



Impact of climate change on insect pollinators and its implication for food security: a review

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ABSTRACT

Climate change implies change in climate as a result of direct or indirect interference of human activities *i.e.* anthropogenic activities resulting in the change in composition of global atmosphere and climate variability over a comparable period of time. It has been found that global temperature hiked by 0.8°C and is believed to reach 1.1-5.4°C by the 25th century. On the contrary, CO₂ concentration has reached to 370ppm from 280ppm which indicates a drastic change in the concentration of CO₂. The factors like volcanic eruptions, oceanic currents, the orbital movements of the earth and other anthropogenic activities are the reasons for this shift. Change in climate results in a number of changes in insect pollinators such as changes in insect phenology, distribution, biodiversity and interactions with plants. In addition to this climate change is also responsible for habitat loss, nutritional inadequacies and lack of diverse food due to effect of climate change on plant and flower growth. Hence, climate change negatively effects plant and pollinator interactions. As most of the flowering plants are in need of insect pollinators for reproduction and fruit and seed set. Therefore, conservation and protection of these pollinators are prime need for food security and the knowledge on the effect of climate change on pollinators and evolve suitable mechanization to prevent them from getting affected by this climatic modification

Keywords: Anthropogenic activities, climate change, food security, mitigation, pollinators, pollination

Climate in a given region refers to a long-term average pattern of wind, precipitation, humidity, temperature, atmospheric pressure, atmospheric particle count, and other meteorological variables (Rehman and Kumar, 2018). Climate is naturally changing at its own pace since the beginning of evolution of the earth. But presently it has gained momentum due to inadvertent anthropogenic disturbances. Change in climate is now a global concern. Climate change is one of the most serious environmental, economic, and social threats the world has ever faced. Evidence of climate change may be found everywhere, from the top of the atmosphere to the deepest depths of the oceans. The climate system is a complicated system made up of 5 components: the atmosphere, hydrosphere, land surface biosphere and cryosphere and their interactions as well. Internal dynamics, external forcing such as volcanic eruptions and solar fluctuations, and man-made forcing such as changing air composition and land use all affect the climate system throughout time. Phrase climatic variability is frequently used to describe variances in climate statistics over a specific time period, whereas United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change in the global atmosphere caused directly or indirectly by human activities Climatic change can be localized

to a single region or happen all over the planet. The persistence of aberrant conditions is a major distinction between climate variability and change. Occasionally, a once in life time events or chain of events occurs, such as the extraordinary tsunami in the Indian oceans in 2004. Even said, natural climate fluctuation could play a factor. Looking back, if such a season does not occur within next 30 years, it will be referred to as an extraordinary year rather than a climate change. Only a season of extraordinary events that occurs repeatedly in view of regional climate parameters can indicate that a probable climate change has occurred. As per IPCC 1996, world temperature will rise 1.4 to 5.8 °C by the 20th century's end. Throughout the twenty-first century, the average global surface temperature is anticipated to rise by 1.1⁰C (low emission scenario) to 6.4⁰C (high emission scenario), with temperature hikes being greater at higher latitudes (IPCC, 2007). Various factual evidences suggest that regional and global climate changes, particularly temperature rises, affect numerous ecosystems (IPCC, 2007). Climate change according to many researchers (Parmesan, 2006; Walther *et al.*, 2002) may be one of the most significant anthropogenic disturbance factors affecting ecosystem today.

Insects are critical to ecosystem structure and function, accounting for greater than half of the world's estimated 1.5 million species of biodiversity. Insect being cold blooded, are most sensitive creatures to climate change (Samways *et al.*, 1994). On every continent, in every ocean, and in majority of important taxonomic groups, the direct impact of human caused climate change has been established. Plants are increasingly vulnerable to new environmental elements in the modern era, such as solar radiation, high temperature, rise in carbon dioxide level and seasonal fluctuation in rainfall patterns due to natural events and activities of humans and their impact on environment. Global change in climate is thought to have significant impact on insect-plant interactions. They may have a direct or indirect impact on the insect. Direct occurs as a result of changes in behaviour, physiology and life history traits, as well as an indirect by changes in the life history of the host plant.

Climate change and variability causes: The evidence of the change in climate is becoming increasingly clear every day, making it nearly hard for anyone to deny the negative effects of climate change that we are witnessing in many places on a daily basis. Climate change has become a worldwide subject of grave worry for the survival of life on Earth in recent decades. However, the question remains as to what is causing this climatic change. There are various factors that contribute to climate change, which are split into two categories: natural and human-caused.

Eruptions of volcanoes, currents in the oceans, the orbital movement of the earth, and solar variation are all natural factors that can affect the earth's climate. In addition to this, humans are also the major contributors of climate change. These all causes have been elaborated briefly as

NATURAL CAUSES:

Volcanic Eruption: When volcanoes erupt, a considerable amount of sulphur dioxide, ash, water vapour (H₂O) and dust are released into the sky. By increasing planetary reflectivity and cooling the atmosphere, large amounts of ash and gases can alter climatic patterns over time. Aerosol is a term used to describe the small particles released by volcanoes. As they reflect solar radiation back into space, they have a cooling effect on the planet. Volcanic outbursts are uncommon and have a short-term impact on the climate.

Oceanic Currents: The oceans make up the majority of the earth's system. Ocean currents transport a huge amount of heat throughout the globe. The wind blows horizontally across the water surface, causing ocean current patterns to change. The seas play a significant function in deciding carbon dioxide amounts in the atmosphere. Climate change could be influenced by changes in circulations of ocean by allowing carbon dioxide to enter or depart the atmosphere.

Earths orbital shifts: The earth completes a full circuit around the sun every year. Its orbital path deviates by 23.5 degrees from the perpendicular plane. Minor but climatically significant changes in the intensity of seasons can be caused by variations in the earth's tilt. If there is increased tilt, summers will be hotter and winters will be cooler. Summers will be colder, and winters will be milder with less tilt in the seasons. Over ten thousand years, slow movements in the earth's orbit cause modest but climatically significant changes in the intensity of seasons.

Variations in the sun: The sun is the source of energy for globes climate system. The sun's energy production looks to remain constant on a daily basis, despite the fact that it is not, so little variations over time can cause climate change. Because the sun is our climate system's principal source of energy, it is plausible to expect climate change due to changes in the sun's energy production.

Sun and Cosmic rays: Climate change is brought about by natural fluctuations in the solar energy reaching the earth. The location of the sun's energy emission varies slightly from day to day. Over millennia, the interaction between the earth and the sun can change as the sun's energy is distributed throughout the planet's surface in a geographic pattern. The orbit of the earth around the sun is an ellipse, and as it changes shape, the earth comes closer to the sun, resulting in much higher temperatures. The amount of sunlight that reaches the earth's surface is also influenced by the earth's axis location. For about 41,000 years, the angle of rotation of the earth's axis has shifted from 22.10 to 25.50 and back. Summers become warmer and winters become colder as the angle increases. The solar wind is made up of particles emitted by the sun, mostly protons and electrons. These particles approach the earth's surface, but the magnetic field prevents them from reaching it. Solar cosmic rays are more intense implementations of the earth's atmosphere. Cosmic sun rays collide with atoms at the top of the atmosphere, causing massive magnetic field disruptions that destroy power lines and electrical equipment. Changes in solar output are thought to have a direct and indirect impact on our climate by altering the pace at which the earth and atmosphere are heated by the sun. Increased solar radiation absorption causes a rise in temperature, which raises CO₂ levels (Hegland *et al.*, 2011).

Human influence: Back to the 19th century, when the industrial revolution began, influences of humans on climate have hiked considerably. Human activities have resulted in an increase in Greenhouse gas emissions. The three main causes of rising greenhouse gas emissions during the last 250 years have been attributed to fossil fuels, land use, and agriculture.

Greenhouse gases: The planet's natural greenhouse effect happens when certain gases are released into the atmosphere, known as greenhouse gases, enable sunlight to enter and absorb heat radiation.

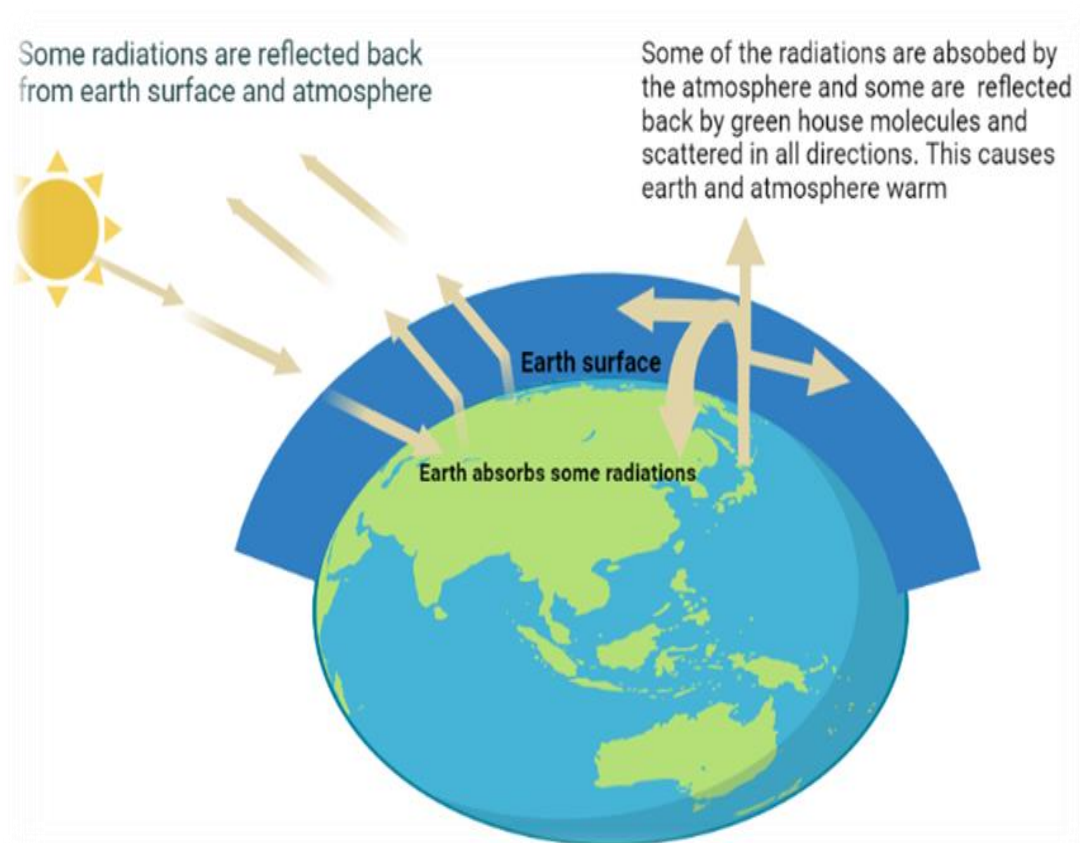


Fig 1: Greenhouse effect

The average surface temperature on the planet maintains around 14 °C due to these gases' ability to absorb heat. Without the natural greenhouse effect, the earth's average surface temperature would be around -19 °C. Since the industrial revolution, human activity has increased the amount of greenhouse gases in the atmosphere. More heat is retained in the atmosphere as a result of the increased quantity of heat absorbing gases, resulting in an increase in global average surface temperature. Global warming is the term for this change in temperature. There are numerous other implications of rising temperatures on the climate system.

The ongoing release of greenhouse gases has the potential to warm the world to levels never seen before in human history; therefore this human-induced enhancement of the greenhouse effect is of concern. The principal greenhouse gases are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFC's). Despite making only a small percentage of the atmosphere, carbon dioxide is one of the most significant greenhouse gases. Volcanic eruptions and animal respiration naturally release carbon dioxide into the atmosphere, but it is also emitted by human activities such as deforestation and fossil fuel combustion. Carbon dioxide also has a lengthy residence time in the atmosphere, amplifying its effects. Methane, the second most important greenhouse gas, is created naturally as well as a result of human activities. The decomposition of organic matter is the most significant generator of methane in anaerobic settings. Another important source is ruminant digestion. Oil drilling, coal mining, leaking gas pipelines, landfills, and sewage ponds are all sources of methane. Methane, despite being significantly less plentiful in the atmosphere, is a more effective greenhouse gas than carbon dioxide because it absorbs more heat. Nitrous oxide (N₂O), a strong greenhouse gas, is generated during the synthesis and use of organic fertilisers. When fossil fuels are burned, it is also produced. CFCs are artificial compounds that are mostly employed in refrigerants and air conditioners. Industrial activity has expanded 40 fold, since the turn of the century, while greenhouse gas emissions have increased 10-fold. Carbon dioxide (CO₂) levels in the atmosphere increased from around roughly 28 parts per million by volume (ppmv) before the turn of the century to 389 ppmv at the end of 2010. In 2050, the level is expected to be 450 parts per million (ppmv), leading in a temperature increase of 1.8 to 3 degrees Celsius. Carbon dioxide level in the atmosphere fluctuate throughout the year due to annual photosynthesis and oxidation cycles fig 1.

Aerosols in the atmosphere: Aerosols in the atmosphere have the power to alter the climate. They have the ability to alter the microphysical and chemical characteristics of clouds as well as their length and extent, by reflecting and absorbing solar and infrared radiation in two primary ways. The world is cooled by solar radiation scattering, while the absorption of solar radiation by aerosols heats the air directly rather than allowing sunlight to be absorbed by the earth. Human activities contribute to the concentration of aerosols in the atmosphere in a variety of means. Agricultural procedures frequently produce dust as a by-product. Depending on the type of raw materials and products, biomass burning and industrial operations produce a wide range of aerosols. Exhaust from transportation emits contaminants that are either aerosols at the onset or are converted to aerosols afterwards (Fytli *et al.*, 2008).

Land use change: Changes in land use, such as clearing forests to make way for farming, have resulted in changes in the amount of sunlight reflected from the ground back into space. The magnitude of these changes is estimated to be around one-fifth of the global climate forcing caused by variations in greenhouse gas emissions. Deforestation is thought to have the greatest impact at high latitudes, where the albedo of previously forested area has increased. This is because snow on trees only reflects about half of the sunlight that falls on them, but snow on open ground reflects about two-thirds. Agriculture alters the earth's land cover, which can modify its ability to absorb or reflect heat and light, and hence contributes to climate change. Deforestation and desertification, as well as the burning of fossil fuels, are major anthropogenic sources of carbon dioxide emission into the atmosphere.

Deforestation: Rainforests are part of a complex ecology that has evolved over millions of years. Because rainforests absorb approximately 20% of human caused emissions each year, so climate change may be exacerbated by deforestation. The carbon cycle is harmed when rainforests are cut down faster than they can be regenerated, contributing 17 per cent more carbon dioxide to the atmosphere. Deforestation, which involves chopping down and burning tropical rain forests, is frequently done to make room for farming and industries, both of which release more CO₂. The forest reduces the damage by converting carbon dioxide into glucose through photosynthesis. About 125 per cent of the carbon in the atmosphere is stored in the world's forests. Carbon sequestration is the process of storing carbon in wood and vegetation. Forest biomass acts as a carbon sink since trees contain roughly 20% of carbon by weight. Organic matter generated in the soil as a result of the breakdown of dead plant material can also be used to store carbon.

Economic value of insect pollinators: Around 90% of higher plants depend on animals to pollinate their flowers so that they can reproduce properly (Nabhan and Buchmann, 1997). Insects are the most important animal agents that provide this ecological service to plants (Proctor *et al.*, 1996). More than 20,000 species of wild bees, domesticated bees and other well-known pollinators are responsible for 23 to 577 billion US dollars in annual global food production (FAO, 2016). In the past 50 years a threefold increase in the global agricultural food production was evident due to pollination by insects (Entomophily) and other animals (Zoophily). Entomophily and Zoophily, in addition to food production, provide substantial contributions in production of bio fuels, fibres, pharmaceuticals, feeds and fodder for live-stocks etc. It is also believed that 80 % of the world's 250,000 flowering plants produce 15% to 30% of the world's food supply, with insects

mostly pollinating these plants. Between million –three million animal species, mostly insects are involved in this important ecosystem services, which has a global economic worth of 200 billion dollars and a value of 40 billion dollars in the United States alone. The annual value of pollination services provided by honey bees in the United States is at 15 billion US dollars, according to a report issued by the United States Department of Agriculture in 2018 calculating 655.6 million us dollars in the case of marketed bees (Bond *et al.* 2014). In Europe, insects, notably bees, pollinate 84 per cent of agricultural crops directly (Williams, 1994). Wild bees are also known to pollinate a wide range of plants (Greenleaf and Kremen, 2006; Kremen *et al.* 2002; Winfree *et al.*, 2007). Some estimated the global economic value of direct insect pollination to be 153 billion dollars. This represents 9.5 per cent of the entire value of global human food production.

Apis mellifera colonies are thought to number 81 million worldwide, with beehive consisting of between 30,000 and 80,000 bees in the low season and peak season respectively. Humans have been associated with *A. mellifera* for a long time; they are depicted in one of the earliest known rock formations from the Holocene Epoch, dating back 10,000 years (Marshman *et al.*, 2019). The importance of pollination services and contribution to human food sources has sparked renewed interest in *A. mellifera* in recent years. The influence of pollinators contribution to medicine, fibre and culture as well as their position as a food source for other species, is one of the least explored elements of pollinator loss. Insect pollination is required by 90 per cent of blooming plants, including food crops. Insect-pollinated blooming plants give not only food, but also instructive and hands-on learning opportunities in schoolyards and gardens, as well as therapeutic advantages provided by gardens for long time, hospital and horticultural treatment programmes. There exists an expanding amount of research on the wellbeing and health advantages of being in nature, much of which is reliant on bees for the purpose of aesthetic appeal and reproduction. The study acknowledges the importance of pollinators and the need to support nature's long-term use and its consequences for quality of life.

Why are pollinators so important: Have we considered what it might be like to live in a world without flowers or fruits? Much of the food we eat, as well as the flowers and plants we appreciate, are made possible by the remarkable work of pollinators like bees. It is not only the bees who do all the effort. Pollination is also carried out by butterflies, birds, beetles, bats, wasps and even flies. However despite their importance, pollinators are sometimes overlooked. Populations are declining at an alarming rate around the world. The main factors are excessive pesticide usage and ever increasing conversion of landscape to human use. More than 1,300 different plant species are grown for food, beverages, pharmaceuticals, condiments, species and even clothes around the world (Nabhan and Buchmann, 1997). Around 75% of them are pollinated by animals; Pollinators are directly responsible for more than one out of every three bits of food or drinks we consume. Pollinators indirectly contribute to the bulk of what we eat and consume. Bees play an important role in maintaining a healthy environment and economy. They are also incredibly attractive and fascinating insects. We may take pollinators for granted, but they are essential for guaranteeing stable and nutritious food sources. They provide us with diets that are varied, colourful, and nutritious. Bees are built to help plants grow, reproduce, and provide food. They do so by transferring pollen from flowering plants, ensuring that the life cycle continues. Bees, on the other hand, are in difficulty. Bee depletion is causing increasing public and political worry around the world. The loss of habitat and food supplies as well as pesticide exposure and the consequences of climate change are all contributing to this reduction. We need to recognize the value of bees in nature and in our lives now more than ever and we must put one word into action to ensure that they not just survive but thrive. Not all bees are created equal. Bees are found in approximately 20,000 different species around the world. In the United Kingdom, there are over 270 species of bees. Only one of them is the well-known *i.e.* honeybee. Pollinators are fundamental for the creation and upkeep of environments and biological systems that give food and heaven to numerous species. Over portion of the fats and oils consumed overall come from creature pollinated crops. They help in generation of 90% of all blooming plants in the world. We have the power to change your living environment for the better. In your landscaping, use a variety of flowering plants and encourage native species. Pesticides should only be used when absolutely necessary, and then only late in the day or evening. Before resorting to a quick fix, consider other options for dealing with insect and disease problems. These frequently come at a cost. Learn about IPM and put it into practice (Integrated Pest Management). Pollinator populations in your environment might be reduced or increased depending on the actions you take in and around your garden. Aside from the large number of hives located around the world, *A. mellifera* is a well-managed species with numerous multiplying programmes all over the world. Instead, native species of bees have been designated as being endangered or threatened in Canada. The federal government declared the species at Risk Act (SARA) in 2003 to safeguard wildlife. The act's purpose is to prevent the extinction of Canadian indigenous species, subspecies, and populations, to aid in the retrieval of threatened or vulnerable species, and to assist in the management of other species to prevent their extinction. The SARA plans are implemented and coordinated by the Department of Environment and Climate Change. Disappearance of bees would not just have an impact on

agriculture; the economic consequences of this loss of industry would be disastrous. Sustain estimates that the ecological consequences of global bee extinction could cost billions of dollars. Farmers would be among the most affected by this development, as manually pollinating their crops might cost £2 billion each year in the United Kingdom. According to the Obama White House Archives, pollination by bees contributes \$24 billion to the US economy, which is a significant amount of money to be lost. Bees are a source of concern that spans continents and generations. Bees have captivated our attention in a variety of settings, including elementary schools, horticultural organizations, and mainstream media campaigns. Concerns about bees increased as a result of a problem known as CCD (Colony Collapse Disorder) that happens when all maintained colonies perish or vanish unexpectedly. In the 2006 and 2007 season, beekeepers of United States lost 30-90 per cent of their Italian bee colonies. Although no single cause of CCD has been identified, various factors have been linked to it that include pesticide use, poor diet, and elevated viral, bacterial, and parasite burdens. Overwinter losses of up to 20% are commonly cited by beekeepers as acceptable, suggesting that about 20% of the hives perish throughout the winter. Amid 2017-2018 winters, beekeepers of Canada lost about 33% of their hives. Although data on the amount and health of North America's 4000 indigenous bee species is scant, tracking and quantifying population and loss for *A. mellifera* colonies is well established. Overall, data suggests that wild pollinators are decreasing in number and dispersion. According to evidence, change in climate is expected to be a great contributor of species extinction over the next 100 years. Anthropogenic climate change, which, along with urbanisation and agriculture, is replacing woods, fields and pastures, thus causing one of the most serious threats to habitat of pollinators (Marshman *et al.*, 2019). In Ontario's Pollinator Health Action Plan, climate change is listed as one of the most significant stressors for bees. Changes in the seasonal timing of pollinator emergence and plant blossoming are one of the most concerning effects of climate change. Habitat ranges are impacted by climate change. Bumble bee species, in particular, do not appear to be following projected warming patterns. Bumble bee species do not follow warming patterns, according to long-term monitoring in North America and Europe in 2015. Plants and pollinators became decoupled, and species relationships and fertility between species changed as a result. With the risks to Italian bee caused by monoculture and evidence of decreasing populations of insects around the world, a global, coordinated effort to save bees is essential.

Impact of changing climate on pollination and pollinators: Pollination is assumed to be a sophisticated mechanism that has evolved over at least 100 million years in the evolution of blooming plants. It is an important stage in the development of fruit and seeds as well as the propagation of blossoming plants; flowering plants cannot replicate seeds without pollination. Pollination is essential for pollen tube formation and subsequent ovule fertilisation in blooming plants and in this process, insect pollinators play an important role (Dhakal, 2003). Fruit crops, vegetable crops, spices, oilseed crops, and fodder crops all benefit from pollination since it boosts their productivity and quality (Partap and Partap, 1997; Thapa and Forrest, 2006; Pudasaini, 2014). Pollination is under threat due to rising population needs, dwindling natural resource bases, and global climate change (Fand, 2012). Humidity, precipitation, temperature, and the frequency and intensity of extreme events will all be affected by climate change, which will have an impact on pollinators. Other crucial parameters of the environment such as snowpack, snow melt timing, and the intensity and drought frequency and floods, all of which can have an impact on pollinators and their host plants, are all affected by these abiotic variables. Changes in species distribution, phenology, physiological processing rates, species interaction, and the quantity, quality and diversity of floral resources will all have an impact on pollinators due to climate change. Insect pollinators, play an essential role in global production through pollination services (Losey and Vaughan, 2006). Previous study has shown that as temperature changes across a geographic range, population abundance and pollination activities of essential pollinator species including bees, moths, and butterflies decrease (FAO, 2008). Flowering, pollination, and fruiting have all been discovered to be critical events in the growth phases of plants have also been discovered to be strongly affected by climate conditions such as temperature and water availability (Cleland *et al.*, 2007). The majority of flowering plants require insect pollinators for reproduction and the development of fruit and seed. Honey bees are unquestionably the most important pollinators due to their floral fidelity. Pollination by insects, principally bees, is required for 75% of the crops consumed directly by humans around the world. As a result, entomophilous pollination plays a critical role in the production of one-third of the world's human food (Klein *et al.*, 2007). Some insects, such as silkworms that produce silk, lac insects that produce lac, and honeybees that produce honey, wax, and other products, directly contribute to human economy (Murugan, 2006). Climate change may jeopardise pollination services even further (Memmott *et al.*, 2007; Hegland *et al.*, 2009; Schweiger *et al.*, 2010). Our knowledge of how climate change affects mutualistic interactions, on the other hand, is limited (Walther *et al.* 2002; Visser and Both, 2005).

Climate change is intimately linked to habitat loss, nutritional inadequacies, and a lack of diverse foods due to the abnormal climate's impact on plant and flower growth. Despite the fact that wild bee populations appear to be far free from human exploitation, they are threatened by anthropogenic climate change. Climate change is most likely to cause harm to bees because of disruptions in the network of plant pollinators. Pollination of flowering plants by pollinator species creates mutually beneficial interactions in this network.

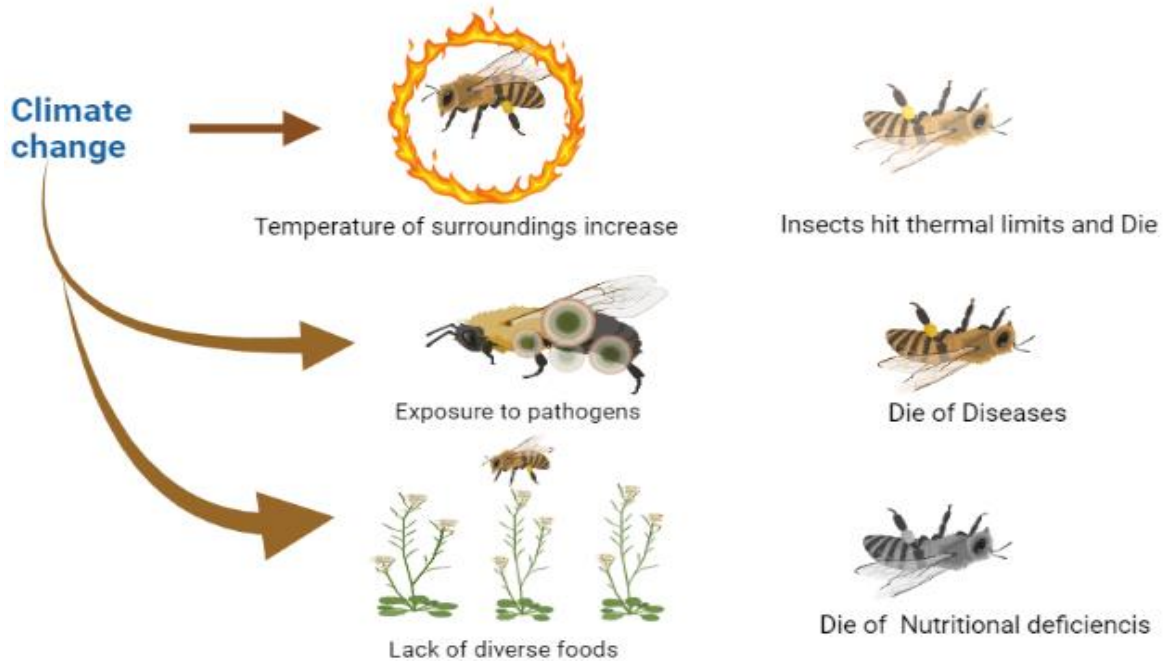


Fig 2: Changing climate impact on pollinators

In order to reproduce, plant species rely on pollinators dropping pollen from other appropriate plants by accident (Ollerton *et al.*, 2011), while pollinators require pollen and nectar to survive (Memmott *et al.*, 2007). Plants and pollinators are so interlinked that disturbances in one population might have a negative impact on the other. The environmental cues that flowering plants rely on to start growth are threatened by rising temperatures. In the case of bees, phenology refers to the time of seasonal activity of animals and plants, which is typically impacted by weather and environment. Temperature, rather than increasing, influences the phenology (time) of blossoming in flowering plants. The phenology (time) of blossoming in flowering plants is influenced by temperature rather than rising CO_2 levels or nitrogen deposition due to changing climate (Walther *et al.* 2002). When it comes to alpine meadows with winter snowpack, the timing of flowering is mostly governed by the timing of snow pack melting in the spring. Because of rising temperatures as a result of climate change, more precipitation falls as rain rather than snow, the snowpack will melt earlier in the spring. Snowmelt warms the ground, allowing plants to increase carbon dioxide levels or nitrogen deposition as a result of climate change. Snowmelt may serve as a phenology trigger or a threshold for when plants can start to grow, with temperature controlling the rate of growth (Forrest and Thomson, 2011). Several studies have found that as a result of warming and/or early snowmelt, flowering phenology has shifted earlier (Jaagus and Ahas, 2002; Fitter and Fitter, 2002; Inouye *et al.*, 2002). For example, a 2.4 °C increase in temperature in Concord, Massachusetts from 1852 to 2006 was associated with a seven-day shift in flowering timing. For every two weeks of earlier snowmelt, the advance in flowering is 11 days according to the experiment. Furthermore, most phenological studies have the potential to overestimate plant responses to climate change. Flowers are blooming half a day earlier each year as a result of global warming. Finally, plants that flower earlier have not been pollinated, causing pollinators to become malnourished. Changes in flowering timing may cause reproductive failure in some plant species. Not only may the plant's early blossoming be due to a lack of pollinators, but flowering can be at different time than neighbouring companions (Hegland *et al.*, 2009). Plants that bloom too soon might not be able to give their young with time-sensitive food sources. Plants use contextual cues to predict when the best food resources will be available, and thus when they should start growing, because growth and reproduction require food. Because of natural selection's affinity for certain cues, changes in climate can cause them to no longer accurately anticipate food availability. As a result, offspring may be unable to obtain sufficient food to ensure their survival. Climate change has an impact on pollinator species as well. The majority of insect

pollinators are small and poikilothermic, which means they can't regulate their body temperature through behaviour. As a result, temperature has a large impact on their life cycle and behaviour (Hegland *et al.*, 2009; Memmott *et al.*, 2007) e.g., between 2001 and 2007, the spring timing of bumble bee flight activity advanced by about 2 weeks, because of the rising soil temperatures, the young bumble bee queens, who are the only ones who survive the winter, are more likely to have emerged from hibernation during the early spring (Sparks and Collinson, 2007; Alford, 1969). Another study conducted in Spain between 1952 and 2014 found that the Italian bee population began to come earlier in the spring in the mid-1970s, indicating that they had adapted to greater temperatures faster by coming earlier in the spring since the mid-1970s (Gordo and Sanz, 2006). Climate change, on the other hand, is likely to have a variety of effects on pollinator species, including physiological changes in individuals, changes in emergence cues, and temporal oscillations in the flowering of the plants they rely on. If temperatures rise too high in some regions, insect pollinators may hit thermal limits that they cannot withstand (Bale and Hayward, 2010). On the contrary, if humidity raises exposure of pollinators to pathogens increases fig 2.

Due to climate change, there may be a misalignment between flowering and pollinator activity, placing the food resource needed for pollinator survival and reproduction in peril (Boggs and Ross, 1993). As pollinators and flowering plants co-evolved to coordinate their activities, the indirect impact of warming on mutualistic interactions could be even more damaging than individual tolerance, resulting in potential mismatches and putting plants and pollinators at risk of extinction. Pollinator and plant species have varying degrees of sensitivity to warming, resulting in timing mismatches between blooming and pollinator activity (Donnelly, 2011). Flowering and pollinator phenology are most likely to alter sooner, although to varying degrees. There is insufficient evidence to conclusively demonstrate how pollinator population losses are linked to flowering shifts. A 30-year dataset of butterflies actually shifted later due to differential reliance on environmental cues, while flowering shifted earlier. The temperature of the preceding month's temperature determined the timing of flower emergence in this example, although the temperature of the 15 days previously to appearance influenced the butterflies to a lesser extent. As a result, butterflies did not pollinate the first-flowering plants (Doi *et al.*, 2008). As a result, while most pollinators emerge in early spring, others may appear later. Differences in climate change responses will produce a tangle of unpredictable results. Certain plant pollinator pairings are likely to stop interacting altogether due to temporal incompatibilities. From 1974 to 2009, phenological records in the southern rocky highlands revealed times of less flower abundance at the time of mid-summer that can affect attractive pollinators if they don't get enough nectar and pollen (Aldridge *et al.*, 2011). Plant-pollinators can be influenced by Asynchrony in other, more ways. Many plant species, examples have evolved to flower in a precise order in order to maintain healthy populations of pollinators during the entire summer season (Waser and Real, 1979). Early in the summer, honey bees pollinate the *Gilia capitata* in the study meadows before moving on to *Eriophyllum lanatum* and later in the summer, *Eriogonum compositum*. On the other side, Bumble bee, *Bombus mixtus* pollinate *Delphinium nuttalianum* in the early summer and *Orthocarpus bricatus* blooms later in the summer season. Both the species of bees depend on several plants for a continuous source of food throughout the summer. Asynchronies may arise if the flowering sequence is disrupted by climate change, resulting in a pollinator scarcity for later flowering species (Waser and Real, 1979).

Synchronization is the process through which plant species collaborate to increase the availability of nectar and pollen to attract more insect pollinators. The quantity of pollinators' attention will be changed due to temporal mismatches between different plant species (Tachiki *et al.*, 2010). The honey bees at the research site, for example, had a diverse and beautiful display of flowers to fertilise throughout the summer. The pale blooms of *Ligusticum grayi* arrive after the lavender inflorescence of *Gilia capitata* in the early part of the season, while scarlet blossoms of *Rumex acetosella* and the bursting, sunshine-like flowers of *Eriophyllum lanatum* appear later. Honey bees would be negligent if they didn't take advantage of such a warm welcome. Asynchronous events may have a higher impact on pollinators than on plants. Plants that haven't been pollinated have the ability to self-fertilize but this isn't a long-term solution because self-pollinated seeds have lower fecundity and survival than cross-pollinated seeds. Pollinators, on the other hand, rely solely on nectar and pollen to survive (Memmott *et al.*, 2007). One study used Illinois plant pollinator data from 1884 to 1916 to estimate that 17-50 per cent of all pollinator species may encounter food shortages as a result of changing climate. A complete scarcity of food, food-free intervals near the end of the season, or a temporal omission in food supply can all affect pollinators. Specialist pollinators, according to the study, may be more vulnerable than generalist pollinators. Pollinators rely on only a few plant species for pollen, so a mismatch could result in pollinator scarcity (Memmott *et al.*, 2007; Donnelly, 2011). Honey bees, for example, have a diverse diet, extensive regional migrations, and long foraging seasons, all of which aid them in adapting to changes in flowering phenology. On the other hand, generalists may continue to suffer as a result of their diet's narrowing. Specialist pollinators, who are better suited to adapt to climate change, are more likely to visit specialistic plants than generalist plants that can be visited by a variety of pollinators (Bascompte *et al.*,

2003) because of their potential to self-reproduce in the short term and their lack of absolute need on sensitive specialised pollinators, plants are likely to suffer less than pollinators. Climate change has a number of subtle consequences on the network of plant pollinators. Some of the processes by which phenological variations can disrupt these networks are summarized in fig 3:

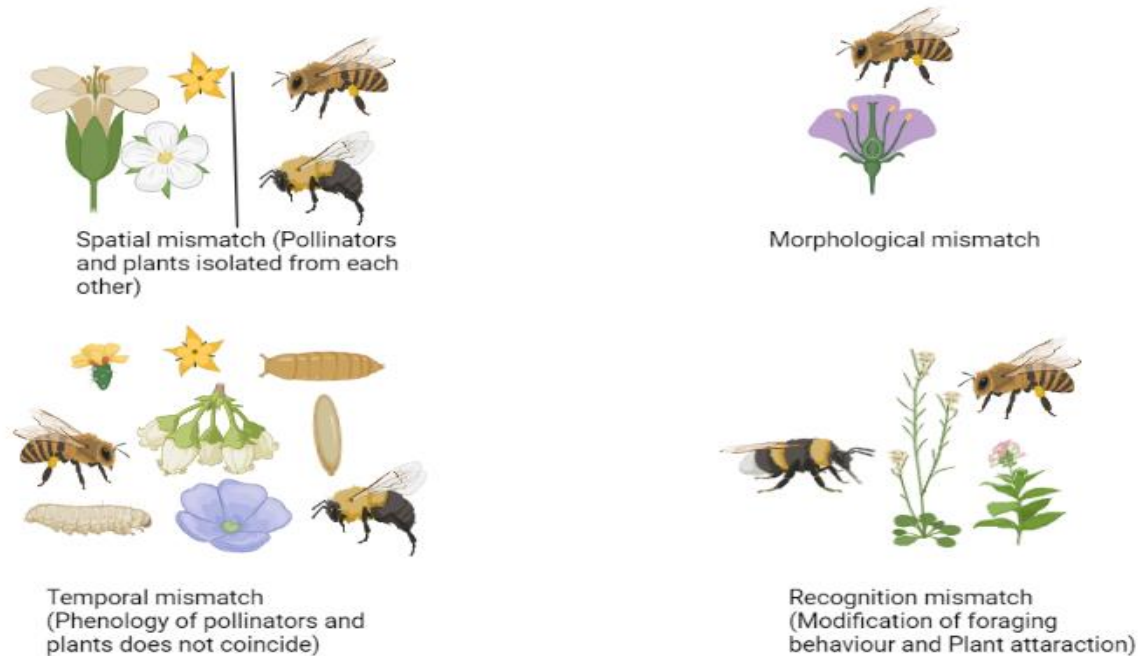


Fig 3: Disruption of plant-pollinator interaction

Climate change has a variety of effect on honey bees. It has the capacity to influence their behaviour and physiology directly. It can also affect the development cycle and impact the quality of the floral environment by increasing or decreasing pollen gathering capability (Le Conte and Navajas, 2003). All bees with a body weight greater than 35mg are capable of endothermic heating (Ziska *et al.*, 2016). As a result of bee's behavioural adjustments to avoid extreme temperatures, pollination services may be jeopardised. Foraging suffers as a result of the time it takes to regulate temperature at a higher temperature (Bishop and Armbruster, 1999). Pollinators are at risk of overheating as pollen removal and deposition efficiency varies, particularly in areas where ambient temperatures are high and climatic conditions remain stable as temperatures rise. There may be a decline in the co-occurrence of interacting partners, as well as mismatches in plant-pollinator interactions, in a shared environment, and this decrease could be temporal or geographical. Such temporal misalignments between plants and pollinating insects have recently received a lot of attention. These mismatches can be caused by changes in the flowering season of the plants and the phenology of the pollinators, both of which can be advanced or delayed. Depending on the adaptability and life cycle traits of the species in issue, the geographical overlap between interacting partners may decrease or grow as a result of global warming. Food security, species variety, ecological stability, and climate change resilience are all affected by pollination quality and quantity (FAO, 2008).

Climate change mitigation effects on pollinators: Given the numerous ways in which climate change could impact pollinators, efforts to mitigate these negative repercussions are likely to aid pollinator populations in the future. By updating and restoring pollinator habitat, it is vital to strengthen pollinator communities' climate resilience. Large, stable, and diverse pollinator groups require habitat with plentiful pollinator-friendly floral resources that bloom all year, as well as the ability to resist bad years and severe weather events, which are becoming more prevalent due to climate change. Pollination is an ecosystem service that requires a diversified pollinator community to function. In the event of future climate shifts, protecting and upgrading habitat today can assist to ensure that suitable habitat for threatened and endangered species, as well as host plant specialists, will be available. Improving habitat connectivity is another important part of developing a climate-resilient environment. Farms, roadsides, and urban habitat are critical for connecting larger natural regions that might act as pollinator diversity reservoirs. Using habitat corridors and stepping stones, bees, butterflies, and other insects can move through the environment and

migrate to new locations. While not all species will adapt to climate change, those that do will benefit from enhanced habitat connectivity. As habitat connectivity increases, individuals will be able to migrate across populations, encouraging gene flow and preventing populations from becoming too small. This strategy will help to alleviate the effects of phenological mismatches between pollinators and hosts by ensuring that some plants are available. Specialist pollinators who require specific plant species, on the other hand, may gain more from this. Pollinators will be impacted by changing climate in terms of the number and quality of floral resources accessible to them. Drought-stressed plants produce fewer blooms and produce less nectar, reducing pollinator carrying capacity. Climate change-related abiotic factors, like as rising temperatures and carbon dioxide concentrations in the atmosphere, may have effect on the quality and quantity of nectar and pollen, as well as flower attractiveness to pollinators (Glenny *et al.*, 2018; Paray *et al.*, 2019). Pollinators will benefit from a diverse range of flowering plants because the effects of climate change on these plant features are expected to be species specific. This type of species-specific reaction to climate change may have an impact on some pollinators. Pollinators will benefit from a varied range of blooming plants as the effects of climate change on these plant traits are predicted to be species specific. Finally, a diverse plant species will have more habitat variability, which will allow pollinators to experience a variety of microclimates during heat waves and other extreme weather events. Use of drought- and heat-tolerant natural plants because drought frequency and severity are likely to increase in the future, integrating drought-tolerant native plant species in bee habitat will help ensure that pollinators have access to floral resources even during dry years. Make sure native bees have somewhere to build their nests. The great majority of bees are solitary, dwelling in the ground or in the woods, and most people associated with bees think about honey bee hives or bumble bee nests. Around 70% of native bees build their nests in the ground; therefore, keeping some soil exposed will give these species greater possibilities to do so. Native bees lay their eggs in wood or pithy stemmed plants in roughly 30% of cases. Some of these species will use fallen logs and snags as nesting sites, while others will use natural, pithy stemmed plants like elderberry. Pollinators are more likely to find the necessary breeding locations and resources in a diversified plant environment. Pollinator paths should be made available. In order to traverse the terrain in pursuit of new climate niches, pollinators will require high-quality travel routes and stepping stone habitats. Farms, range lands, roadside vegetation, and urban and suburban parks are just a few examples of urban and rural landscapes that could provide habitat connections. According to new research, existing linear habitat such as field boundaries, hedge rows, roadsides, and greenways can function as pollinator corridors. As the temperature changes, providing additional habitat along roadside corridors, as well as preserving and repairing far-flung habitat, may allow for more habitable locations. Other sources of stress for native pollinators should be eliminated. Other pressures on pollinators can be exacerbated by climate change. The cumulative impact of multiple stressors is frequently more than expected based on the impacts of each stressor separately, amplifying adverse pollinator consequences. To help pollinators cope with the consequences of climate change, efforts must be taken to reduce other key stressors such as pesticide exposure and diseases. Pesticides should be used less often. Due to quicker development rates and increased performance of insect pests envisaged at warmer temperatures, pesticide use is expected to rise as a result of climate change (Delcour *et al.*, 2015). Pollinators can be harmed by pesticides such as insecticides, fungicides, and herbicides. Furthermore, pollinators are exposed to a variety of pesticides on a regular basis, potentially magnifying the negative effects of each chemical. The negative effects on many pollinator species could be magnified if these exposures are combined with climate change. Pesticides should only be used when pest levels are causing economic harm, and physical, mechanical, and other non-chemical pest management measures should be incorporated into pest management systems. Fungicide impacts on pollinators include advice for habitat installation near treated areas as well as methods of implementing various mitigation measures. By planning and implementing an integrated pest management plan and trying to reduce chemical dependency, the overall number of stressors on pollinators can be reduced, making pollinator colonies more resilient to climate change's effects. Pathogen exposure is certainly a major factor in many native bee reduction. Commercial bumble bees, honey bees and Megachilid bees are examples of managed pollinators that can spread disease to wild bees. To reduce disease exposure to native pollinators, it is recommended that managed bees be deployed as far away from native pollinator habitat as possible in natural areas. It is not suggested to use managed bumble bee colonies on open fields. In greenhouses with managed bees, queen excluders should be employed to prevent the managed bees from escaping. Keep a high level of genetic diversity, species must either migrate to a more suitable climate or adapt to the new climate as a result of climate change. Those who are unable to adapt or migrate will die. The ability of a population to adapt to climatic change is determined by the amount of genetic variety in the population. Pollinators and their host plants may be more resilient to climate change if conservation approaches that increase and maintain genetic diversity are used (Sgro *et al.*, 2011). Increased habitat availability and connectivity, which boosts population sizes, will also increase genetic diversity because larger populations have more genetic variation than smaller populations. By enhancing gene flow, high

habitat connectedness improves genetic diversity. Natural areas are valuable because they provide ideal habitat for a wide range of pollinators. On some farms, natural spaces around farms have been shown to improve pollinator services. Healthy ecosystems operate as carbon sinks; supplying natural climate solutions that can aid in meeting international climate change goals (Grissom *et al.* 2017) thereby mitigate climate change's effects on pollinators and other creatures. Several insect crop pests may increase feeding rates and population proliferation as temperatures rise due to climate change. As a result, pesticide consumption is predicted to rise due to climate change (Glenny *et al.* 2018). Hedgerows and cover crops promote the establishment of beneficial insects like predators, lowering pesticide use. Pollinator and beneficial insect habitat should not be contaminated with pesticides. Integrated pest management and other options could help to reduce the use of pesticides. Pesticide use in agriculture can be lowered while profits and output are maintained (Lechenet *et al.*, 2017; Catarino *et al.*, 2019).

Climate change impact for food security: To fulfil the requirements of an ever-growing population, the most difficult issue in the twenty-first century will be to quadruple food production while maintaining a sustainable natural resource base (Deka *et al.*, 2008). As a result of shifting climatic regimes, pollinator difficulties are expected to grow, posing a threat to food security in countries where agriculture is largely relied. Climate change is projected to affect the breadth of entomophily pollination by disrupting the synchronisation of plant–pollinator life cycles (Kudo *et al.*, 2004) resulting in a one-third reduction in world food supply (Klein *et al.*, 2007). This could have a direct impact on the lives of the rural poor, whose survival is inextricably related to the food production system's outcomes. Food prices could rise as a result of decreasing output, putting a strain on the urban population (IPCC, 2007). Pollinators perform a unique role in our daily lives, pollinating roughly 35% of worldwide crop production. Other pollinators include flies, wasps, beetles, bats, and other insects, but bees are responsible for 70% of biotic pollination. Pollination by bees contributes significantly to food security because entire ecosystems rely on insect and other pollinator pollination.

Pollinator species that are not regulated are referred to as "wild Pollinators." In Canada, there are over 850 native wild pollinator species, the majority of which are solitary bees that build their homes in the ground. Many pollinators in the wild are generalists, meaning they eat a wide range of plants. Others are specialists, having co-evolved in physiology or behaviour with specific plant species to form a mutually beneficial relationship. Despite the fact that some bees, such as bumble bees, are generalists, they may exhibit particular behaviour that allows them to consume and pollinate plants efficiently. Sonication or buzz pollination, for example, is used by some bee species. Some bees collect pollen from blooms with small pores for pollen to escape via sonication. Sonication is beneficial to a variety of agricultural crops, including blueberries, cranberries, kiwis, chilli peppers, eggplants, and tomatoes. Some native bee species, notably those of the genus *Bombus*, can undertake floral sonication. *A. mellifera* lacks this ability and has been shown to be ineffective pollinators of these types of crops. Pollinators and pollinator diversity decline, resulting in the extinction of both co-evolved and generalist plants that rely on insect pollination to reproduce. Plant diversity loss should be at the forefront of ecological concerns, especially given the extra issues offered by a changing climate, because we have yet to uncover the tipping points for ecological breakdown. Pollination has an estimated yearly market value of up to \$577 billion USD, accounting for around 10% of the worldwide crop market. Changes in crop production without these biotic pollination services could raise consumer costs and cost producers about \$2 billion annually. Pollination will be hampered in the future due to a dearth of pollinating insects, implying a greater necessity for hand pollination (or innovative technology). Hand pollination has the potential to be highly costly in terms of labour, with costs in the United States alone estimated at \$90 billion each year. This anticipated increase in food production costs would lead to higher food prices, potentially resulting in a new form of food elitism in which only those who can afford the higher food costs can eat those foods. Given that many poor people already struggle to get affordable food, this could exacerbate an already considerable obstacle to obtaining nutritious and sufficient food. There are also dietary repercussions, in addition to the economic issues highlighted by threats to pollinators around the world. Pollinators play an important part in urban agriculture around the world. Food insecurity, global climate change, the urban heat island effect, various types of malnutrition, and the development of more sustainable and resilient communities are all benefits of urban agriculture. Urban agriculture is not a new concept; humans have been cultivated food and rearing animals within city bounds for as long as cities have existed. Urban agriculture, also known as urban self-growing, is presently practised by over 800 million people worldwide.

A lack of pollination in areas already sensitive to nutritional deficits could increase vitamin A, iron, and folate shortages. Micronutrient deficiencies, commonly referred to as "hidden hunger," can make it difficult for people to thrive and have long-term health consequences. Plants that rely on pollinators contain around 90% vitamin C, 100% lycopene, practically the full amount of the anti-oxidants b-cryptoxanthin and b-

tocopherol, the majority of lipids, vitamin A, and so on. These data show that a drop in pollinator populations could lead to an increase in diseases linked to a healthy diet that are preventable. By affecting the synchrony of plant pollinator life cycles, climate change is expected to have an impact on the extent of entomophilous pollination (Kudo *et al.*, 2004). This has a profound impact on food security and nutrition (FAO, 2008). This could have a direct impact on the rural poor's survival, as the outcome of food production systems is intrinsically linked to their survival. Increased food prices as a result of reduced food production may have a negative impact on the urban population (Fand *et al.*, 2012). Understanding and tackling the difficulties of abiotic stresses and pollinator–plant interactions under changing climate conditions is without a doubt a priority. Given the potential impact of future climate change on agricultural sustainability and productivity, particularly in developing countries, farmers, extension workers, and other supply chain management stakeholders in India must be educated on the impact of climate change on insect pollinators, as well as the various adaptation strategies available to address the situation. This can be accomplished through public awareness campaigns, training and capacity-building programmes, the creation of learning materials and support guides for specific insect pollinator risk scenarios, and other means. Farmer's decision-making and adaptive capability can be enhanced by combining a participatory and interdisciplinary research technique that includes research and development organisations as equal partners with farmers. This will help to strengthen contact between researchers and farmers in order to disseminate knowledge and information about current weather and climate data advancements. Humanity is confronted with a severe problem in the shape of a diminishing resource base as a result of anthropogenic development. Farmers who implement climate-friendly strategies such as integrated pest management, biocontrol, and habitat preservation for critical insect pollinators, among other things, can benefit financially from financial incentives. Combining scientific and indigenous technological competence in adaptation and coping measures could be advantageous, particularly in developing countries with little technology. ITK can help you adapt to the harmful effects of climate change.

CONCLUSION

For humanity, climate change is an once-in-a-lifetime problem. While this issue may sound daunting, we can take steps to minimize the effects of climate change and make pollinators more resilient to them. We can increase pollinator habitat availability and connectivity by taking benefit of the various opportunities provided by urban areas, agricultural areas and natural ecosystems. Many insect pollinators have mutually beneficial ecological relationships with their host plants, which are likely to be influenced by climate change. At the long run, this disruption will put the survival, reproduction, and habitat of both plants and insect pollinators in jeopardy, potentially leading to extinction. Finally, environmental interference with pollination would have a detrimental influence on the global economy in terms of food production. Addressing the climate change is a tough task due to its complexity, ambiguity, unpredictability, and changing effects throughout time and geography. Understanding abiotic stress responses in insect–plant interactions is a fundamental challenge in agricultural science. Climate change impacts on crop outputs must be studied, as mediated by changes in insect pollinator populations, in order to determine the possible effects of climate change on crop protection and establish appropriate treatments.

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