Scientific Papers. Series A. Agronomy, Vol. LXVII, No. 1, 2024
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

MAIZE INSECT PEST MANAGEMENT IN A CHANGING CLIMATE - A REVIEW

Andrei CHIRILOAIE-PALADE[1, 2], Mihai GÎDEA[2], Valentin-Marius CIONTU[1, 2], Raluca-Gabriela GEORGESCU[1]

[1]Research-Development Institute for Plant Protection, 8 Ion Ionescu de la Brad Blvd, 013813, District 1, Bucharest, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, 011464, Bucharest, Romania

Corresponding author email: andrei.chiriloaie@gmail.com

Abstract

Due to human activity, climate change has emerged as one of the most important issues of our time. Climate change has been generally recognized to have an impact on rising temperatures and extreme weather events, but it also has an equally serious impact on agricultural systems, particularly with regard to insect pests. The role of insect pests holds substantial importance in determining global food security and the sustainability of agriculture. According to the Food and Agriculture Organization (FAO), there is a projected need for a 60% increase in global food production by the middle of this century to meet the demands of a growing world population and their evolving dietary preferences. However, the existing impacts of climate change on agriculture are evident, affecting the biology, distribution, and potential outbreaks of pests across diverse land uses like maize crops. The concept of Integrated Pest Management (IPM), initially centered on insect control, underscores a strategic approach emphasizing the reduction of insecticide use. This reduction is achieved by prioritizing biological control, cultural practices, and other non-chemical tactics for pest management.

***Key words**: monitoring, insect pest management, maize, climate change.*

INTRODUCTION

It is widely acknowledged that since the onset of the industrial revolution, there has been a noticeable rise in both land and ocean temperatures globally. This warming trend is predominantly attributed to escalating concentrations of greenhouse gases. Even in the absence of additional greenhouse gas emissions, it is anticipated that the average global surface temperature will continue to ascend throughout the next century (Diffenbaugh et al., 2008) Fuhrer's examination of climate impacts suggests that although there may be certain beneficial effects on agriculture due to climate change, they are anticipated to be counterbalanced by unfavourable outcomes. Among these, there is a prevailing concern that the warming climate will lead to an increase in the abundance of insect pests in mid- to high-latitude areas (Fuhrer, 2003). In their study, Porter et al. (1991) outlined various impacts of temperature on insects, which encompass restrictions in geographical distribution, overwintering capabilities, population growth rates, annual generation counts, synchronization with crop-pest cycles, dispersal and migration patterns, as well as the accessibility of host plants and refuges. Experimental evidence from laboratory studies and modelling simulations lends support to the idea that the biology of agricultural pests is expected to react to rising temperatures (Ma et al., 2020). During the growing season, the warming effects may result in heightened levels of feeding and growth among insect populations, potentially leading to the occurrence of extra generations within a single year (Ma et al., 2022). Of particular concern is the susceptibility of maize crops to pest pressure. Maize cultivation, serving both as animal feed and human food, ranks among the most extensive agricultural land uses globally (Diffenbaugh et al., 2008; Meissle et al., 2010). The two Americas, North America and South America, along with Asia, dominate the maize market, collectively producing over half of the global maize production 83.1% (FAOSTAT, 2022). (Figure 1)

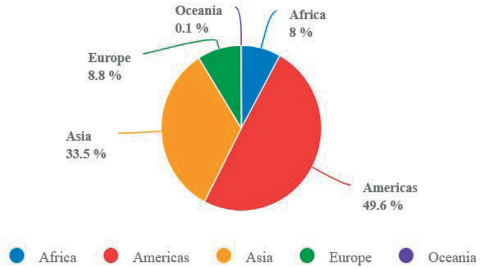

Figure 1. Production share of maize by region
Source: FAOSTAT, 2022

Despite maize being a significant global crop, it is commonly cultivated without the implementation of modern or comprehensive integrated pest management (IPM) practices. IPM serves as a strategy to mitigate or prevent economic losses and reduce the environmental footprint associated with pest control, as opposed to the indiscriminate application of pesticides (Vasileiadis et al., 2011). An IPM program incorporates a variety of tools and strategies derived from the biology and population ecology of crops and pests, the economic viability of the crop, as well as decision-making and action thresholds (Sharma, 2023). The most significant allocation of resources in maize production globally is attributed to losses caused by insect pests and the expenses associated with their control. While there exist over 90 insect species categorized as pests of maize, the majority of these can be regarded as minor or sporadic pests. Nonetheless, there are several crucial pests that all producers must be vigilant of each year (Diffenbaugh et al., 2008). Among these are the European corn borer, *Ostrinia nubilalis* (Hübner, 1796), and the corn earworm, *Helicoverpa armigera* (Hübner, 1808), which collectively contribute to the destruction of approximately 2% of the maize crop annually. Additionally, they pose significant threats to several other key crops, such as cotton, tomato, and grain sorghums (Huang & Hao, 2020). In terms of insect pests, forecasts made by Kocmánková et al. (2011) indicate that the European corn borer is likely to expand its distribution in numerous regions of Europe, occupy higher elevations, and boost its annual generation count due to projected temperature rises. Alternatively, climate warming might lead to temperature elevations approaching the upper lethal thresholds of certain insect species, particularly during summer in temperate climates, as well as in already warm tropical regions (Harvey et al., 2020). This variation in impact with geographical location means that generalizations should be treated with extreme caution and researchers need to be very careful when extrapolating their results (Miedaner & Juroszek, 2021).

The economic and social ramifications of climate-induced shifts in maize yield distribution will hinge on their effect on global supply in comparison to global demand. This balance will ultimately determine the price of maize (Diffenbaugh et al., 2008). Assessing the probable effects of climate change on pest invertebrates and quantifying the resulting outcomes are essential to offer guidance to farmers on adaptive measures. Possible responses could include adjustments to pesticide application, enhancements in pest surveillance technologies, optimization of timing and administration of insecticide applications, alterations to crop rotation schedules, modifications to tillage practices and stubble retention methods, and even broader changes to land-use practices at the enterprise level. Certain responses are cost-effective and signify a transition towards more sustainable pest management approaches (Macfadyen et al., 2018).

This paper will review the impact of some of the predicted climate change effects on the biology and ecology of harmful insects, which can be a major problem in crop production. Potential solutions for the current issues in plant production will be presented, mostly in the form of modified integrated pest management (IPM) strategies, in an environmentally friendly way as well the monitoring techniques using examples from, journal articles, research papers, books and other sources available in English published over a period from 1960’s onwards.

Changing climate

Climate change is characterized by an increase in the combined surface-air and sea-surface temperatures averaged globally over a 30-year span. This warming trend is measured relative to the period between 1850 and 1900, which serves as an approximation of pre-industrial temperatures. The warming observed from pre-industrial levels compared to the decade spanning 2006 to 2015 has been determined to be 0.87°C. Since the year 2000, the estimated magnitude of human-induced warming aligns closely with the observed warming levels, with a likely range of ±20 percent, accounting for uncertainties arising from contributions of solar and volcanic activity throughout the historical period (Allen et al., 2018).

In northern Europe, where mean temperatures are rising, particularly during winter and spring, the immediate consequences of climate change could be beneficial due to an extended growth season. Similarly, the anticipated increase in atmospheric CO^2 and temperature may enhance plant growth if adequate water, nutrients, and pest control measures are available (Gullino et al., 2018). Alternatively, in southern Europe, temperatures are projected to rise even more than the estimated global average increase. Combined with a heightened frequency and severity of heatwaves and reduced precipitation, this could lead to increased desertification rather than a rise in agricultural productivity (Björkman et al., 2015). Due to a mix of high temperatures and drought conditions, significant agricultural production declines are forecasted across most European regions throughout the 21st century, with no compensatory gains anticipated in Northern Europe. Maize yields are projected to drop by 50% in response to global warming levels of 3°C (GWL), particularly in Southern Europe (Lee et al., 2023). Climate change is anticipated to impact agricultural systems and pests in both direct and indirect manners. Consequently, establishing a causal link between climate change and the biology of pest species can pose challenges (Björkman et al., 2015).

Methods developed to look at how climate change affects plant pests

Over the last three to four decades, researchers have assessed the impact of various factors such as rising temperatures, CO^2 levels, ozone or ultraviolet-B radiation, and shifting water or humidity patterns on the occurrence and intensity of plant diseases. Some studies have conducted experiments to examine the effects of alterations in one or more weather parameters, while others have explored species along latitudinal or elevational gradients as indicators of climate changes over time. In addition to these empirical methods, "theoretical" approaches have also been utilized, including meta-analyses of published findings or analyses of long-term datasets. Certain studies have relied on expert opinion or have developed simulation models to forecast how anticipated changes in climate or atmospheric composition will impact the distribution, prevalence, severity, and control of pests and other organisms. Experimental methods can provide valuable insights into the impact of climate change on plant diseases and pests, although few studies have accurately replicated a changing climate. Research conducted in free air CO^2 enrichment facility (FACE) systems and open-topped chambers as part of climate-change studies has enhanced our comprehension of the effects of various factors on the progression of plant diseases across different crops (Figure 2) (Juroszek et al., 2011). Similar systems have been utilized to explore weed dynamics and insect behaviours (Mitchell et al., 2016). Overall, the majority of insect and disease issues examined in FACE systems under elevated CO^2 condition have demonstrated increases, as recently outlined by Ainsworth and Long (2021). Efforts to enhance predictions of climate-warming impacts on insects have been undertaken by integrating data from long-term datasets, large-scale experiments, and computer modelling. For instance, a meta-analysis of laboratory study data concluded that higher trophic levels (such as predators) are more vulnerable to climate change compared to lower-order organisms (such as plants or herbivorous insects) (Fussmann et al., 2014).

Figure 2. Studying the impacts of increased air CO^2 concentration in a soybean crop Source: https://soyface.illinois.edu/

Simulation of future pest risk

Simulation studies aiming to assess future pest risks under climate change scenarios have primarily utilized species distribution models, population dynamics models, or combinations of both (Table 1).

Table 1. Research on climate change biology examples of both theoretical and experimental methods. Source: Modified after FAO on behalf of the IPPC Secretariat, 2021

Type of research approach	Description and comments	Selected references
Experiments under controlled conditions	Controlled conditions are useful for studying a few environmental parameters due to their lower variability and interactions.	Gullino et al., 2018
Type of research approach	Description and comments	Selected references
Studies along an elevation gradient from low to high elevation sites	Short distances can be used to study the effects of temperature and precipitation changes while maintaining the same day length (e.g. characteristics of a single species can be compared).	Betz, Srisuka and Puthz, 2020.
Expert perspective	Experts' long-term experiences and knowledge can be applied. In theory, a pest species' whole life cycle can be taken into account, although this method is fairly arbitrary.	Karkanis et al., 2018
Modelling approach using one or several climate-change scenarios or models	Models or scenarios can be categorized in a range from "conservative" to "worst case."	Launay et al., 2020.

Climatic factors examined in these investigations typically encompass temperature, precipitation, and humidity, with elevated CO^2 levels often excluded from consideration (Juroszek et al., 2011). Predicting the effects of climate change is likely more straightforward for pest species primarily influenced by temperature. However, forecasting becomes more challenging for pests whose reproduction and dispersal are closely tied to factors such as water availability, wind, and crop management. The results of simulations depend on various factors, including the choice of global climate model, emission scenarios, regional climate model, specific pest model, and the precise parameters utilized in the simulation All these factors collectively contribute to the results of pest risk projections (Miedaner et al., 2021). It is important to recognize that the impact of climate change on pest risk can differ significantly across different regions within a country, such as between lowlands and mountains, or between northern and southern areas, as well as between summer and winter seasons, and between hot and wet versus cool and dry conditions, as recently underscored by Gullino et al. (2018) and Miedaner et al. (2021). Climate warming might result in temperature elevations nearing the upper lethal limit of certain insect species, particularly during summer in temperate climates and in the already very warm tropics (Addo-Bediako et al., 2000).

Effects on pest species

The effects of climate change on pest species are complex and encompass both direct and indirect impacts, as well as potential interactions between them. In a particular area, changes in warming and other climatic and atmospheric conditions may lead to consequences for insect pests, pathogens, and weeds. Potential direct and indirect effects on pests encompass changes in their geographic distribution, which may involve expansion or reduction; adjustments in seasonal behaviour, such as changes in activity during spring or synchronization of pest life stages with their host plants and predators; and modifications in different aspects of population dynamics, such as rates of overwintering and survival, population growth, or the number of generations for species with multiple cycles. (IPPC, 2021).

Overall, the key life-cycle phases of weeds, pathogens, and insect pests (survival, reproduction, and dispersal) are more or less directly impacted by temperature, humidity, light intensity and duration, wind patterns, or combinations. The physiological functions of the majority of pest species exhibit particular sensitivity to temperature (Figure 3) (Juroszek et al., 2015). Reynaud et al. (2009) conducted a three-year field experiment in maize grown under tropical climate conditions. They found that both the incidence of maize streak disease (caused by the maize streak virus) and the abundance of the maize leafhopper (*Cicadulina mbila* Naudé, 1924), which is the disease's vector, were closely correlated with temperature, rising quickly above 24°C. However, they also found that temperatures of 30°C and above might be harmful to the maize leafhopper and the transmission of the virus. Therefore, it stands to reason that, at least within a given temperature range, global warming will favour a large number of insect vectors and the viruses they deliver (Juroszek et al., 2013). Elevated average air temperatures, particularly during early spring in temperate climates, could lead to earlier occurrences of life-cycle stages in the host plant during the season (Merlos et al., 2015).

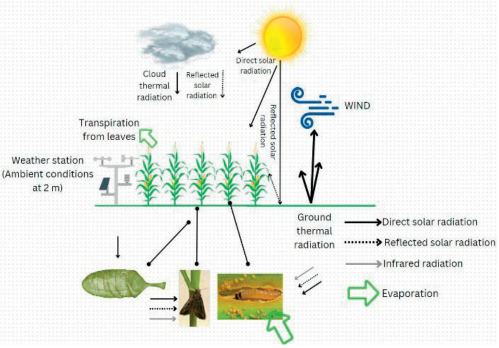

Figure 3. Schematic representation of energy dynamics in crop ecosystems Source: Modified after Terblanche et al., 2015

The widespread distribution of the European corn borer suggests its significant adaptability to diverse climatic regions across Europe and America. In Europe, analysis of biological constants and climatic data suggests that its northern expansion is limited to approximately 58°N latitude. In Romania, the pest is found in all regions where maize is the primary crop (Pintilie et al., 2023). The climate of the Carpathian Basin forces the European corn borer to overwinter. Fully developed larvae can withstand low temperatures of approximately 20°C for three months or more, provided they do not come into contact with moisture (Beck & Hanec et al., 1960).

Due to the shift in larval diapause timing, adults mate earlier (in June) and then undergo a mating flight for the second generation at the end of the season (in August) (Figure 4).

Recent research indicates that increasing temperatures have created favourable conditions for the development of this species in the southern part of the country for two complete generations per year (Pintilie et al., 2023). The population increase is attributed to the interaction between climatic factors (long, warm, and dry autumns followed by mild winters without snow cover and low temperatures) and agronomic factors (neglect of cultural hygiene measures such as destruction of crop residues and monoculture). In hindsight, if the development of the first generation is not affected by drought stress, the second generation will face a soil water deficit, leading to changes in egg hatching.

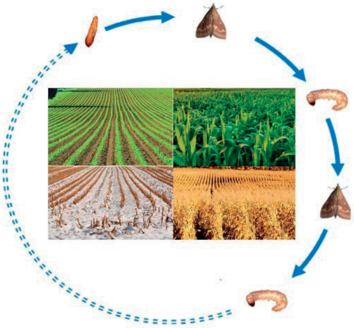

Figure 4. The life stage of European corn borer and their temporal adaptability to temperature (Source: Modified after Wadsworth et al., 2020)

This is due to the decrease in relative humidity to 50% and the mating process, which will reduce the population of overwintering larvae. A rainy spring influences insect development, increasing moth fecundity and creating conditions for the emergence of the second generation from the first eggs. (Pintilie et al., 2023).

Strategies for managing pests in a dynamic climate through adaptation and mitigation approaches

Variations in seasonal conditions have historically prompted alterations in agricultural practices, as has the advancement of new tools and crop varieties aimed at maximizing yield (Macfadyen et al., 2018). Minimum tillage or no-till practices have been widely adopted, primarily aimed at enhancing water conservation and mitigating soil erosion, particularly exacerbated during dry years. However, this practice is associated with an increase in wireworms (*Agriotes* spp., Eschscholtz, 1829), cockchafer (*Melolontha melolontha*, Linnaeus, 1758) and others pests, creating problems due to the creation of more favourable habitats (Thomson et al., 2010). As climate change progresses and global trade accelerates, uncertainties surrounding existing and new pests, as well as their frequency of occurrence, are sure to escalate. Increasing the ability to adapt rapidly to disturbances and climatic changes will therefore become all the more important. The strategies most frequently cited include adjusted integrated pest management (IPM) techniques and the monitoring of both climate patterns and insect pest populations (Kiss et al., 2017)

IPM

Integrated pest management (IPM) is a concept introduced for adoption by growers to mitigate or control pest damage through strategic planning and decision-making. It involves balancing the advantages and disadvantages of various tactics employed to minimize pest damage. IPM systems are customized for particular contexts, such as groups of crop fields or entire farms, and encompass all factors relevant to the pest management tactics employed, including effectiveness, cost, risks, and potential environmental impact (Bottrell & Schoenly, 2018)

Originally, the IPM concept primarily targeted insect management, prioritizing a decrease in insecticide usage by first relying on biological control, cultural practices, and other nonchemical methods for pest management. It advocated applying insecticides only as necessary. Over time, IPM was broadened to encompass weeds, plant pathogens, and nematodes, along with integrating pest management practices for various types of pests. Successful IPM programs enable producers to sustain profitable crop production while minimizing the adverse effects of pest management practices. Tactics for managing maize insects include cultural, biological, and chemical controls, and plant resistance (Gross & Gündermann, 2016).

Cultural Control

Cultural control methods for maize insects encompass various common practices necessary for crop production and management. These include crop rotation, planting date, hybrid selection, plant density, soil fertility management, irrigation, tillage, and harvest timing. These practices serve several purposes: preventing pest infestations, lowering insect population densities, mitigating the impact of insect damage by enhancing maize plant resilience or tolerance, or shortening the vulnerability period of the crop to insect damage. Cultural control tactics should take advantage of an insect's biology (Subedi et al., 2023). For example, in most areas of Romania, maize cultivation faces a severe problem with the attack of the maize leaf weevil (*Tanymecus dilaticollis*, Gyllenhal, 1834). It has a single generation per year and overwinters in the adult stage in the soil. By the end of March and sometimes even earlier, adults can be seen on the soil surface where they begin to feed on young maize plants (Georgescu, 2023). A viable alternative to replace seed treatment with active substances from the neonicotinoid class (imidacloprid, clothianidin, thiamethoxam) has not been found (Kathage et al., 2017). Consequently, interrupting the maize leaf weevil life cycle by annually rotating maize with a nonhost crop such as annual legumes, wheat, barley, linseed provides an acceptable control of this key pest. Continuous maize culture provides a suitable host for maize leaf weevil every year. Even with the availability of enhanced crop varieties that offer greater yield potential, optimal production is often not achieved due to inadequate crop management practices (Toader et al., 2020). Cropping systems will need to be more durable and adaptable to withstand extreme weather events such as droughts and floods. New agricultural practices must not only prevent ongoing soil degradation but also enhance system resilience while decreasing production costs. Conservation agriculture has been suggested as a set of management principles that ensures more sustainable agricultural production, reducing costs while enhancing profitability. It involves reduced tillage, maintaining adequate levels of crop residues to preserve soil surface cover, and implementing crop rotation. The principles of conservation agriculture can be applied across various crop production systems, although their implementation will differ based on climate, soil characteristics, management practices, and individual farmer situations. Besides the influence of climate change on pests, there are indirect alterations resulting from changes in agricultural practices that could affect the potential for pest outbreaks. (Macfadyen et al., 2018).

Natural and applied biological control

The natural regulation of insect pests in maize happens without human intervention. Various species of predators, parasitoids, and pathogens play a role in controlling insect pest populations in maize. Some of these natural enemies effectively reduce pest densities to levels below economic thresholds. Applied biological control involves the deliberate and targeted utilization of beneficial organisms to manage pests. There are three primary strategies of biological control: conserving existing natural enemies, augmenting natural enemy populations through periodic releases when required, and introducing and establishing new species of natural enemies. Presently, the conservation of existing populations of beneficial organisms and the introduction of natural enemies are the most commonly employed strategies in maize IPM programs (Torres et al., 2018).

Conservation certain agricultural practices aimed at crop production and pest management can enhance the survival of beneficial organisms within or around maize fields. Research indicates that practices such as conserving crop residue and minimizing tillage promote the survival of various ground-dwelling predators like ground beetles and spiders, which are natural predators of maize pests (Li et al., 2019). Conversely, the application of broad-spectrum insecticides eliminates many beneficial insects, and those that manage to survive may face starvation due to the depletion of prey populations. As a result, employing the minimal effective dosage of an insecticide solely when pest density surpasses the economic threshold significantly mitigates the adverse impacts of broad-spectrum insecticides. Whenever feasible and efficient, utilizing selective insecticides, such as those containing *Bacillus thuringiensis* (*Bt*), enhances the survival of natural enemies. Additionally, the cultivation of maize hybrids that are resistant or tolerant to pests diminishes the necessity for insecticide use (Meissle et al., 2011). A variety of cropping systems and uncultivated areas bordering maize fields can serve as overwintering sites and supplementary food sources (such as nectar, pollen, and alternate prey) for beneficial insects. Beneficial insects play a role in regulating populations of certain pests in nearly all fields annually. However, their significant contribution to suppressing pest populations is frequently overlooked (Gurr et al., 2012).

Chemical control and insecticides

Insecticides represent the predominant method of remedial control for insects that attack maize. They are favored for their ease of application, immediate reduction of pest populations, and the ability for growers to swiftly respond to pest outbreaks surpassing economic thresholds. However, drawbacks of chemical insecticides include their potential for adverse effects on human health, the environment, and ecosystems, especially when not used correctly. Commonly utilized insecticides in maize farming include organophosphates, carbamates, and pyrethroids. Chemical control techniques involve the use of pheromones and insecticidal baits. Although not conventional chemicals, microbial insecticides, particularly those containing Bt protein toxins, are utilized similarly to chemical insecticides for remedial purposes (Meissle et al., 2010).

The harmful effects of pesticides on non-target creatures, such as beneficial insects (predators, parasitoids, and honey bees), wildlife, and people, are reduced by the use of selective insecticides and selective application techniques. An insecticide's mode of action and formulation determine how selective it is.

The application of pesticides can be made selective by adjusting the timing, rate, and technique as well as the region of treatment.

Choosing the right pesticide for the pest to be controlled and applying it precisely are necessary for efficient insecticide use. For pesticides to be used effectively and economically, application equipment must be calibrated and operated correctly (Serrão et al., 2022).

IPM includes managing pesticide resistance as a key component. The efficacy and accessibility of pesticides for maize will be preserved by resistance management techniques. The rate at which insecticide resistance emerges can be slowed down by a combination of applying pesticides only when required and at the lowest effective rates; switching between different classes of insecticides, especially those with distinct modes of action; and employing suitable nonchemical control strategies. Strategies for managing resistance include spot treatments within a field and treatments intended to control only a fraction of a pest population (Way & Van Emden, 2000).

Plant resistance to insects

The suitability of hybrid maize plants as insect food sources and their vulnerability to insect pests differs. Commercial hybrids now include resistance to a few main insect pests thanks to plant breeding initiatives. The plant aglucone 2-4 dihydroxy-7-methoxy-l, 4-benzoxazin-3one (DIMBOA), which is primarily abundant in whorl-stage maize, provides resistance against maize borers (Larsen & Christensen, 2000). With the use of transgenic biotechnology, insect-resistant hybrids of maize have been created recently. Utilizing cutting-edge gene transfer methods, a gene from the naturally occurring, soilborne bacterium *Bacillus thuringiensis* (*Bt*) has been incorporated into maize plants. Certain insect species are poisoned by the crystalline protein produced by the gene, known as endotoxin.

A few *Bt* maize hybrids (GMOs) also decrease the amount of insects that cause damage to the ear, which lowers the concentration of mycotoxins (such aflatoxins) in the grain. The possibility for using a variety of *Bt* proteins and resistance factors-aside than *Bt* endotoxins-in transgenic maize hybrids to manage additional maize insect pests is being investigated (Tabashnik et al., 2015).

Regrettably, the European Commission has granted authorization for only three new genetically modified (GM) varieties and renewed approvals for two others intended for food and animal feed, making this technology unavailable to the majority of farmers (EU Commission, 2023). Insect-resistant maize hybrids likely will become an essential component of maize insect management programs (Miedaner & Juroszek, 2021).

The degree of damage inflicted by some insect pests may also be influenced by additional features of maize plants that are not always chosen as insect-resistance variables. For instance, hybrids that possess strong stalks and are resistant to organisms that produce stalk rot can withstand damage from many insects that induce stalk boring. Western corn rootworm (*Diabrotica virgifera virgifera* LeConte, 1868) infections are tolerated by hybrids possessing broad root systems or the capacity to adjust for root damage. Because the plants are vulnerable to seed and seedling pests for a shorter period of time, hybrids that thrive in cold soils are less likely to suffer damage. Additionally, certain hybrids of maize make up for plants lost to insects that feed on seedlings by increasing the yield of the plants that remain. The approaches may change depending on the target pest, insect resistance sources, and geographic location (Ivezić et al., 2009).

Sampling and monitoring

For an insect control program to be successful, surveying insect populations is necessary. Surveys can be carried out throughout an extensive area (monitoring) or inside fields (scouting). Based on precise and up-to-date data on pest densities and circumstances, all integrated pest management choices should be made. Depending on the type of insect present and the state of the crop, a farmer or agricultural engineer might use a variety of sample procedures to assess the insect pest situation in a field. Insect presence and/or density can be determined by counting the insects present or by examining plant harm (e.g., percentage defoliation, declines in plant population, proportion of plants with injury) (Stenberg et al., 2017). Plants may need to be dissected or dug up in order to count the insects, such as European corn borer larvae and Western corn rootworm larvae, or counts can be conducted on intact plants in the field (e.g., European corn borer eggs, Western corn rootworm adults). This depends on the pest and its stage of development. Traps can sometimes be used to measure relative pest densities (e.g., adults of Western corn rootworms and wireworms). The insect and stage of development to be sampled determine the sort of trap to be utilized. For instance, Western corn rootworm larvae are drawn to yellow sticky traps containing pheromones in the field, while wireworm larvae are drawn to sprouting seeds in bait traps buried in the ground (Hesler & Sutter, 1993). While these monitoring methods may not give an exact density (numbers of insects per plant or per hectare), they do show patterns in population sizes and suggest when to start looking for pests. Still, they rarely give enough details to indicate when a control action need to be implemented. Pheromone traps are useful for monitoring purposes as well. For numerous significant maize insect pests, such as the European corn borer, corn earworm, and Western corn rootworm, pheromone traps loaded with a chemical sex attractant are available. The creation of pheromones and traps is a field in flux, and alternative equivalent traps may find use. For identifying insect activity, informal monitoring methods (such as observations made by a farmer while walking across fields) might be helpful (Grasswitz, 2019). According to Barbedo (2019), a lot of pest outbreaks are highly unexpected, therefore using contemporary agricultural technologies makes early identification, monitoring, and efficient treatment possible. In fields, advanced imaging technologies are employed as non-invasive crop monitoring techniques to identify pests and diseases early on. Once more, drones are quickly gaining popularity in precision agriculture as a tool for surveillance, early pest and disease identification, and crop preservation. In the long run, drones can be a more cost-effective alternative than manual labour or conventional ground monitoring techniques, saving a substantial amount of human resources and optimizing the use of pesticides. An unmanned aerial vehicle (UAV) platform can identify plant-eating beetles and produce high-resolution RGB footage for additional analysis using various algorithms. This allows the platform to provide automated early crop damage assessments, monitoring, and biosecurity surveillance (Srinivasan et al., 2022). Pesticide use has increased dramatically worldwide during the past 20 years, from 3.5 billion to 45 billion kg/year, posing several risks to the environment and public health. According to Grant et al. (2022), using drones to manage agricultural pests and diseases offers a number of benefits, including the tendency to reduce spray drift, a low risk of chemical exposure for users, and a simpler deployment method. Shamshiri et al. (2018) highlighted the function of small-scale drones and robots working together to optimize agricultural inputs related to agricultural pest management. They underlined that although drones are already dependable tools in contemporary agriculture, it is unrealistic to anticipate fully automated farming in the near future. If significant pests had a differential preference for certain plant species as substitute hosts, remote sensing may be used to inform decisions about vegetation management. A list of research using drones for remote sensing was created by Barbedo (2019) and covers a range of uses, such as identifying pests, diseases, nutrient shortages, and drought. The usage of drones for remote sensing research is growing, and they are especially economical when inspecting smaller fields. They could also become more competitive for application in broader industries as technology advances and costs come down. In the end, each grower's demands will determine how beneficial drone-based remote sensing is for identifying insect issues (Iost et al., 2020).

CONCLUSIONS

A number of maize pest management factors are changing quickly and will do so in the future. Increases in cold-season survival and the number of insect generations in a single warm season, warming may exacerbate pest stresses in certain places. Due to higher costs of seeds and insecticides, lower yields, and the fluctuation effects of modified crop output variability, these expansions in range could carry significant economic implications.

The predicted reductions in cold limitation and increases in heat accumulation have the potential to drastically change the pest management landscape, which would necessitate additional inputs for pest management (such as potential costs for monitoring/scouting, applying pesticides, and/or using transgenic hybrids).

In 1996, transgenic maize was made comercially accessible for the first time when Br corn hybrids were developed to control European corn borer infestations. Transgenic or other genetically modified hybrids resistant to other insects will probably be made available soon. Novel classes of insecticides that exhibit reduced environmental disruption potential and unique mechanisms of action are now under development. There are bait formulations available for controlling adult Western corn rootworms that contain extremely low levels of pesticide.

While their applications to maize pest control are being researched, site-specific management techniques (yield mapping and remote sensing) are being used in the production of maize. Maize insect pests are also evolving, and they have the potential to eventually adjust to new control strategies. It is more crucial than ever to keep up with the latest developments in pest control strategies and scientific findings and to use this knowledge to economic and sustainable maize production systems.

ACKNOWLEDGEMENTS

This research study is a part from the PhD thesis and was carried out with the support of Faculty of Agriculture, University of Agronomic Sciences and Veterinary Medicine of Bucharest.

REFERENCES

Addo-Bediako, A., Chown, S. L., & Gaston, K. J. (2000). Thermal tolerance, climatic variability and latitude. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 267(1445), 739-745. https://doi.org/10.1098/rspb.2000.1065

Ainsworth, E. A., & Long, S. P. (2021). 30 years of free-air carbon dioxide enrichment (FACE): what have we learned about future crop productivity and its potential for adaptation? *Global Change Biology*, 27(1), 27-49. https://doi.org/10.1111/gcb.15375

Allen, M., Dube, O. P., Solecki, W., Aragón-Durand, F., Cramer, W., Humphreys, S., & Kainuma, M. (2018). Special Report: Global Warming of 1.5 C. *Intergovernmental Panel on Climate Change* (IPCC).

Barbedo, J. G. A. (2019). A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. *Drones*, 3(2), 40. https://doi.org/10.3390/drones3020040

Beck, S. D., & Hanec, W. (1960). Diapause in the European corn borer, Pyrausta nubilalis (Hübn.). *Journal of Insect Physiology*, 4(4), 304-318. https://doi.org/10.1016/0022-1910(60)90056-1

Betz, O., Srisuka, W., & Puthz, V. (2020). Elevational gradients of species richness, community structure, and niche occupation of tropical rove beetles (Coleoptera: Staphylinidae: Steninae) across mountain slopes in Northern Thailand. *Evolutionary Ecology*, 34(2), 193-216.Evolutionary Ecology, 34: 193–216.

Björkman, C., & Niemelä, P. (Eds.). (2015). *Climate change and insect pests*. Cabi.

Bottrell, D. G., & Schoenly, K. G. (2018). Integrated pest management for resource-limited farmers: challenges for achieving ecological, social and economic sustainability. *The Journal of Agricultural Science*, 156(3), 408-426.

Diffenbaugh, N. S., Krupke, C. H., White, M. A., & Alexander, C. E. (2008). Global warming presents new challenges for maize pest management. *Environmental Research Letters*, 3(4), 044007. DOI 10.1088/1748-9326/3/4/044007

Fuhrer, J. (2003). Agroecosystem responses to combinations of elevated CO2, ozone, and global climate change. *Agriculture, Ecosystems & Environment*, 97(1-3), 1-20. https://doi.org/10.1016/S0167-8809(03)00125-7

Fussmann, K. E., Schwarzmüller, F., Brose, U., Jousset, A., & Rall, B. C. (2014). Ecological stability in response to warming. *Nature Climate Change*, 4(3), 206-210.

Georgescu, E. (2023): Tanymecus dilaticollis (maize leaf weevil). In: CABI Compendium. Wallingford, UK: CAB International. https://doi.org/10.1079/cabicompendium.54122

Grant, S., Perine, J., Abi-Akar, F., Lane, T., Kent, B., Mohler, C., & Ritter, A. (2022). A wind-tunnel assessment of parameters that may impact spray drift during UAV pesticide application. *Drones*, 6(8), 204. https://doi.org/10.3390/drones6080204

Grasswitz, T. R. (2019). Integrated pest management (IPM) for small-scale farms in developed economies: Challenges and opportunities. *Insects*, 10(6), 179.

Greener Agronomy. *Corporate Sustainable Management Journal*, 1(2), 103–108.

Gross, J., & Gündermann, G. (2016). Principles of IPM in cultivated crops and implementation of innovative strategies for sustainable plant protection. *Advances in insect control and resistance management*, 9-26.

Gullino, M. L., Pugliese, M., Gilardi, G., & Garibaldi, A. (2018). Effect of increased CO 2 and temperature on plant diseases: A critical appraisal of results obtained in studies carried out under controlled environment facilities. *Journal of Plant Pathology*, 100, 371-389.

Gurr, G. M., Wratten, S. D., & Snyder, W. E. (Eds.). (2012). *Biodiversity and insect pests: key issues for sustainable management*. John Wiley & Sons.

Harvey, J. A., Heinen, R., Gols, R., & Thakur, M. P. (2020). Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns. *Global change biology*, 26(12), 6685-6701. https://doi.org/10.1111/gcb.15377

Hesler, L. S., & Sutter, G. R. (1993). Effect of trap color, volatile attractants, and type of toxic bait dispenser on captures of adult corn rootworm beetles (Coleoptera: Chrysomelidae). *Environmental Entomology*, 22(4), 743-750. https://doi.org/10.1093/ee/22.4.743

High Temperatures. *Annual Review of Entomology*, 66(1). doi:10.1146/annurev-ento-041520-074454

Huang, J., & Hao, H. (2020). Effects of climate change and crop planting structure on the abundance of cotton bollworm, Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae). *Ecology and evolution*, 10(3), 1324-1338. https://doi.org/10.1002/ece3.5986

Iost Filho, F. H., Heldens, W. B., Kong, Z., & de Lange, E. S. (2020). Drones: innovative technology for use in precision pest management. *Journal of economic entomology*, 113(1), 1-25. https://doi.org/10.1093/jee/toz268

IPPC (2021). *Scientific review of the impact of climate change on plant pests*. FAO on behalf of the IPPC Secretariat. https://doi.org/10.4060/cb4769en

Ivezić, M., Raspudić, E., Brmež, M., Majić, I., Brkić, I., Tollefson, J. J., & Šimić, D. (2009). A review of resistance breeding options targeting western corn rootworm (*Diabrotica virgifera virgifera* LeConte).

Agricultural and forest Entomology, 11(3), 307-311. https://doi.org/10.1111/j.1461-9563.2009.00434.x

Juroszek, P., & von Tiedemann, A. (2015). Linking plant disease models to climate change scenarios to project future risks of crop diseases: a review. *Journal of Plant Diseases and Protection*, 122, 3-15.

Juroszek, P., & Tiedemann, A. V. (2013). Climatic changes and the potential future importance of maize diseases: A short review. *Journal of Plant Diseases and Protection*, 120, 49-56.

Karkanis, A., Ntatsi, G., Alemardan, A, Petropoulos, S. & Bilalis, D. (2018). Interference of weeds in vegetable crop cultivation, in the changing climate of Southern Europe with emphasis on drought and elevated temperatures: A review. *The Journal of Agricultural Science*, 156: 1175–1185

Kathage, J., Castañera, P., Alonso-Prados, J. L., Gómez-Barbero, M., & Rodríguez-Cerezo, E. (2017). The impact of restrictions on neonicotinoid and fipronil insecticides on pest management in maize, oilseed rape and sunflower in eight European Union regions. *Pest Management Science*, 74(1), 88–99. doi:10.1002/ps.4715

Kiss, J., Zanker, A., & Eke, I. (2017). Eight principles of Integrated Pest Management. Növényvédelem, 53(10), 429-453.

Kocmánková, E., Trnka, M., Eitzinger, J., Dubrovský, M., Štěpánek, P., Semeradova, D., & Žalud, Z. (2011). Estimating the impact of climate change on the occurrence of selected pests at a high spatial resolution: a novel approach. *The Journal of Agricultural Science*, 149(2), 185-195.

Larsen, E., & Christensen, L. P. (2000). Simple method for large scale isolation of the cyclic arylhydroxamic acid DIMBOA from maize (Zea mays L.). *Journal of Agricultural and Food Chemistry*, 48(6), 2556-2558. https://doi.org/10.1021/jf0000934

Launay, M., Zurfluh, O., Huard, F., Buis, S., Bourgeois, G., Caubel, J., & Bancal, M. O. (2020). Robustness of crop disease response to climate change signal under modeling uncertainties. *Agricultural Systems*, 178,102733.https://doi.org/10.1016/j.agsy.2019.102733

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., & Zommers, Z. (2023). Synthesis report of the IPCC Sixth Assessment Report (AR6), Longer report. IPCC.

Li, Y., Li, Z., Cui, S., Jagadamma, S., & Zhang, Q. (2019). Residue retention and minimum tillage improve physical environment of the soil in croplands: A global meta-analysis. *Soil and Tillage Research*, 194, 104292. https://doi.org/10.1016/j.still.2019.06.009

Ma, C.-S., Ma, G., & Pincebourde, S. (2020). Survive a Warming Climate: Insect Responses to Extreme

Ma, G., & Ma, C. S. (2022). Potential distribution of invasive crop pests under climate change: incorporating mitigation responses of insects into prediction models. *Current Opinion in Insect Science*, 49, 15-21. https://doi.org/10.1016/j.cois.2021.10.006

Macfadyen, S., McDonald, G., & Hill, M. P. (2018). From species distributions to climate change adaptation: knowledge gaps in managing invertebrate pests in broad-acre grain crops. *Agriculture, Ecosystems & Environment*, 253, 208-219. https://doi.org/10.1016/j.agee.2016.08.029

Meissle, M., Mouron, P., Musa, T., Bigler, F., Pons, X., Vasileiadis, V. P., Oldenburg, E. (2010). Pests, pesticide use and alternative options in European maize production: current status and future prospects. *Journal of Applied Entomology*, 134(5), 357-375. https://doi.org/10.1111/j.1439-0418.2009.01491.x

Meissle, M., Romeis, J., & Bigler, F. (2011). Bt maize and integrated pest management-a European perspective. *Pest Management Science*, 67(9), 1049-1058. https://doi.org/10.1002/ps.2221

Merlos, F. A., Monzon, J. P., Mercau, J. L., Taboada, M., Andrade, F. H., Hall, A. J., & Grassini, P. (2015). Potential for crop production increase in Argentina through closure of existing yield gaps. *Field Crops Research*, 184, 145-154. https://doi.org/10.1016/j.fcr.2015.10.001

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 Pathology*, 70(5), 1032-1046. https://doi.org/10.1111/ppa.13365

Mitchell, C., Brennan, R. M., Graham, J., & Karley, A. J. (2016). Plant defense against herbivorous pests: exploiting resistance and tolerance traits for sustainable crop protection. *Frontiers in plant science*, 7, 1132.

Pintilie, P. L., Trotuș, E., Tălmaciu, N., Irimia, L. M., Herea, M., Mocanu, I., & Tălmaciu, M. (2023). European Corn Borer (Ostrinia nubilalis Hbn.) Bioecology in Eastern Romania. *Insects*, *14*(9), 738. https://doi.org/10.3390/insects14090738

Reynaud, B., Delatte, H., Peterschmitt, M., & Fargette, D. (2009). Effects of temperature increase on the epidemiol-ogy of three major vector-borne viruses. European journal of plant pathology, 123, 269-280.

Serrão, J. E., Plata-Rueda, A., Martínez, L. C., & Zanuncio, J. C. (2022). Side-effects of pesticides on non-target insects in agriculture: A mini-review. *The Science of Nature,* 109(2), 17.

Shamshiri, R. R., Hameed, I. A., Balasundram, S. K., Ahmad, D., Weltzien, C., & Yamin, M. (2018). Fundamental research on unmanned aerial vehicles to support precision agriculture in oil palm plantations. *Agricultural Robots-Fundamentals and Application*, 91-116.

Sharma, S. (2023). Cultivating Sustainable Solutions: Integrated Pest Management (IPM) For Safer and
https://doi.org/10.26480/csmj.02.2023.103.108

Srinivasan, T. S., Thankappan, S., Balasubramaniam, M., & Bhaskar, V. (2022). Impact of Plant Health on Global Food Security: A Holistic View. In *Agriculture, Environment and Sustainable Development: Experiences and Case Studies* (pp. 43-66). Cham: Springer International Publishing.

Stenberg, J. A. (2017). A Conceptual Framework for Integrated Pest Management. *Trends in Plant Science*, 22(9), 759–769. doi:10.1016/j.tplants.2017.06.010

Subedi, B., Poudel, A., & Aryal, S. (2023). The impact of climate change on insect pest biology and ecology: Implications for pest management strategies, crop production, and food security. *Journal of Agriculture and Food Research*, 14, 100733. https://doi.org/10.1016/j.jafr.2023.100733

Tabashnik, B. E., Zhang, M., Fabrick, J. A., Wu, Y., Gao, M., Huang, F., & Li, X. (2015). Dual mode of action of Bt proteins: protoxin efficacy against resistant insects. *Scientific reports*, 5(1), 15107.

Terblanche, J. S., Karsten, M., Mitchell, K. A., Barton, M. G., & Gibert, P. (2015). Physiological variation of insects in agricultural landscapes: potential impacts of climate change. *Climate change and insect pests*, 8, 92.

Toader, M., Georgescu, E. M. I. L., Ionescu, A. M., & Șonea, C. O. S. M. I. N. (2020). Test of some insecticides for Tanymecus dilaticollis Gyll. control, in organic agriculture conditions. *Romanian Biotechnological Letters*, 25(6), 2070-2078.

Torres, J. B., & Bueno, A. D. F. (2018). Conservation biological control using selective insecticides–a valuable tool for IPM. *Biological Control*, 126, 53-64. https://doi.org/10.1016/j.biocontrol.2018.07.012

Thomson, L. J., Macfadyen, S., & Hoffmann, A. A. (2010). Predicting the effects of climate change on natural enemies of agricultural pests. *Biological control*, 52(3), 296-306. https://doi.org/10.1016/j.biocontrol.2009.01.022

Wadsworth, C. B., Okada, Y., & Dopman, E. B. (2020). Phenology-dependent cold exposure and thermal performance of Ostrinia nubilalis ecotypes. *BMC evolutionary biology*, 20(1), 1-14.

Way, M. J., & Van Emden, H. F. (2000). Integrated pest management in practice—pathways towards successful application. *Crop protection*, 19(2), 81-103. https://doi.org/10.1016/S0261-2194(99)00098-8

***EU Commission - New GMO approvals and authorisation renewals. (2023). Food Compliance. Retrieved from https://foodcomplianceinternational.com/industry-insight/news/3806-eu-commission-new-gmo-approvals-and-authorisation-renewals-1

***FAO. Faostat Database, Crops and Livestock Products. Available online: https://www.fao.org/faostat/en/#data/QCL/visualize (accessed on 25 January 2024).