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INTEGRATION AND FUNCTIONALITY OF IPM STRATEGIES FOCUSING ON INSECT PESTS IN VARIOUS CROPS

Ioana GROZEA, Diana-Maria PURICE, Ramona ȘTEF, Alin CARABET, Adrian GROZEA, Ana-Maria VIRTEIU

University of Life Sciences "King Mihai I" from Timisoara,
119 Calea Aradului Street, Timisoara, Romania

Corresponding author email: ioanagrozea@usvt.ro

Abstract

Integrated Pest Management (IPM) is an increasingly used tool for sustainable pest management with the clear aim of reducing adverse environmental impacts and providing long-term economic and ecological benefits. Holistically, this approach aims to manage pest populations through combined and compatible techniques and methods. It is not focused on eradicating and eliminating pesticides but rather on keeping pest populations under control and reducing pesticide use. With this in mind, it is essential to bring to attention of both farmers and researchers in agriculture and plant protection the latest available tools, reflecting the advantages and disadvantages by exemplifying them on crop systems (cereals, vegetables). This review is by far an analysis of what is already used, tested and applicable and on the other hand highlighting the challenges in digital context through the scientific, economic and social potential. All of this helps to make decisions to organize pest management activities and encourage direction towards a safe path for human health and environmental protection by supporting precision agriculture.

Key words: *IPM, insect pests, monitoring, classic and modern tools.*

INTRODUCTION

IPM (Integrated Pest Management) is an approach that integrates information about the life cycles of pests and their interactions with the environment to provide effective control, reducing risks to humans and the environment (Holm, 2022, Zhou et al., 2024).

In order to achieve agricultural sustainability, IPM promotes ecological and sustainable practices, contributing to reducing dependence on pesticides and increasing biodiversity in agricultural systems (Angon et al., 2023; Virteiu et al., 2023).

By combining multiple tactics such as biological control, selective use of insecticides and physical/mechanical methods, it aims to reduce negative environmental impacts and increase efficiency (Riyaz & Kathiravan, 2019).

Although IPM is recognized as an effective strategy, its implementation has been slowed by the complexity of technologies and the lack of financial and human resources (Wearing, 1988; Grozea, 2010). However, it is clear that its implementation has demonstrated a significant decrease in pesticide use and negative environmental impacts, without compromising effectiveness in pest reduction (Moffitt, 1993; Costea et al., 2024).

Another quality is that it supports safe and high-quality food production, contributing to the growing demand for organic food products (Dhawan & Peshin, 2009).

IPM also allows strategies to be adapted according to the specific conditions of the crop and the geographical region, maximizing efficiency and reducing environmental risks (Green et al., 2020).

Another facility is the creation of international research and implementation networks that can help overcome challenges related to communication, knowledge transfer and coordination between countries (Lamichhane et al., 2016).

Considering all these favourable aspects already found at the international and national level, we think it appropriate to detail the information through a review of the sources of IPM application to two important categories of crops (cereals and vegetables) at a global level in diversified systems, for relevant pests and in terms of technological progress, demonstration of efficiency and adoption by farmers.

MATERIALS AND METHODS

Crop Selection

In this review study, we focused on wheat, maize, tomatoes and cucumbers. These are the most commonly grown crops globally, with proven importance and increased research attention.

Wheat is grown globally on an area of approximately 222 million ha, of which just over 2 million are in Romania (Erenstein et al., 2022). According to FAO Stat (2022), maize is grown on approximately 200 million ha globally and 2.5 million ha in Romania(Vili et al., 2022). Tomatoes occupy approximately 5 million ha (open field and greenhouse) being grown with this vegetable, of which in Romania it occupies around 40,000 ha (according to FAO, 2022). Cucumbers are cultivated on an area of 1.2 million hectares, while only at a somewhat unspecified national level, i.e. approximately 5000 ha (FAO Stat, 2022; Anghelache et al., 2023) (Table 1).

Table 1. Summary of statistics on areas occupied by target crops, at global and national level

Crop	Area (ha)		Cultivation System
	Globally	National*	
Wheat	222.000.000	2.000.000	Field
Corn	200.000.000	2.500.000	Field
Tomatoes	5.000.000	40.000	Mixed (field +greenhouses)
Cucumber	1.200.000	5000	Greenhouses and solariums

*Surface area in Romania at the level of 2022

Factors considered

In our searches from various sources at a global level, we took into account the following factors: crop type, cultivation system (organic, conventional), degree of economic development, range of pests, classical methods of keeping them under control and modern methods (as appropriate).

Evaluations and analyses

Based on the information found in the electronic system, methods and the adoption of modern methods by farmers in a non-polluting context. So, mainly we have constructed several diagrams with the most used methods within IPM for each category of crops taken into analysis, as well as the effects on production through pesticide reductions and environmental pollution, for example.

The level of farmers' adoption of modern methods was also assessed through the prism of socio-economic characteristics.

RESULTS AND DISCUSSIONS

It seems that from what was found and analysed, implementing IPM can bring major benefits by reducing pests and increasing yields and farmers' adoption of modern methods in pest IPM.

Pest reduction and yield increase

In wheat crops (Figure 1), the application of IPM (by combining mechanical, biological and chemical methods) was able to reduce aphid populations, mainly with an emphasis on reducing the use of insecticides (even selective) and increasing the share of non-chemical methods. Among the mechanical methods effective in reducing aphid populations (*Schizaphis graminum* Rondani), we highlight sticky traps and yellow liquid traps, and among biological methods, the protection of ladybugs. Clearly, these 2 methods will lead to a reduction in insecticide application. As a result, aphids were reduced, while the ladybug population increased, which is beneficial for the environment and the future. All of this can also lead to yield increases of about 10% of the harvest (Singh & Jasrotia, 2020).

In corn crops, IPM methods to control *Ostrinia nubilalis* (Hubner) (one of the most persistent pests) (Costea et al., 2022) and to increase crop yield can include a combination of biological control (*Trichogramma*, Bt), selective insecticides and crop rotation, according to many studies in this regard (Figure 2). As such, crop rotation reduces the population pressure of the pest and favours natural control by preserving beneficial insects (Camerini et al., 2024).

Biological control with *Trichogramma brassicae* (Bezdenko) has demonstrated similar efficiency to chemical methods, reducing infestation and maintaining mycotoxin levels below EU food safety thresholds, while increasing profitability (Gardner et al., 2011; Razinger et al., 2016). The application of *Bacillus thuringiensis* (Berliner) as a biological insecticide also provides good control of the pest (Tembo, 2009).

The application of selective insecticides maintains beneficial insect populations and is as effective as conventional chemical methods against *Ostrinia nubilalis* (Vasileiadis et al., 2017).

Genetically modified maize hybrids (Bt maize) provide effective protection against the pest, completely reducing infestation and increasing yield by up to 15% compared to conventional methods (Kocourek & Stará, 2018).

From analysed data for cereals, an IPM strategy cannot be applied only taking into account the crop but also the pest. Practically for each crop and pest an IPM must be developed, depending on the morpho-bio-ecological characteristics.

In tomatoes, IPM for the management of the most common pest (*Tuta absoluta* Meyrick) (Biondi et al., 2018), in field and protected area, combines agronomic, biological, chemical and mechanical methods to reduce the pest population and its impact on tomato crops (Figure 3).

Among agronomic methods, crop rotation and intercropping with repellent plants can reduce the pest population between seasons (Mahmoud et al., 2020). Also, removal and destruction of plant debris contributes to the elimination of larval development sites (Chepchirchir et al., 2021).

Biologically, effective are the use of natural predators (such as *Nesidiocoris tenuis* and *Macrolophus pygmaeus*) that consume the eggs and early larvae of the pest (Giulianotti, 2010) or the application of bioinsecticides with entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* to infect and destroy the larvae (Buragohain et al., 2021).

The use of attractant-repellent substances to disrupt insect behaviour is also of interest (Desneux et al., 2016).

Sex pheromone traps are widely used to capture males, reduce mating and estimate population density (Guedes & Picanco, 2012).) and light and water traps are used in Nigeria to reduce the number of adults (Oke et al., 2020).

Due to the perishable nature of tomatoes, insecticide use should be minimized and, when necessary, limited to low-toxicity bioinsecticides or selective compounds with short pre-harvest intervals (e.g., *Bacillus thuringiensis*, neem-based formulations).

Integration of these measures helps to maintain long-term effectiveness and prevent insecticide resistance.

In cucumber, IPM for the management of the most widespread pest in both protected areas and in the field, such as *Bemisia tabaci* Gennadius (whiteflies), combines agronomic, cultural, biological, mechanical and chemical methods to effectively reduce pest populations, while reducing the transmission of devastating viruses (Figure 4).

Among the agronomic ones, crop rotation with non-host plants helps to disrupt the whitefly life cycle and reduces infestation pressure. And intercropping cucumbers with repellent plants, such as marigolds or basil, can reduce the attraction of whiteflies (Hegab et al., 2016).

Regarding the cultural ones, the removal of infested plant debris reduces whitefly breeding sites and the use of insect-resistant nets prevents whiteflies from entering greenhouses and open field crops (Stansly et al., 2004).

Biologically, the predatory insect *Phytoseiulus persimilis* and entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*) can control whiteflies populations in greenhouses (Abou-Haidar et al., 2021; Singh & Kaur, 2020).

Mechanically, the use of yellow sticky traps is highly attractive to *Bemisia tabaci*, with capture rates of up to 44% (Hoelmer & Simmons, 2008). In Romania, studies on the effectiveness of traps in pest control are lacking.

Low-toxicity insecticides, such as botanical extracts (neem, aloe), have been shown to be effective against this pest (Darwish et al., 2022).

By implementing these strategies, pest populations can be kept below economic thresholds, reducing the risk of virus transmission and ensuring higher yields.

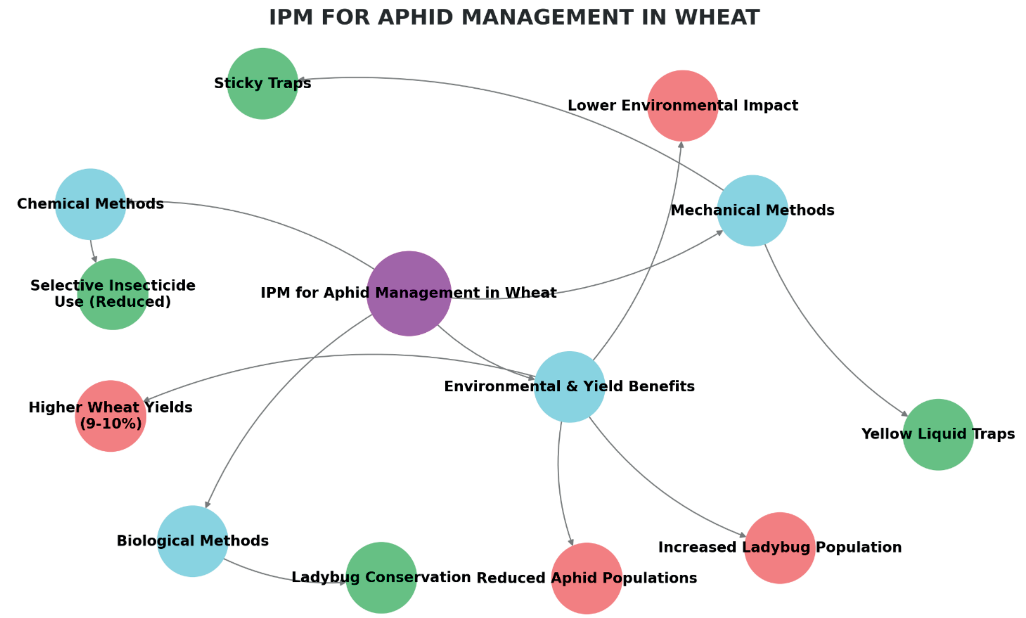

Figure 1. IPM scheme for managing aphids of the genus *Schizaphis graminum* Rondani in wheat crops

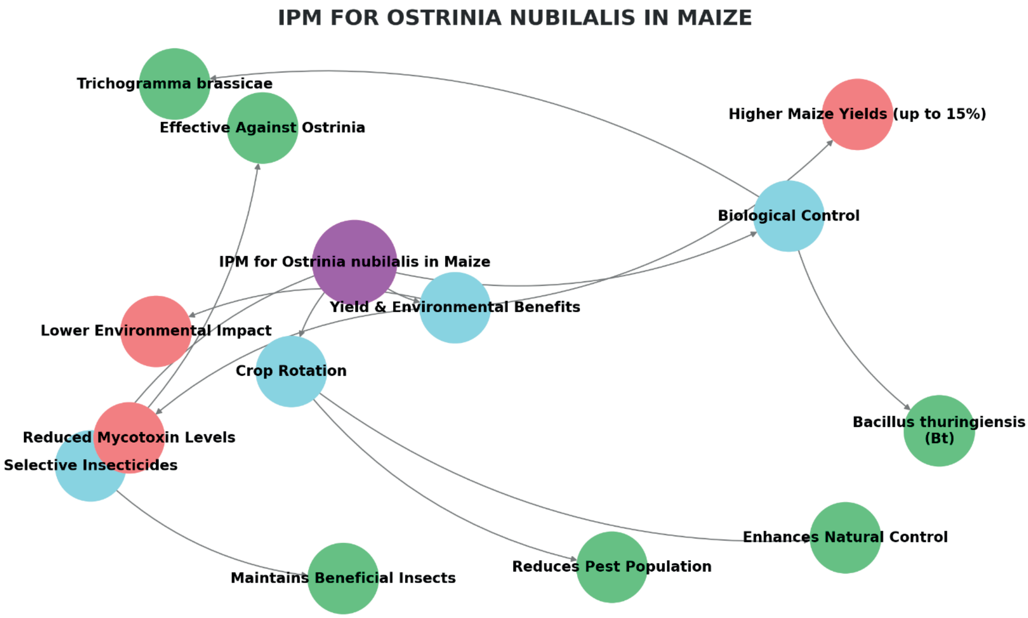

Figure 2. IPM scheme for managing *Ostrinia nubilalis* Hubner in corn crops

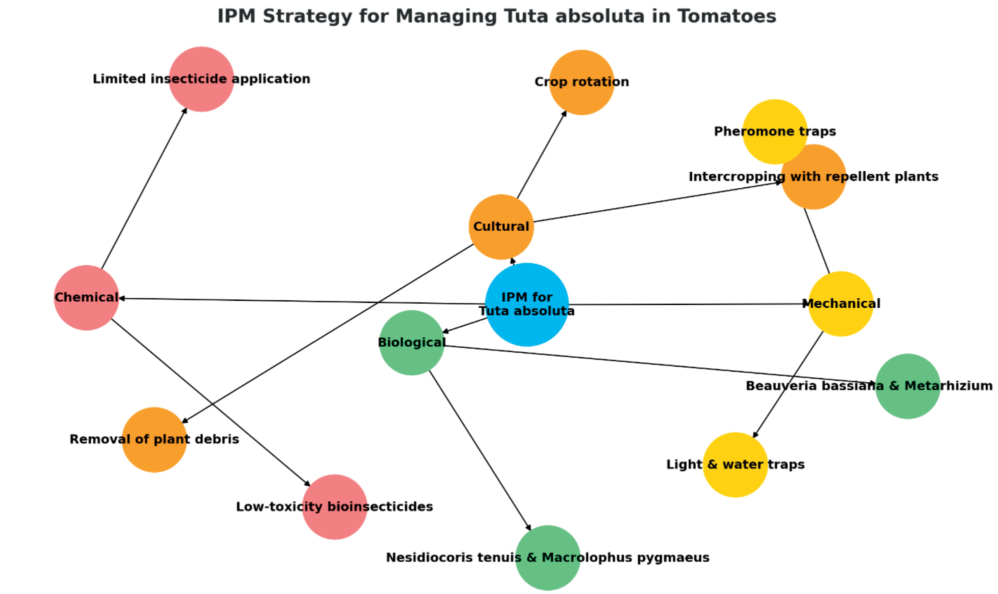

Figure 3. IPM scheme for managing of *Tuta absoluta* Meyrick in tomatoes crops

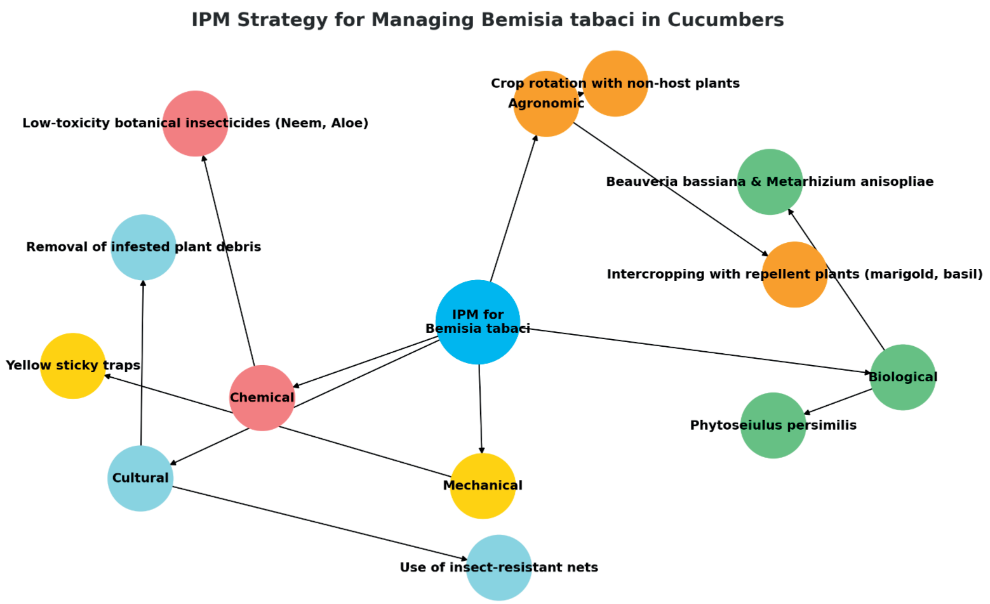

Figure 4. IPM scheme for managing *Bemisia tabaci* Gennadius in cucumbers crops

Farmers' adoption of modern methods in pest IPM

Among the modern methods of managing aphids in wheat crops, unmanned aerial vehicles (UAVs) for pesticide application have been widely adopted by farmers. Their effectiveness has been proven by spraying at low altitude (1.5 m) with optimized droplet distribution, which significantly improves the effectiveness of aphid control (Sun et al., 2022). Digital and smart traps for aphid detection have also been proven effective in estimating aphid populations.

Yellow sticky traps combined with digital monitoring have been proven effective in early detection of aphids in the crop. However, farmers have combined UAVs with classic traps to maintain constant monitoring and reduce the need for chemical control (Jasrotia et al., 2022).
In managing *Ostrinia* populations, new studies have focused on light traps that use UV or fluorescent lamps to attract adults and also on optimizing their energy source for field applications that are easily adopted by farmers.
Combining real-time digital monitoring with UAV-based biological control (based on the principle that drones release *Trichogramma* only in infested areas), significantly reduces costs and pesticide use, making the work of farmers much easier (Beres, 2023).
In management of vegetable pests (tomatoes and cucumbers), the GLT trap using yellow light has been shown to be very effective in capturing both whiteflies and *Tuta absoluta* in protected areas. The GLT trap captured three times more insects than conventional yellow sticky traps, making it a promising method that is easy for farmers to apply and maintain non-chemical control (Mirza & Abdi, 2019).
Green LED traps have also been tested to monitor whitefly populations in greenhouses, and have been shown to detect populations earlier than traditional yellow sticky traps, allowing farmers to intervene in a timely manner (Grupe & Meyhöfer, 2024).
UV light traps combined with sex pheromones have been tested to optimize capture efficacy based on the flight activity of *Tuta absoluta* and have proven applicable and effective (Zhang et al., 2023).
AI adoption in agriculture is unevenly distributed, with large commercial farms and younger, more educated farmers leading adoption, while smallholder farmers face financial and infrastructural barriers (Table 2).

Table 2. Economic and social drivers behind farmers' adoption of AI methods

Farm type	AI adoption	Key drivers
Large commercial farms	High	High access to capital, advanced digital literacy
Mid-sized farms	Moderate	Partial access to AI tools, cost-sharing initiatives
Smallholder farms	Low	High costs, lack of access to funding and training
Cooperative farms	High	Knowledge sharing, government incentives

Government policies, digital training programs, and increased access to finance can help bridge this gap (Eunice et al., 2022).

CONCLUSIONS

Based on the findings, it is clear that for the 4 crops taken into account (wheat, corn, tomato and cereals) there are currently IPM approaches that combine classical and modern methods. The terms behind are focused on reducing the use of pesticides and increasing efficiency by increasing production in a context of low environmental impact.
Of course, the acceptance of adopting modern methods is influenced by economic and social terms, the higher the economic level and financial potential and social involvement, the higher the acceptability of the novelty. And the size of the farms is a decisive factor, that is, the larger or more aggregated they are, the higher the acceptability. As a recommendation, combining methods taking into account the crop, pest and socio-economic context is essential in maintaining an IPM at the expected level.

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