safe as well as sustainable and do not require any additional budget for the control of insect pests. Alteration of cropping system, including crop production practices like crop variety selection, sowing, intercultural operations such as tillage, sanitation, crop irrigation activities, pruning and thinning, etc., can be adopted in the agro-ecosystem for sustainable crop production in dryland areas. So, there is a necessity for planning these activities in advance. These activities make the environment less attractive for pest establishment, dispersal, growth, reproduction, and survival, ultimately helping in reducing the pest population (Reddy 2016). Regular cultural practices can help in eliminating the carryover of pest populations (Koul et al. 2004). Other activities like crop mulching and composting are responsible for enhancing the spiders, earthworms, predators, and parasitoid populations that are responsible for controlling insect pests (Thomson and Hoffmann 2007). Contrastingly, the addition of large amounts of decomposable organic matter in the surface soil may stimulate the population of white grubs *Holotrichia oblita* or cutworms *Agrotis ipsilon and Agrotis segetum* that would result in the complete loss of the crop by cutting the roots of cereals under severe incidence (Giller et al. 2009). Reduced tillage in the field favors natural enemy populations (Sharley et al. 2008). Inadequate use of fertilizers may increase the insect population; therefore, need-based use of a pesticide may reduce the infestation of insect pests and help in sustaining crop production in dryland areas (Litsinger 1994). Intercropping in dryland areas has huge importance for the management of pests such as dryland rice intercropped with cotton or pigeon pea, resulting in lowering the number of green leafhoppers and white-backed planthoppers (Satpathy et al. 1997). Intercropping rice with *Pontederia cordata* reduced 33–34% of infestation of the rice leaf folder (Xiang et al. 2021). In dryland areas, cover crops have been shown to enhance the ground beetles and natural enemies' population for controlling insect pests (DuPre et al. 2021). Cover crops can provide habitat and food for several beneficial organisms (Jian et al. 2020).

Crop planting in dryland areas can inhibit many aquatic insects. Pruning, thinning, and clipping off of seedlings inhibit egg-laying of many insects, hence reducing the risk of insect pest infestation in the field. The movement of pests can be inhibited by installing barriers that help to reduce the risk of insect pests such as non-flying armyworm larvae, ants, locust nymphs, chinch bugs, etc. from one field to another field. Plowing of fields exposes insect pests to extreme weather conditions and straw burning can kill them by heat. Dense planting of crops may interfere with crop growth, its development, and microclimate and cause obstructions for flying insects (Litsinger 1994). On the other hand, flooding conditions in the field may kill soil-inhabiting insect pests such as armyworm, cutworm, etc. Trapping insects using sticky colored traps may reduce the infestation of pests. Adhikari and Menalled (2018), reported higher diversity of ground beetles and weeds in organic fields compared to conventionally managed wheat fields, enhanced conservation biological control, and sustainable agriculture in dryland cropping systems. *Drosophila melanogaster* fecundity was better under the influence of both temperature and relative humidity rather than individually (Maurya et al. 2021). Similarly, the lower incidence of *Riptortus pedestris* and *Clavigralla gibbosa* in early sown cowpea was due to their negative correlation with relative humidity, rainfall, and rainy days in the dryland ecosystem (Prasad et al. 2021). Mulching shows an abundance of parasitoid Hymenoptera, ground beetles, and spiders collected with pitfall traps; also in the canopy cover, the number of parasitic and predatory Diptera and predatory Hemiptera was increased in vineyard fields (Thomson and Hoffmann 2007).

3.3 Host Plant Resistance

The use of insect-resistant crops has revolutionized the area of pest management strategies. The insect-proof plants reduce the insect pest population in an eco-friendly manner (Chakravarthy et al. 2019). The ability of insects to develop resistance against insecticidal traits calls for the development of novel and durable pest management strategies. While the host plant resistance acts as a sustainable practice to manage insect pests, the duration of development of insect-resistant plants, the risk of development of resistance in insects, and specifically the abiotic factors influence the efficacy of insect-resistant plants are some of the bottlenecks in the area of host plant resistance (Stout 2014). In previous decades, host plant resistance has made significant progress and acquired sufficient space to become a part of integrated pest management programs. Despite the significant progress, there has been a potential lag in translating the research to practical solutions.

Abiotic factors play an important role in utilizing insect-resistant crops since they possess the ability to modulate the plant defense responses to insects. For instance, wild cotton plants under dry conditions have been shown to enhance the plant defenses and consequently decrease the insect attack (Abdala-Roberts et al. 2019). Contrastingly, drought stress did not elevate the plant defenses such as jasmonates and protease inhibitors in tomatoes (Ximénez-Embún et al. 2017). Several reports show that sap-sucking insects are predicted to cause more damage to drought-stressed plants and subsequently lead to cause more vector-borne diseases (Nachappa et al. 2016; Sconiers and Eubanks 2017; Florencio-Ortiz et al. 2018). Monarch caterpillars have also been shown to grow better on water-deficit milkweed plants (Hahn and Maron 2018). However, the variability in insect performance depends on the intensity of water-deficit and herbivore type.

Specifically, thrips and whiteflies are the main vectors of plant pathogens. Thus, abiotic factors may not only affect the insect feeding but also involve the risk of higher viral disease incidence. Thrips have been reported to cause significant damage in cotton and onions under water-deficit conditions (Fournier et al. 1995; Sconiers and Eubanks 2017). Simultaneously, it could be more complex for insects such as whiteflies. Whiteflies prefer to grow on plants under dry conditions at the expense of lower oviposition rates (Paris et al. 1993; Inbar et al. 2001). Thus, understanding insect biology is very crucial while engineering plants for insect resistance. Plants not only respond locally to defend against insects, but they also transmit systemic signals to other parts of the plants. The resistance signals can also travel from aboveground to belowground and vice versa. In maize, it has been shown that belowground herbivory induces aboveground resistance to insects and the resistance levels have been associated with the reduced quality of the leaves due to in-planta hydraulic changes (Erb et al. 2011). This study provides another perspective on induced plant resistance under dry conditions. Recently, the fall armyworm, *Spodoptera frugiperda*, has expanded its range in the United States and caused significant yield losses and the underlying reasons have been mainly attributed to climate change (Miedaner and Juroszek 2021).

Antixenosis, antibiosis, and tolerance constitute the main categories of host plant resistance (Smith 2004). Antibiosis has been the most extensively studied category among the plant breeding approaches for pest management (Sharma and Ortiz 2002; Stout 2014). Therefore, it becomes crucial to explore the antixenosis and tolerance categories of host plant resistance in order to compensate for plant yield losses caused by insect damage (Peterson et al. 2017; Grover et al. 2020). Though dry conditions can alter the plant defense status, it is still a reliable and stable strategy compared to others. But there is a need for improvements in insect resistance breeding approaches that are suitable for dryland farming. Breeding for drought-tolerant and insect-resistant traits together can help to manage the insect pest management in changing trends.

Simultaneously, there will be a strong need to assess the risk of the spread of other insects and pathogens favored by dry conditions in the breeding process (**Fig. 1**).

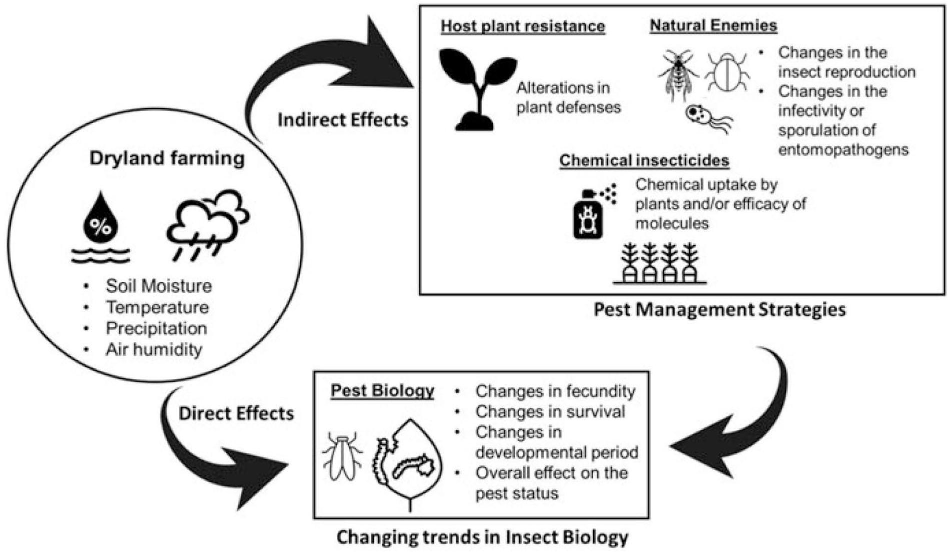

Fig. 1 Changing climatic conditions in drylands can impact insect pests indirectly and directly. Changing climatic trends affect the plant resistance, biology of natural enemies, and chemical insecticide efficacy, which further impact the pest biology positively or negatively. Direct effects of changing climate involve changes in pest biology.

3.4 Biological Control

Biological control involves the utilization of living organisms, predators, parasites, and pathogens for the control of pests. The strategy is considered safe and eco-friendly, compatible with other IPM technologies. Since the biological agents are slow-acting and take more time to be effective, they are less used by farmers. Though there are reports suggesting the decreased abundance of the predators and parasitoids in dryland landscapes, this approach could act as a safeguard to reduce the crop yield losses caused by insect damage, if managed sustainably (Adhikari et al. 2019). Abiotic factors can impact the biology of insect pests and their natural enemies as well. Therefore, it is very important to understand insect biology with changing trends and quantify the impact of dryland conditions on the efficacy of natural enemies. In order to minimize the reduction in natural enemies' performance, several agronomic measures can be adopted. For instance, cover crops have been suggested to enhance communities of ground beetles, a natural predator of insect pests, in dryland cropping systems (DuPre et al. 2021). Also, multi-cropping has been suggested over monoculture for effective pest management (Palmu et al. 2014).

Furthermore, organic farming in dryland landscapes has been shown to increase the biodiversity of plants supporting natural enemies' populations by strengthening ecological networks (Adhikari et al. 2019). Entomopathogenic nematodes (EPNs) can also serve as a biocontrol agent to control the insect pests. In dryland landscapes, EPNs have been suggested to be sprayed with polymer gel to prevent nematode desiccation (Shapiro-Ilan et al. 2016). Also, further investigations are required to identify the drought-tolerant EPN strains which could be better utilized in dryland farming. Moreover, the other category of natural enemies to insects, entomopathogens, can vary in their effectiveness from one location to another depending on the weather conditions (Mandakini and Manamgoda 2021). 452 R. Kashyap et al.

4 Conclusions

Climate change is inevitable, and its effects are visible on the insect pest population, directly and indirectly affecting agriculture (Chander et al. 2016). The challenging issue of food security has made dryland agriculture more and more important; especially in these changing climate times, we need to develop adaptation strategies for sustainable agriculture production (Jat et al. 2012). Some of these strategies include efficient utilization and management of natural resources and use of genetically improved crops, coupled with adequate socio-economic policies. Diversifying agriculture systems through conservation agriculture is another strategy that can help combat these changes (Pedrick 2012). Climate change mitigation in drylands can be addressed by the conservation and restoration of ecosystems in drylands. The dryland ecosystem can be enriched by perennial plants which will improve the soil health and increase CO2 sequestration and population of predators in a well-maintained ecosystem. The adoption of climate resilience strategies in drylands involves the use of drought-tolerant crops, drought-resistant crop varieties, water-efficient agronomic practices, modified existing pest management strategies, and development of next-generation crop protection compounds that work efficiently in high temperatures (IUCN 2019).

Besides improving pest management strategies, it also becomes important to evaluate and monitor climate change critically and early predict the changes in the insect populations and use the global information system (GIS) for invasive species and assessment of pest risk (Cook 1932). The use of new-generation pesticides, genetically modified organisms, biotechnological approaches, etc. is one of the latest reliable techniques which need more future explorations. The use of artificial neural networks (ANN) in combination with appropriate databases and software such as semi-automated digital image encoding systems might have practical implications in studying insect systems (Fedor et al. 2009). The trends in the pest population of drylands due to dynamic climatic factors can be predicted using various climate models (Tang et al. 2021). The use of deep learning and image-based technologies is important for correct insect pest diagnosis (Xin and Wang 2021). The disease forecasting models earlier based on algorithms can be strengthened now by the use of deep learning and AI-based tools. These strategies coupled with adequate research and extension can help mitigate some of the challenges and problems faced by the agriculture sector in drylands due to the changing climate and onset of rapid variations in insect pest scenarios.

Acknowledgments The “bacteria” icon by Jaime Serra, “wasp” icon by Parkjisun, “caterpillar” icon by Juraj Sedlak, “insect” icon by VectorStall and Ragal Kartidev, “insecticide” icon by Adrien Coquet, “crops” icon by Made, and “plant” icon by Tulpahn have been obtained from the Noun Project for making the figure used in this chapter. We are thankful to Noun Project for these icons.

References

Abdala-Roberts L, Quijano-Medina T, Moreira X, Vázquez-González C, Parra-Tabla V, Berny Mier Y, Terán JC, Grandi L, Glauser G, Turlings TC, Benrey B (2019) Bottom-up control of geographic variation in insect herbivory on wild cotton (*Gossypium hirsutum*) by plant defenses and climate. Am J Bot 106(8):1059–1067

Adams RM, Hurd BH, Lenhart S, Leary N (1998) Effects of global climate change on agriculture: an interpretative review. Clim Res 11(1):19–30

Adhikari S, Menalled FD (2018) Impacts of dryland farm management systems on weeds and ground beetles (Carabidae) in the Northern Great Plains. Sustainability 10(7):2146

Adhikari S, Adhikari A, Weaver DK, Bekkerman A, Menalled FD (2019) Impacts of agricultural management systems on biodiversity and ecosystem services in highly simplified dryland landscapes. Sustainability 11(11):3223

Arias-Estévez M, López-Periago E, Martínez-Carballo E, Simal-Gándara J, Mejuto JC, García-Río L (2008) The mobility and degradation of pesticides in soils and the pollution of groundwater resources. Agric Ecosyst Environ 123(4):247–260

Bebber DP, Ramotowski MA, Gurr SJ (2013) Crop pests and pathogens move polewards in a warming world. Nat Clim Chang 3(11):985–988

Blenkinsop S, Fowler HJ, Dubus IG, Nolan BT, Hollis JM (2008) Developing climatic scenarios for pesticide fate modelling in Europe. Environ Pollut 154(2):219–231

Brown PT, Caldeira K (2017) Greater future global warming inferred from earth's recent energy budget. Nature 552(7683):45–50

Chakravarthy AK, Luis EJ, Naik SO, Rajkumar B (2019) Economic and ecological values of resistant plants. In: Experimental techniques in host-plant resistance. Springer, Singapore, pp 253–263

Chander S, Husain M, Pal V (2016) Insect pest management in climate change. In:

Chattopadhyay C, Prasad D. eds. Dynamics of crop protection and climate change. Studera Press, New Delhi, pp 115–130

Coakley SM, Scherm H, Chakraborty S (1999) Climate change and plant disease management. Ann Rev Phytopathol 37(1):399–426

Cook WC (1932) Insects and climate. JSTOR:96–99

de Beeck LO, Verheyen J, Stoks R (2017) Integrating both interaction pathways between warming and pesticide exposure on upper thermal tolerance in high- and low-latitude populations of an aquatic insect. Environ Pollut 224:714–721

Dillon ME, Wang G, Huey RB (2010) Global metabolic impacts of recent climate warming. Nature 467(7316):704–706

DuPre ME, Weaver DK, Seipel TF, Menalled FD (2021) Impacts of dryland cropping systems on ground beetle communities (Coleoptera: Carabidae) in the Northern Great Plains. J Insect Sci 21(1):19

Erb M, Köllner TG, Degenhardt J, Zwahlen C, Hibbard BE, Turlings TC (2011) The role of abscisic acid and water stress in root herbivore-induced leaf resistance. New Phytol 189(1):308–320

Fedor P, Vaňhara J, Havel J, Malenovský I, Spellerberg I (2009) Artificial intelligence in pest insect monitoring. Syst Entomol 34(2):398–400

Florencio-Ortiz V, Sellés-Marchart S, Zubcoff-Vallejo J, Jander G, Casas JL (2018) Changes in the free amino acid composition of *Capsicum annuum* (pepper) leaves in response to *Myzus persicae* (green peach aphid) infestation. A comparison with water stress. PLoS One 13(6): e0198093

Fournier F, Boivin G, Stewart RK (1995) Effect of *Thrips tabaci* (Thysanoptera: Thripidae) on yellow onion yields and economic thresholds for its management. J Econ Entomol 88(5): 1401–1407

Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crops Res 114(1):23–34

Grover S, Agpawa E, Sarath G, Sattler SE, Louis J (2020) Interplay of phytohormones facilitates sorghum tolerance to aphids. Plant Mol Biol 109:1–12

Hahn PG, Maron JL (2018) Plant water stress and previous herbivore damage affect insect performance. Ecol Entomol 43(1):47–54

Hannah L (2021) Climate change biology. Academic Press, London

Harvey JA, Heinen R, Gols R, Thakur MP (2020) Climate change-mediated temperature extremes and insects: from outbreaks to breakdowns. Global Chang Biol 26(12):6685–6701

Hooper MJ, Ankley GT, Cristol DA, Maryoung LA, Noyes PD, Pinkerton KE (2013) Interactions between chemical and climate stressors: a role for mechanistic toxicology in assessing climate change risks. Environ Toxicol Chem 32(1):32–48

Huberty AF, Denno RF (2004) Plant water stress and its consequences for herbivorous insects: a new synthesis. Ecology 85(5):1383–1398

Hulme M (1996) Climate change and Southern Africa: an exploration of some potential impacts and implications in the SADC Region: a Report Commissioned by WWF International and Co-ordinated by the Climatic Research Unit, UEA, Norwich, Climatic Research Unit, University of East Anglia

Iannella M, De Simone W, D'Alessandro P, Biondi M (2021) Climate change favours connectivity between virus-bearing pest and rice cultivations in sub-Saharan Africa, depressing local economies. Peer J 9:e12387

Inbar M, Doostdar H, Mayer RT (2001) Suitability of stressed and vigorous plants to various insect herbivores. Oikos 94(2):228–235

IPCC (2015) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri RK, Meyer LA, eds]. IPCC, Geneva, pp vol 218

IUCN (2019) Drylands and climate, issues brief 2. https://www.iucn.org/sites/dev/files/iucn_issues_brief_drylands_and_climate_change_sept_2019.pdf Accessed 4 Dec 2021

Jat RA, Craufurd PQ, Sahrawat KL, Wani SP (2012) Climate change and resilient dryland systems: experiences of ICRISAT in Asia and Africa. Curr Sci 102(12):1650–1659

Jian J, Du X, Reiter MS, Stewart RD (2020) A meta-analysis of global cropland soil carbon changes due to cover cropping. Soil Biol Biochem 143:107735

Jones DA, Hassan OT (1991) Climate change and agriculture. Trends Ecol Evol 6(3):101–101

Karthik S, Reddy MS, Yashaswini G (2021) Climate change and its potential impacts on insect-plant interactions. In: The nature, causes, effects and mitigation of climate change on the environment, IntechOpen, London

Khan HA, Akram W, Shehzad K, Shaalan EA (2011) First report of field evolved resistance to agrochemicals in dengue mosquito, *Aedes albopictus* (Diptera: Culicidae), from Pakistan. Parasit Vectors 4(1):1–1

Koul O, Dhaliwal GS, Cuperus GW (2004) Integrated pest management potential, constraints and challenges. CABI, Wallingford

Kroschel J, Sporleder M, Tonnang HE, Juarez H, Carhuapoma P, Gonzales JC, Simon R (2013) Predicting climate-change-caused changes in global temperature on potato tuber moth *Phthorimaea operculella* (Zeller) distribution and abundance using phenology modeling and GIS mapping. Agric For Meteorol 170:228–241

Kuczyk J, Raharivololoniaina A, Fischer K (2021) High temperature and soil moisture reduce hostplant quality for an insect herbivore. Ecol Entomol 46(4):889–897

Laban P, Metternicht G, Davies J (2018) Soil biodiversity and soil organic carbon: keeping drylands alive. IUCN, Gland

Litsinger JA (1994) Cultural, mechanical, and physical control of rice insects. In: Biology and management of rice insects. International Rice Research Institute, Philippines, pp 549–584, 779 p

Liu H, Cheng H, Wang X (1995) A general study on Chinese diet: pesticide residue. J Health Res 24(6):356–360

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333(6042):616–620

Maeno KO, Piou C, Kearney MR, Ould Ely S, Ould Mohamed SA, Jaavar ME, Ould Babah Ebbe MA (2021) A general model of the thermal constraints on the world's most destructive locust, *Schistocerca gregaria*. Ecol Appl 31(4):e02310

Mandakini HT, Manamgoda DS (2021) Microbial Biopesticides: development and application. In: Microbial technology for sustainable environment. Springer, Singapore, pp 167–189

Matzrafi M (2019) Climate change exacerbates pest damage through reduced pesticide efficacy. Pest Manag Sci 75(1):9–13

Maurya R, Swamy KB, Loeschcke V, Rajpurohit S (2021) No water, no eggs: insights from a warming outdoor mesocosm experiment. Ecol Entomol 46(5):1093–1100

Maxmen A (2013) Crop pests: under attack. Nature 501(7468):S15–S17

McKenzie BM (2009) In: Koohafkan P, Stewart BA, eds. Water and cereals in drylands. Earthscan, London, p 110. ISBN: 978-1-84407-708-3. Exp Agric 45(4):514

Meynard CN, Lecoq M, Chapuis MP, Piou C (2020) On the relative role of climate change and management in the current desert locust outbreak in East Africa. Glob Chang Biol 26(7): 3753–3755

Middleton NJ, Thomas DS (1997) World atlas of desertification. UNEP, Geneva

Miedaner T, Juroszek P (2021) Global warming and increasing maize cultivation demand comprehensive efforts in disease and insect resistance breeding in north-western Europe. Plant Pathol 70(5):1032–1046

Mullen JD, Norton GW, Reaves DW (1997) Economic analysis of environmental benefits of integrated pest management. Agric Appl Econ 29:243–253

Nachappa P, Culkin CT, Saya PM, Han J, Nalam VJ (2016) Water stress modulates soybean aphid performance, feeding behavior, and virus transmission in soybean. Front Plant Sci 7:552

Nawaz A, Razpotnik A, Rouimi P, de Sousa G, Cravedi JP, Rahmani R (2014) Cellular impact of combinations of endosulfan, atrazine, and chlorpyrifos on human primary hepatocytes and HepaRG cells after short and chronic exposures. Cell Biol Toxicol 30(1):17–29

Nolan BT, Dubus IG, Surdyk N, Fowler HJ, Burton A, Hollis JM, Reichenberger S, Jarvis NJ (2008) Identification of key climatic factors regulating the transport of pesticides in leaching and to tile drains. Pest Manag Sci 64(9):933–944

Noyes PD, Lema SC (2015) Forecasting the impacts of chemical pollution and climate change interactions on the health of wildlife. Curr Zool 61(4):669–689

Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC, Erwin KN, Levin ED (2009) The toxicology of climate change: environmental contaminants in a warming world. Environ Int 35(6):971–986

Otieno PO, Owuor PO, Lalah JO, Pfister G, Schramm KW (2013) Impacts of climate-induced changes on the distribution of pesticides residues in water and sediment of Lake Naivasha, Kenya. Environ Monit Assess 185(3):2723–2733

Paini DR, Sheppard AW, Cook DC, De Barro PJ, Worner SP, Thomas MB (2016) Global threat to agriculture from invasive species. Proc Natl Acad Sci 113(27):7575–7579

Palmu E, Ekroos J, Hanson HI, Smith HG, Hedlund K (2014) Landscape-scale crop diversity interacts with local management to determine ground beetle diversity. Basic Appl Ecol 15(3): 241–249

Paris HS, Stoffella PJ, Powell CA (1993) Sweet potato whitefly, drought stress, and leaf silvering of squash. Hort Sci 28(2):157–158

Pedrick C (2012) Strategies for combating climate change in drylands agriculture: synthesis of dialogues and evidence presented at the International Conference on Food Security in Dry Lands, Doha, Qatar

Peterson RK, Varella AC, Higley LG (2017) Tolerance: the forgotten child of plant resistance. Peer J 5:e3934

Prakash A, Rao J, Mukherjee AK, Berliner J, Pokhare SS, Adak T, Munda S, Shashank PR (2014) Climate change: impact on crop pests. Applied Zoologists Research Association (AZRA), Central Rice Research Institute, Odisha

Prasad CR, Rajesh A, Rao SK, Murthy BR (2021) Seasonal incidence of pod bugs in cowpea (*Vigna unguiculata* L.) in dry land eco-system. J Pharm Innov 10(5):154–158

Pu J, Wang Z, Chung H (2020) Climate change and the genetics of insecticide resistance. Pest Manag Sci 76(3):846–852

Reddy PP (2016) Cultural approaches. In: Sustainable intensification of crop production. Springer, Singapore, pp 289–304

Rosenzweig C, Major DC, Demong K, Stanton C, Horton R, Stults M (2007) Managing climate change risks in New York City’s water system: assessment and adaptation planning. Mitig Adapt Strateg Glob Chang 12(8):1391–1409

Salih AAM, Baraibar M, Mwangi KK, Artan G (2020) Climate change and locust outbreak in East Africa. Nat Clim Chang 10(7):584–585

Satpathy JM, Das MS, Naik K (1997) Effect of multiple and mixed cropping on the incidence of some important pests. J Entomol Res 1(1):78–85

Sconiers WB, Eubanks MD (2017) Not all droughts are created equal? The effects of stress severity on insect herbivore abundance. Arthropod Plant Interact 11(1):45–60

Shapiro-Ilan DI, Cottrell TE, Mizell RF III, Horton DL (2016) Efficacy of *Steinernema carpocapsae* plus fire gel applied as a single spray for control of the lesser peach tree borer, *Synanthedon pictipes*. Biol Control 94:33–36

Sharley DJ, Hoffmann AA, Thomson LJ (2008) Effects of soil tillage on beneficial invertebrates within the vineyard. Agric For Entomol 10:233–243

Sharma HC (2014) Climate change effects on insects: implications for crop protection and food security. J Crop Improv 28(2):229–259

Sharma HC, Ortiz R (2002) Host plant resistance to insects: an eco-friendly approach for pest management and environment conservation. J Environ Biol 23(2):111–135

Skevas T, Stefanou SE, Lansink AO (2013) Do farmers internalise environmental spillovers of pesticides in production? J Agric Econ 64(3):624–640

Smith CM (2004) Plant resistance to arthropods: molecular and conventional approaches. Springer Science & Business Media, Netherlands

Sparks TH, Dennis RL, Croxton PJ, Cade M (2007) Increased migration of lepidoptera linked to climate change. Eur J Entomol 104(1):139

Stout MJ (2014) Host-plant resistance in pest management. In: Integrated pest management. Academic Press, London, pp 1–21

Tang X, Yuan Y, Li X, Zhang J (2021) Maximum entropy modeling to predict the impact of climate change on pine wilt disease in China. Front Plant Sci 12:764

Thomson LJ, Hoffmann AA (2007) Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macroinvertebrates in vineyards. Agric For Entomol 9(3):173–179

Venette RC, Hutchison WD (2021) Invasive insect species: global challenges, strategies & opportunities. Front Insect Sci 1:650520

White TC (1969) An index to measure weather-induced stress of trees associated with outbreaks of psyllids in Australia. Ecology 50(5):905–909

Xiang H, Lan N, Wang F, Zhao B, Wei H, Zhang J (2021) Reduced pests, improved grain quality and greater total income: benefits of intercropping rice with *Pontederia cordata*. J Sci Food Agric 101(14):590–5917

Ximénez-Embún MG, Glas JJ, Ortego F, Alba JM, Castañera P, Kant MR (2017) Drought stress promotes the colonization success of a herbivorous mite that manipulates plant defenses. Exp Appl Acarol 73(3):297–315

Xin M, Wang Y (2021) Image recognition of crop diseases and insect pests based on deep learning. Wirel Commun Mob Comput 2021:5511676

Zaveri E, Russ J, Damania R (2020) Rainfall anomalies are a significant driver of cropland expansion. Proc Natl Acad Sci 117(19):10225–10233