



REVIEW

Current Status and Future Perspective of Pesticide Use and Pest Management in Kuwait Agriculture: A Comprehensive Review

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Abstract

The widespread overuse of pesticides in agriculture has generated increasing concerns about the negative effects of pesticides on human health and the environment. The review provides perspectives on the main trends regarding pesticide overuse in Kuwait and its potential impacts on human health and the environment. Factors driving the excessive use of pesticides, including climate change and the introduction of invasive pest species, and the challenges of adopting alternatives to chemical pesticides, are also reviewed. The review further outlines the status of an invasive pest species, the South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), in Kuwait and the Middle East, and efforts to develop sustainable management strategies for the pest. Finally, recommendations on how to achieve sustainable control of the *T. absoluta* and other pests using integrated pest management strategies, and the comprehensive intervention measures to be adopted to reduce health and environmental risks of pesticides are discussed. Although the review has focused on Kuwait, it is relevant in other countries where greater and widespread use of synthetic pesticides to manage pests is a dominant trend.



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Statement of Sustainability: Climate change will affect crop protection in Kuwait and globally by changing the abundance of pests, including invasive species (e.g., *Tuta absoluta*), and consequently, the overuse of pesticides by farmers. The review explored pesticide overuse by farmers and the effects on human health and the environment, and factors enhancing pesticide overuse. Potential Integrated Pest Management (IPM) strategies to adopt that could strengthen the resilience of crop protection systems while simultaneously safeguarding environmental sustainability and maximum consumer protection are highlighted. This is of crucial importance in order to reduce the potential human health and environmental hazards associated with pesticide overuse.

1. Introduction

Kuwait faces major challenges in achieving long-term self-sufficiency in food production. Limited arable land, declining soil fertility, severe water shortage for agricultural use, and insect pests and diseases undermine the long-term agricultural sustainability and food security. Addressing food security in line with the increasing population and ensuring reliable and consistent national food supplies are critical issues for the government of Kuwait. Recognizing this challenge, the government has made significant investments in the past three decades to develop new agricultural strategies to help facilitate at least a modest level of self-sufficiency in food production. Consequently, there is a growing interest in agricultural activities, especially vegetable production for fresh market consumption. Cropping systems are based mainly on greenhouse production, accounting for more than 50% of the total agricultural land (Kuwait Agricultural Statistics, 2024). Apart from the local produce, which meets less than 45% of the country's total demand, Kuwait imports huge quantities of vegetables, fruits, pulses, and other food commodities from neighboring countries in the Middle East and the rest of the world (FAO, 2019). While enhancing the acceptable level of food security is critical for Kuwait's future, it is equally important to ensure the production of high-quality products while simultaneously safeguarding environmental sustainability and maximum consumer protection.



Like other countries aiming to facilitate self-sufficiency in food production, Kuwait has significantly increased its agricultural pesticide use, especially on fruit and vegetable crops, due to the prevalence of insect pests and diseases (Jallow et al., 2017a, b, c; 2019a, b). For most farmers, crop production, especially in greenhouse environments, is impossible without intensive use of chemical pesticides (Jallow et al., 2019a, 2020, 2022). Pesticide use is further complicated by the fact that farmers do not perceive these chemicals as hazardous or that they have to be handled correctly. Farmers hardly adhere to the restricted entry intervals or pre-harvest intervals required after applying pesticides on their farms. Most farmers tend to apply pesticides too close to harvest, potentially contaminating the crop prior to sending their produce to the market. Personal protective equipment (PPE) that reduces pesticide exposure is hardly worn, partly due to the discomfort under the hot and humid conditions in Kuwait, but mainly due to a lack of knowledge of health risks associated with pesticides (Jallow et al., 2017b). Similarly, the concept underlying pesticide environmental impacts is poorly understood by farmers (Jallow et al., 2017b).

Pesticide misuse has considerable repercussions because of the unintended long-term adverse effects on the environment and human health (Guedes, 2017). To ensure food safety for consumers and to protect human health and the environment, many countries and regional organizations have established maximum residue limits (MRLs) for pesticides in food (USDA, 2011; Codex, 2015, 2015), water, and the soil (Li et al., 2017; Silva et al., 2019). Regulatory and enforcement mechanisms, including international treaties and conventions, are also put in place to monitor compliance with MRLs and other risks posed by pesticides. Kuwait is a signatory to several of these treaties and conventions on hazardous chemicals and pesticides, including the *Codex Alimentarius* Commission (Codex), the Montreal Protocol, Basel, Rotterdam, and Stockholm conventions, and the International Code of Conduct on Pesticide Management (FAO, 2013). Of particular importance are Codex MRLs, which are internationally accepted standards for food safety and widely used as a reference point to regulate pesticide residues in food. Although regulations on MRLs in food commodities exist in Kuwait, using Codex MRLs as a reference point, these regulations are often not fully enforced. Kuwait is also a signatory to several laws and regulations on pesticides common to the member states of the Gulf region, including Law No. 42 of 2014, dealing with banning the circulation of hazardous pesticides to protect human health and the environment.

Despite being a signatory to a number of regional and international laws and regulations intended to minimize the hazards associated with pesticides, the overuse and management of pesticides in Kuwait remain a major concern. For example, farmers are not obliged to report pesticides applied, and there is no regular monitoring for pesticide residues in local agricultural produce, nor seldom for imported produce at the point of entry. Apart from a single study (Jallow et al., 2017c), there is a lack of information on the levels of pesticide residues in consumed agricultural produce in Kuwait, especially for fruits and vegetables that constitute a major component of the Kuwaiti diet. The only information available is based on studies conducted more than a decade ago (Sawaya et al., 1999a, 1999b, 2000; Saeed et al., 2001, 2005), and most of these studies are limited in scope based on the number of commodities and pesticides analyzed. Moreover, patterns of pesticide use in Kuwait have altered since these studies, and farmers are using more pesticides, including newer products (Jallow et al., 2017a).

2. Pesticide Overuse and Implications for Human Health and the Environment

Pesticides are considered a vital component of modern farming, playing a major role in maintaining high agricultural productivity. Consequently, in high-input, intensive systems of agricultural production, the widespread use of pesticides to manage pests has emerged as a dominant feature (Handford et al., 2015). Global pesticide use in agriculture has increased significantly in the last three decades, with over 3.8 million tons applied in 2017, most of which are herbicides, insecticides, and fungicides (WHO and FAO, 2019; Sharma et al., 2019). Average application rates ranged from 6.5 to 60 kg active ingredients per hectare, depending on the crop (Sharma et al., 2019). A similar trend in pesticide overuse is observed in the Middle East, including Kuwait, in line with rapid agricultural growth (Jallow et al., 2017a, b; Bashour, 2007) (Table 1). With increased growth in agricultural activity to meet the food demands of an increasing global population, the demand for pesticides is likely to increase. The annual consumption of pesticides in Kuwait was about 4.5 kg ai ha⁻¹ per year in 2007 (Bashour, 2007), and by 2015, this figure had increased to 12.8 kg ai ha⁻¹ per year, and 58% of farmers overused pesticides (Jallow et al., 2017a).

Despite their benefits, reliance on pesticides is difficult to sustain because of the unintended long-term adverse effects on the environment and human health. Problems like pesticide resistance and secondary pest outbreaks (Guedes



Table 1. Frequency of pesticide application on selected key crops in Kuwait per cropping season^a.

Number of applications	Tomato respondent (%)	Cucumber respondent (%)	Eggplant respondent (%)	Capsicum respondent (%)
< 5	0	0	0	0
6-10	8	15	38	54
11-15	20	40	46	39
16-20	27	34	16	6
> 20	45	11	0	1
Average ^b	28	14	11	8
Range ^c	7-42	6-27	6-20	6-24

Source: Jallow et al. (2017c); ^a Number of applications in one cropping season for the four major pesticide types (insecticides, fungicides, bactericides, and nematocides); ^b Average number of pesticide applications in one cropping season for individual crops; ^c Range of pesticide applications in one cropping season for individual crops.

et al., 2017, Gross and Rosenheim, 2011; Jallow et al., 2019b), destruction of non-target species (Zeller and Brühel, 2019), soil, water, and air contamination (Sun et al., 2018), and pesticide residues in primary and derived agricultural products that endanger both the environment and human-health are a consequence of improper and excessive use of pesticides (Osman et al., 2010; Ramadan et al., 2020; Jallow et al., 2017c). Various human health-related concerns are associated with pesticides, ranging from acute impacts (short-term exposure), such as headaches and nausea, to chronic impacts (long-term exposure) such as various cancers, birth defects, infertility, endocrine and immune system disruption, diabetes, Parkinson’s and Alzheimer’s disease (Cecchi et al., 2012; Asghar et al., 2016). Children, in particular, are more endangered by short-term and chronic exposure to pesticides (Lozowicka, 2015). There is mounting evidence that pesticide exposure from various sources can induce neurodevelopment and neurobehavioral effects (delayed cognitive and intellectual development, attention deficit and hyperactivity, etc.) and various cancers in children (Lanphear, 2015).

Exposure to pesticides can occur through the ingestion of residue in food and drinking water, inhalation of pesticide-contaminated air, and dermal contact with contaminated soil and other surfaces (Gangemi et al., 2016). The widest exposure to pesticides, however, is through residues in primary and derived agricultural products, especially fruits and vegetables consumed either raw or semi-processed (Quijano et al., 2016). Farmers, in particular, and especially those directly involved in the handling of pesticides, are at a high risk of greater exposure to pesticides through contact with pesticide residues on treated crops, unsafe handling, storage and disposal practices, poor maintenance of spraying equipment, and the lack of protective equipment or failure to use it properly (Litchfield, 2005; Matthews, 2008). The World Health Organization estimates 15,000–20,000 fatalities of agricultural workers yearly through occupational exposure to pesticides, mostly in developing countries (WHO and FAO, 2019).

Pesticide residues on fresh market produce pose increasing concern, particularly with respect to the general consumer health in Kuwait. Pesticide residues, including 1-naphthol, 3-*H*-carbofuran, vinclozolin, fenuron, carbendazim, captan, and thiabendazole, have been detected in several vegetables and other produce in Kuwait (Saeed et al., 2001). Residues of the pesticides, namely, monocrotophos, diazinon, quinalphos, chlorpyrifos-methyl, and fenitrothion, were also detected in some vegetables and fruits (Saeed et al., 2001, 2005; Hajjar et al., 2012; Al-Mazeedi et al., 2012). Although some residue levels were below the maximum MRL allowed, a few were above the limits established for these pesticides in food. More recently, pesticide residues above the maximum MRL allowed were detected in 21% of sampled fruits and vegetables in Kuwait, with some produce contaminated with multiple residues (Jallow et al., 2017c). Of the pesticides investigated, imidacloprid, deltamethrin, cypermethrin, malathion, acetamiprid, monocrotophos, chlorpyrifos-methyl, and diazinon exceeded their MRLs (Jallow et al., 2017c). Similarly, the presence of chlorinated pesticides in the breast milk of lactating women in Kuwait and many countries has raised even greater concerns about possible health risks to breastfed infants (Saeed et al., 2005; Kuang et al., 2020). Breast milk samples randomly collected from 32 Kuwaiti donors were found to contain the organochlorine pesticides (OCPs) dichlorodiphenyltrichloroethane (DDT), aldrin, and endrin (Saeed et al., 2001, 2005; Jallow et al., 2017c). Because of the extremely harmful effects of OCPs on human health and their long-term persistence in the environment, especially in agricultural soils, continuous monitoring of these pesticides is demanded. Several studies have detected OCP residues in different commodities, including fruits and vegetables from Ghana (Bempah et al., 2011), Saudi Arabia (Osman et al., 2010), and China (Liu et



al., 2016), and in agricultural soils from China (Sun et al., 2018), Europe (Silva et al., 2019), and Kuwait (Alshemmari et al., 2021). The study in Kuwait identified several OCPs and their metabolites, including α -BHC, β -BHC, γ -BHC, δ -BHC, P-P-DDE, P-P-DDD, O-P-DDE, endrin, and endosulfan-1 (Alshemmari et al., 2021). However, it is yet to be determined whether residues of these OCPs and other persistent organic pollutants (POPs) are detectable in crops grown in these soils.

The problem of pesticides in aquatic environments is also a serious challenge worldwide. High levels of pesticide residues in surface and ground water resources have been detected in intensive agricultural regions of Iran (Shakerkhatibi et al., 2014), Saudi Arabia (Al-Hatim et al., 2015), and India (Syafrudin et al., 2011), posing a threat to human health directly, and *via* the food chain through bioaccumulation. Similarly, there is substantial published literature on the effects of pesticides on wildlife and biodiversity. Pesticide overuse has significantly contributed to the decline in the populations of beneficial insects, rendering vital ecosystem services impossible (Siviter et al., 2020). For example, systemic insecticides such as neonicotinoids have been shown to impair the foraging behavior of honey bees, consequently reducing their function as pollinators (Lundin et al., 2015). In addition, pesticides can negatively affect the behavior and life-history parameters of natural enemies of insect pests in agroecosystems, aggravating the subsequent incidence of pest outbreaks. Beyond beneficial insects, pesticides can be toxic to soil microbial communities, including nitrogen-fixing microbes, leading to higher fertilizer requirements and crop vulnerability to insect pests and diseases (Feld et al., 2015).

3. Drivers of Excessive Use of Pesticides and Challenges of Adopting Alternatives

The drivers of excessive and improper pesticide use is linked to lack of alternatives to synthetic pesticides, stringent market requirements for crop aesthetic perfection, unwillingness of farmers to accept the risk of crop loss, lack of education and training in pesticide use, weak enforcement of pesticide laws, lack of access to extension services, farmers' perceptions of pesticide risk, the inadequate information on related hazards, etc. (Jallow et al., 2017a, b, c; Damalas et al., 2010; Jin et al., 2015; Fan et al., 2015). A major contributing factor to pesticide overuse specifically related to Kuwait is the lack of education and training in pesticide use, particularly among migrant farmers, who constitute the majority of the agricultural labor force (Jallow et al., 2017a, b). A considerable number of the farmers are illiterate or have limited formal education, and 64% have no training in pesticide use and safety (Jallow et al., 2017a, b). Consequently, these farmers are hampered in their ability to read and understand pesticide labels or assimilate the safety precautions and regulations related to pesticides, resulting in irrational utilization of these chemicals. The influence of pesticide retailers and farmers' perception of the inefficiency of extension personnel, their lack of training, and the questionable reliability of the information they provide also played an important role in the overuse of pesticides in Kuwait (Jallow et al., 2017a, b). The overuse of pesticides is also linked to farmers' lack of understanding of pest biology and how overuse of pesticides can lead to pests developing resistance. Another contributing factor to pesticide overuse in Kuwait is farmers' limited or lack of access to alternatives to chemical pest control methods and the challenges of the alternatives themselves. Hence, farmers feel forced to use pesticides, despite the potential negative effects (Jallow et al., 2017a, b). Greater priorities must also be given to developing and promoting viable alternatives to non-synthetic methods of pest control, such as biological control and pheromone-based pest management, while at the same time promoting integrated pest management (IPM) practices. Farmers' acceptance and adoption of alternative pest management strategies, and the complexity of shifting from chemical-based pest control to non-chemical control, will be a significant challenge. This challenge, however, is not unique to Kuwait. Farmers are understandably reluctant to adopt new pest management strategies that they are not familiar with, and will need to see convincing on-farm results before shifting from chemical-based pest control strategies to non-chemical alternatives (Damalas et al., 2010).

Since active ingredients of pesticides are not formulated in the country, Kuwait is reliant on importing pesticides from neighboring countries, or from Asia and Europe. The Ministry of Health (MOH), the Environment Public Authority (EPA), the Public Authority for Food and Nutrition (PAFN), and the Public Authority for Agriculture and Fish Resources (PAAFR) share authority for the importation, registration, distribution, and regulations of pesticides and other hazardous chemicals in Kuwait. However, the limited capacity of these regulatory agencies hinders the enforcement of current pesticide laws, and this could partially explain why some farmers continue to use highly hazardous class Ib pesticides (Jallow et al., 2017a, b). The aforementioned negative effects of pesticides and factors driving their overuse



pose some unique challenges for the long-term viability of the environment and the adequate, safe, and healthy food production in Kuwait.

4. Integrated Pest Management (IPM) Strategies and Constraints to IPM Adoption

Integrated pest management has long been promoted globally as a more sustainable approach to pest management (Lewis et al. 1997; Kogan, 1998). The definition of IPM is numerous, but all involve the coordinated integration of multiple complementary pest management practices to suppress pests in a safe, cost-effective, and environmentally friendly manner, thereby potentially reducing the reliance on chemical pesticides (Yu et al., 2024). In general, IPM aims to use preventative measures and environmentally friendly pest control strategies where possible, and insecticides only when needed. Integrating different control strategies as part of an IPM program provides a viable alternative for farmers to manage pests sustainably, especially in organic farming, where economic, environmental, or human-health risks may entirely preclude the use of chemical pesticides. Organic farming is gaining a foothold in Kuwait's agriculture, but farmers suffer a general lack of non-chemical-based pest control options. IPM contributes to the reduction of pesticide use and is an important principle on which sustainable crop protection is based, and is considered a powerful tool for enhancing the sustainability of agricultural production and the long-term viability of the environment (soil, water, and biodiversity). IPM strategies include pest monitoring and early detection, use of reduced-risk pesticides, resistant plant genotypes, pheromones, biopesticides and biological control, cultural including sanitation practices, physical and chemical control, etc. (Staten et al., 1997).

It is important to accurately monitor and identify pests to effectively implement control strategies. Crop monitoring is the practice of routine surveillance to detect the presence of pests at the very early stage of outbreak and linking them to their respective damage symptoms. Crop monitoring should begin when the crop is still at the seedling or transplant stage. Pathogens are normally monitored through visual inspection and/or using indicator plants (Kogan, 1998). For insects, visual inspection of neonates, in addition to installing yellow sticky traps or delta traps laced with pheromone and light traps to detect adults, is the most effective strategy (Kogan, 1998). Cultural control involves providing the conditions that favor the growth and health of the crop, and preventing the build-up of insect pests and disease pressure. Common cultural practices include sanitation practices, hand destruction of pests and diseases, rotating crops, intercropping, appropriate irrigation management, ensuring plants are properly fertilized with the right fertilizer, pruning, use of protective insect screens, planting disease and insect-tolerant and/or resistant crop varieties, etc. Good sanitation practices minimize insect pests and diseases by creating a non-conducive environment for the pests to thrive and spread. For example, maintaining greenhouse environments clean by removing trash, old crop debris, regularly disinfecting walls, floors, growing media, pots, transplant trays, pruning tools, and other equipment will reduce pest incidence. Crop rotation prevents the carryover of pests and pathogens from one crop to another, and intercropping can limit the spread of pests and diseases. Appropriate irrigation and plant nutrition management reduce crop stress, which enhances tolerance to insect pests and disease attacks. Similarly, selecting crop varieties to plant that are tolerant and/or resistant to insect pests can reduce the incidence of insect pests and diseases.

Biological control uses beneficial organisms, primarily insect predators and parasitoids, and pathogens (bacteria, fungi, viruses that attack insects or other pathogens) to control pest populations (Desneux et al., 2011). Biological control may provide even greater control of pests when used in combination with other control strategies. Most biological control agents are harmless to humans and the environment, have a reduced risk of pest resistance, and sometimes are self-perpetuating, offering long-term pest control (Vacas et al., 2011). Similarly, natural pesticides or reduced-risk pesticides derived from plants or other natural materials are effective in controlling insect pests and diseases. Most commonly used natural pesticides include neem and pyrethrum, derived from the extraction of neem seed and chrysanthemum flowers, respectively. Pheromone-based pest management is also an important component of IPM strategies for a number of insect pests. Sex pheromones, in particular, have been utilized successfully to manage many greenhouse pest species, including the tomato fruitworm (Vacas et al., 2013; Jallow et al., 2020). Pheromone-based pest control strategies include mass trapping in which a large number of pests are captured and removed; mating disruption, through the saturation of a crop area with a synthetic sex pheromone, thereby altering the ability of males to locate females and mate, thus preventing reproduction and population increase; and attract- and-kill, through combining a pheromone with an insecticide (Desneux et al., 2011). In attract-and-kill, the insects responding to a pheromone attractant come into direct contact with an insecticide, thus killing the insect. A key benefit of attract-



and-kill is that pesticides are usually not applied directly on the plants; consequently, there are no residues left on the crop. Just like other biologically based pest management strategies, pheromones are environmentally friendly, harmless to humans and non-target organisms, and have a reduced risk of pest resistance. Pesticides are used as a last resort in an IPM program when other methods fail to reduce the incidence of insect pests and diseases. When pesticides are utilized, care must be taken to ensure that they are compatible with biological control agents, are less toxic, and have a reduced risk (Oztemiz, 2013).

Despite the strong evidence that IPM is necessary to ensure the sustainability of food production and the environment, the adoption of IPM by farmers in Kuwait, like in many countries, has been slow or poor. Lack of knowledge and information about IPM, level of education, and lack of alternatives to chemical pest control are major constraints to IPM adoption by farmers in Kuwait (Jallow et al., 2017a, b). Farmers who are educated, with greater knowledge of IPM and have access to alternative pest control strategies, implement more IPM practices on their farms. These farmers were likely to employ preventative practices such as using resistant crop varieties and destroying crop residue to reduce pest problems in the future. Likewise, they were more likely to monitor pests using pheromones and sticky traps rather than wait for plant damage before scouting, and have a higher tendency of using reduced-risk pesticides and applying them more judiciously in addition to rotating pesticide classes (Jallow et al., 2017a, b). Unfortunately, these farmers represent less than 10% of the total farming population in Kuwait (Jallow et al., 2017a, b).

4.1. Case Study: Integrated Pest Management of the South American Tomato Pinworm

Climate change and less stringent agricultural product import policies have also facilitated the recent introduction of invasive pest species that are emerging as a greater threat to agricultural production in Kuwait. Of recent introduction is the world's most destructive pest of vegetable crops, the South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Desneux et al., 2010, 2011). *T. absoluta* is native to South America and was first reported as a major pest in the early 1980s; since then, it has rapidly invaded Europe, Africa, the Middle East, and parts of Asia (Biondi et al., 2018). In the Middle East, *T. absoluta* was first reported in Jordan in 2008 and, since then, its presence has been definite in Syria, Iran, Saudi Arabia, Iraq, Yemen, Qatar, UAE, Kuwait, Oman, and Bahrain (Abdul-Razzak et al., 2010). Current simulations and estimates all indicate the potential spread of *T. absoluta* to all tomato-growing regions of the world, including Australia, China, and Japan (Biondi et al., 2018). The presence of *T. absoluta* was first reported in Kuwait in 2009, in a tomato greenhouse in the southern part of the country, and has subsequently spread throughout the country (CABI/EPO, 2013). Tomato plants can be attacked at any developmental stage, from seedlings to mature plants, and yield losses of up to 90 to 100% have been reported (Desneux et al., 2010). *T. absoluta* control is a challenge because of several factors related to its feeding behavior and biology (Cocco et al., 2013). The pests' larval stages are concealed inside plant parts (leaves, stems, and fruits) where they feed and thus are protected and inaccessible to most insecticides. Furthermore, the pest has a short developmental life cycle and a high reproductive capacity (Cocco et al., 2013). The aforementioned factors pose some unique challenges for the sustainable management of this pest.

4.1.1. *Tuta absoluta* Rapid Spread in the Middle East

T. absoluta has rapidly spread in the Middle East since its first detection in Jordan in 2008. A number of important factors could explain its fast spread. First, *T. absoluta* has a strong intrinsic invasiveness with high reproduction potential, and can adapt to newly invaded areas. Similarly, *T. absoluta* is a multivoltine species with high overwintering capacity in greenhouse facilities and with strong heat tolerance in open fields (Van-Damme et al., 2015). Consequently, these intrinsic characteristics allow the pest to thrive and increase rapidly over the years (Van-Damme et al., 2015). Conceivably, warmer conditions in greenhouses may play an important role in sustaining and promoting the pest population growth and rapid spread. The environment in the Middle East, including Kuwait, is characterized by high ambient temperatures, with summer temperatures exceeding 45 °C, and most greenhouses are hardly below 30 °C due to the cost and difficulty associated with cooling (Droogers et al., 2012). Although information on the population development of *T. absoluta* under the environmental conditions associated with Middle Eastern crop production is lacking, it is conceivable that the pest may complete 10 to 12 generations per year because of favorable weather conditions (high temperatures) and continuous availability of host plants. Second, current quarantine measures are not effective in preventing the spread of *T. absoluta* within the Middle East region. It is believed that *T. absoluta* was introduced into Kuwait through the importation of fresh tomatoes from neighboring countries. A combination of factors, including geographic closeness of countries within the region, ineffectiveness of early surveillance, and weak phytosanitary efforts,



has increased its spread in the region. To our knowledge, no official quarantine or early warning systems have so far been recommended to prevent *T. absoluta* from spreading in the region. Establishing surveillance networks within the region will provide added benefit to slow down the spread of the pest. However, due to the status of trade of fresh tomatoes among the countries in the region, it will be difficult to impose stringent quarantine measures on thousands of tons of fresh tomato products.

4.1.2. Biology

T. absoluta is polyphagous with a short developmental life cycle and a high reproductive capacity, and with 10–12 generations per year in its native geographic range, depending on temperatures. The mean generation time under optimum laboratory conditions (25 °C, 65% RH) is around 24 days (Gharekhani et al., 2014). *Tuta absoluta* life cycle comprises four development stages: egg, larva, pupa, and adult. Adult females usually lay up to 260 eggs on the underside of leaves, stems, and petioles, and to a lesser extent on fruits. After hatching, young larvae penetrate leaves, aerial fruits, or stems, on which they feed and develop. Feeding within the mesophyll of leaves creates leaf mines, which lower the photosynthetic activity of the plant and eventually cause the death of leaf tissues. Additionally, larval entry into tomato fruits and fruits of other host plants creates entry holes for secondary pathogens, leading to fruit rot. There are four larval stages. Tomato plants can be attacked at any developmental stage, from seedlings to mature plants, and yield losses of up to 90 to 100% have been reported in South America, Europe, North Africa, and the Middle East (Desneux et al., 2010). The pest pupates mostly in the soil or on the fabric of greenhouses, even though pupation may also occur on leaves. Pupae are cylindrical in shape and greenish when just formed, becoming darker in color as they near adult emergence. Adults are 6–7 mm in length with filiform antennae and silver to grey scales. Black spots are present on the anterior wings, and the females are wider and more voluminous than the males. Adults are nocturnal and usually remain hidden during the day, but sometimes show greater morning activity by dispersing within crops. Adult moths' lifespan ranges between 10 and 15 days for females and 6–7 days for males (Desneux et al., 2010). Females mate only once a day and can mate up to six times during their lifespan, with a single mating bout lasting 4–5 hours. The most prolific oviposition period is 7 days after first mating, and females lay 76% of their eggs at that time.

4.1.3. Host Plants, Damage, and Economic Impact

Solanaceae crops, especially tomatoes (*Lycopersicon esculentum* L.), appear to be the primary host of *T. absoluta*. The pest can also feed, develop, and reproduce on other cultivated Solanaceae crops such as potato (*Solanum tuberosum* L.), eggplant (*S. melongena* L.), and pepper (*Capsicum annuum* L.) as well as on non-cultivated Solanaceae (e.g., *S. nigrum* L., *S. eleagnifolium* L., *S. bonariense* L.) (Desneux et al., 2010). Studies have confirmed that the pest is expanding its host range within the Solanaceae and other plant families. *T. absoluta* is now known to attack alfalfa (*Medicago sativa*), wild radish (*Raphanus raphanistrum*), common beans (*Phaseolus vulgaris*), broad beans (*Vicia faba*), and cowpea (*Vigna unguiculata*) in the absence of a highly preferred primary host plant like tomato (Abdul-Ridha et al., 2012). *T. absoluta* attacks solanaceous plants, especially tomatoes, in different growing stages in greenhouse and field conditions (Siqueira et al., 2000). The pest attacks leaves, buds, stems, and fruits of host plants. The larvae feed vigorously, producing large galleries in leaves, and they are capable of causing up to 100% yield loss (Siqueira et al., 2000). All developing stages of *T. absoluta* can be found throughout the crop growing season, with generations of the pest overlapping. Larval feeding activity reduces crop yield (Desneux et al., 2010). Severe injuries to seedlings can occur, leading to the death of young plants when larvae develop inside the main stem. Fruits can be attacked as soon as they are formed, significantly reducing quality and yield (Desneux et al., 2011). Secondary pathogens that may enter through the wounds caused by the pest can lead to fruit rot, especially those caused by bacteria, which can actively penetrate damaged tissues. The economic impact of invasive pest species like *T. absoluta* includes, increase in costs of crop production, pest management costs, a decrease in marketability of produce, and potential loss of trading partners. For *T. absoluta*, this could have a tremendous impact on tomato production.

4.1.4. Management Efforts

An array of management options, including chemical insecticides, cultural practices, pheromones, entomopathogens, biological control (using predators and parasitoids), and host plant resistance, has been evaluated against *T. absoluta*. Entomopathogens represent one of the most promising options for IPM and offer several advantages over chemi-



cal pesticides. Entomopathogens have a reduced risk of pest resistance, are environmentally friendly and sometimes self-perpetuating, offering long-term control, and are harmless to humans and non-target organisms (Huang et al., 2004). The entomopathogenic bacterium *Bacillus thuringiensis* (Bt) is widely used for controlling various agricultural pests. More than 3,000 species, belonging to 16 orders of insects, have been reported as susceptible to *B. thuringiensis* (Huang et al., 2004). Several studies have evaluated the efficacy of *B. thuringiensis* on *T. absoluta* with significant control effects (Molla et al., 2009; Giustolin et al., 2001; Jallow et al., 2019a). *Bacillus thuringiensis* applied on tomato provided 40 to 60% control of *T. absoluta* in laboratory, greenhouse, and open field experiments (Jallow et al., 2019a). Toxicity against all larval instars was observed, with the first instars more susceptible to *B. thuringiensis*. Other entomopathogens against *T. absoluta* have been studied and documented, notably the potential use of entomopathogenic nematodes (Jallow et al., 2019a). Entomopathogenic nematodes are very attractive pest management alternatives to synthetic pesticides and are ideally suited for biologically based IPM systems for many economically important insect pests, particularly for soil-dwelling insect pests (Boemare, 2002). These nematodes, belonging to the families Steinernematidae and Heterorhabditidae, are obligate parasites that kill insects with the help of mutualistic bacteria that inhabit the intestine of the infective juveniles (Boemare, 2002). Control of *T. absoluta* with nematodes has been variable. For example, Grewal et al. (2005) evaluated the susceptibility of several species of entomopathogenic nematodes against *T. absoluta* larvae and pupae under laboratory conditions. They reported 60% and 70% larval mortality when *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* were applied, respectively. In greenhouse studies where entomopathogenic nematodes were applied, *T. absoluta* severity was reduced by 40 to 50% (Garcia-Del-Pino et al., 2011). Similarly, in greenhouse trials on tomato, pest infestation and fruit damage were significantly lowered in plants treated with the entomopathogenic fungus *Beauveria bassiana* (Jallow et al., 2019a).

Several predators and parasitoids are known to be associated with *T. absoluta*, mainly in South America and the Mediterranean regions (Desneux et al., 2010, 2011). In particular, the egg parasitoid *Trichogramma achaeae* and the predatory bugs *Nesidiocoris tenuis* and *Macrolophus pygmaeus* are reported to be some of the most effective in suppressing *T. absoluta*. *Trichogramma achaeae* and *N. tenuis* are already commercially available for augmentation biological control against *T. absoluta*. These two biological control agents appear to be very well adapted to warmer conditions, and are currently evaluated in tomato greenhouses in Jordan (Desneux et al., 2010, 2011). These natural enemies have been shown to be able to regulate *T. absoluta* populations under greenhouse and field conditions (Molla et al., 2009; Jallow et al., 2022). A fifty-six percent reduction in *T. absoluta* damage was demonstrated when *N. tenuis* was established in field tomatoes (Molla et al., 2009). Similarly, 65% parasitism of *T. absoluta* by *T. achaeae* was reported under greenhouse conditions (Desneux et al., 2010). Biological control agents may provide even greater control of *T. absoluta* when used in combination with other control strategies. For example, additive and synergistic interaction between *B. thuringiensis* and *N. tenuis* for *T. absoluta* control under greenhouse conditions was demonstrated, resulting in more than 70% reduction in crop damage (Molla et al., 2009). Similarly, the additive effect of *T. achaeae* and *N. tenuis* was observed when the two natural enemies were released simultaneously in greenhouses to control *T. absoluta* (Desneux et al., 2010). The combination of *B. thuringiensis* and the entomopathogenic fungus *Beauveria bassiana* was also shown to be more effective in controlling *T. absoluta* than *B. thuringiensis* alone (Jallow et al., 2019a). Synergism between entomopathogens and resistant tomato genotypes, and between the egg parasitoid *T. achaeae* and the predator *Macrolophus pygmaeus* for the control of *T. absoluta* in tomato greenhouses has also been demonstrated (Chailleux et al., 2012).

Since the identification and synthesis of the pheromone components of *T. absoluta*, successful control of the pest with mating disruption, mass trapping, and attract-and-kill strategies has been reported, especially in greenhouse tomato crops (Cocco et al., 2013; Jallow et al., 2020). Fifty to sixty percent control of *T. absoluta* by mating disruption was recorded in greenhouse tomatoes treated with 35 to 50 g ai ha⁻¹ of sex pheromone (Vacas et al., 2013). Similarly, mating disruption applied at high doses (1000 dispensers/ha; 60 g ai/ha⁻¹ of sex pheromone) was as effective as insecticides in managing *T. absoluta* in greenhouse environments (Jallow et al., 2020). The use of other control strategies such as alternating tomato a host crop with non-host crops and destruction of crop residues, monitoring for resistance development (Jallow et al., 2019b), and preservation and/or augmentation of natural enemies, such as the predatory bugs *N. tenuis* and *M. pygmaeus*, employed alone or in combination with parasitoids can also ensure long term reduction of *T. absoluta* population densities in greenhouse and open field environments (Naselli et al., 2017).



5. Conclusions and Recommendations

Pesticide misuse is a major threat to the environment as well as to farmers and ultimately to the public consumers' health in Kuwait, and indeed in many other countries where widespread use of pesticides has emerged as a dominant trend in agriculture. The reliance of growers solely on pesticides will not provide the flexibility required for a rational management of pests in agricultural ecosystems. Therefore, the successful integration of diverse strategies, involving both preventative and corrective control measures, will remain crucial for the sustainable management of agricultural pests. Priority must also be given to promoting capacity-building among farmers to enhance their knowledge about pest management and judicious use of pesticides, thus modifying their behavior towards reducing pesticide use and promoting viable alternatives to non-synthetic methods of pest control. These efforts should be complemented with stringent enforcement of existing pesticide laws and regulations, both at the retail and at the farm level. In addition, policy interventions are necessary to restrict the importation, sale, and use of unnecessary pesticides.

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