WHAT IS ENVIRONMENTALLY ACCEPTABLE PLANT PROTECTION?

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ABSTRACT

Agricultural researchers strive to develop cropping systems that produce abundant, nutritious and safe food for consumers, as well as systems that are profitable to the business of farming and have the least negative impact on the environment. To achieve these goals requires understanding the biology and ecology of the crops and their pests, the environment in which they interact, and scientific innovation. In her 1962 seminal book, *Silent Spring*, Rachel Carson described to the general public and the scientific community the problems caused by excessive use of broad-spectrum pesticides in agriculture. Before publication of *Silent Spring*, Vern Stern and colleagues in California developed and published in 1959 the concept of integrated pest management (IPM). They defined IPM as a series of multiple tactics to avoid or reduce pest outbreaks and to use pesticides only when needed. This philosophy of IPM guides crop protection practices in many countries today. A cornerstone of IPM is the use of pest-resistant plants, whether developed through traditional breeding, mutation breeding or genetic engineering (GE). However, the use of GE plants has engendered controversy and, in many cases, taken useful tools out of the toolbox growers need.

Key words: crop protection, biotechnology

IZVLEČEK

KAJ JE OKOLJSKO SPREJEMLJIVO VARSTVO RASTLIN?

Raziskovalci v kmetijstvu stremijo k razvoju sistemov rastlinske pridelave, s katerimi bi bilo mogoče pridelati večjo količino hranljive in za potrošnika varne hrane, obenem pa bi bili takšni sistemi donosni in bi imeli čim manj negativnih vplivov na okolje. Da bi dosegli te cilje, moramo poznati biologijo in ekologijo gojenih rastlinskih vrst in njihovih škodljivih organizmov, okolja, v katerem sobivajo, in novosti v znanosti. Rachel Carson je leta 1962 v knjigi Nema pomlad seznanila javnost in znanstveno srenjo o negativnih okoljskih vplivih, ki jih lahko povzroči prekomerna uporaba fitofarmacevtskih sredstev v kmetijstvu. Pred izdajo knjige Nema pomlad so Vern Stern in sodelavci leta 1959 v Kaliforniji razvil in objavil koncept integriranega varstva rastlin (IVR). IVR so definirali kot skupek različnih strategij, s katerimi se je mogoče izogniti močnemu pojavu škodljivih organizmov ali pa je mogoče njihovo številčnost zmanjšati, FFS pa uporabimo le tedaj, ko je to potrebno. Še dandanes se omenjena filozofija IVR uporablja v številnih državah. Temelj IVR je uporaba rastlin, odpornih na škodljive organizme, ki jih bodisi vzgojimo prek naravne selekcije, žlahtnjenja mutantov ali genskega inženiringa. Kakorkoli že, uporaba gensko spremenjenih rastlin vzbuja polemike in v številnih primerih pridelovalcem otežuje njihovo uporabo.

Ključne besede: varstvo rastlin, biotehnologija

I hope the title of my talk will challenge all of us as we do research on insects, weeds and pathogens affecting our food and fibre crops. Pest management practices that were common

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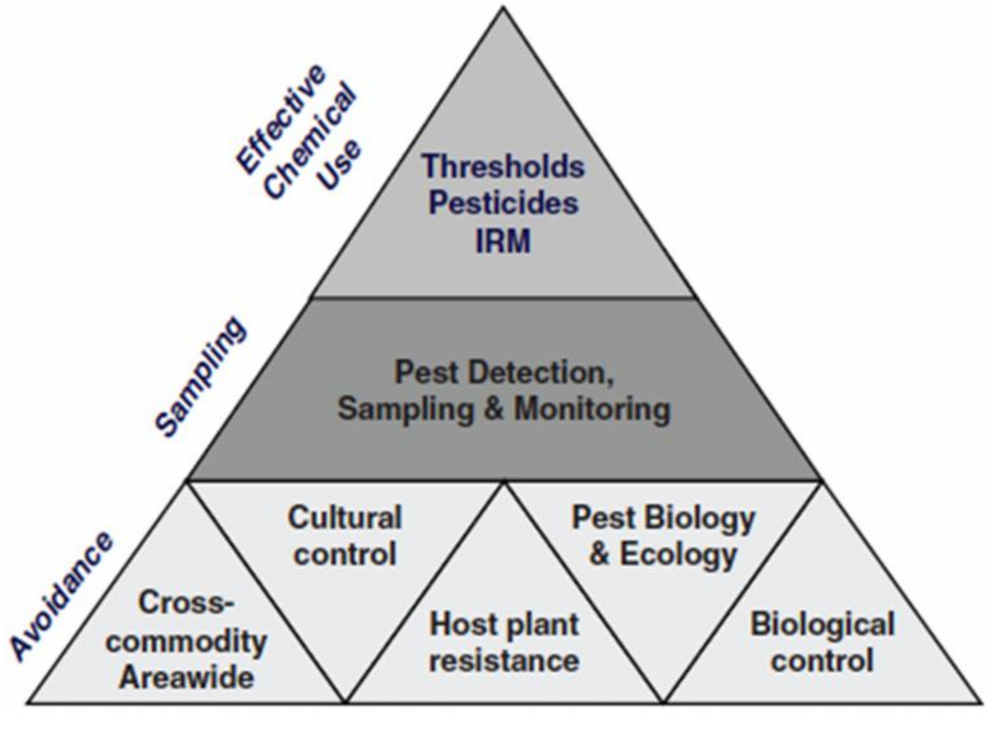
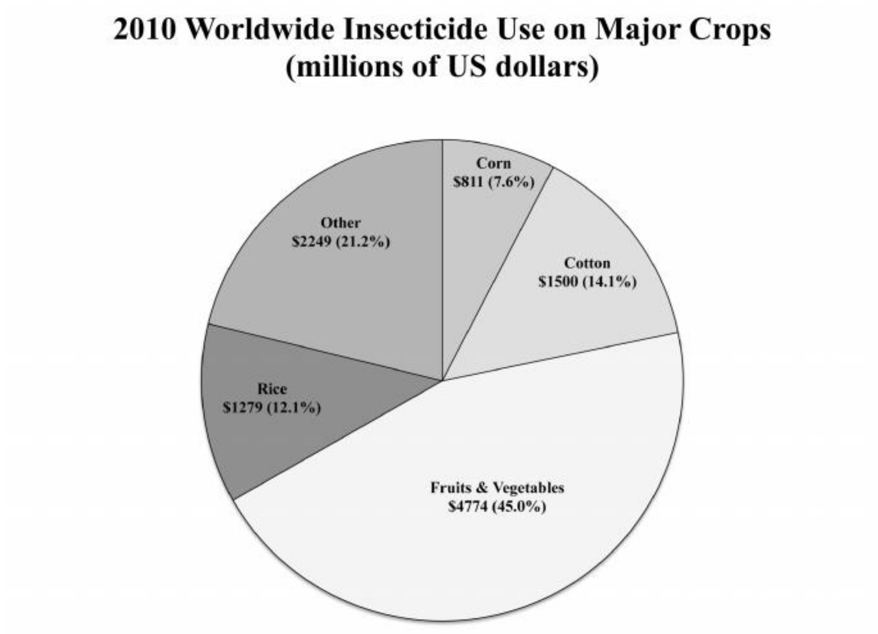
in the past may no longer be suitable. In many countries, Rachel Carson's *Silent Spring* was a wake-up call to the hazards of depending too much on the broad-spectrum pesticides that were developed during and soon after WWII. But even before her seminal book, insightful people who worked in crop protection had developed the concept of integrated control (Stern *et al.*, 1959), which developed into the field of integrated pest management (IPM). The components of IPM are illustrated in the diagram below. Avoiding or reducing the likelihood of pest attack is the foundation of IPM, and the central building block in avoidance is host plant resistance. If host plant resistance to the key pest can be achieved, then secondary pests can be controlled as needed with specific tactics. On the other hand, if broad-spectrum insecticides are used to control the key pest, this often disrupts the system and results in secondary pest outbreaks. From an IPM standpoint, it should not matter how the host plant resistance is created, but only how it functions against the pest population (Kennedy, 2008). But how can we develop host plant resistance for the many types of injury insects cause?
Insect injury to crops can be categorized by: feeding on seedlings and destroying or setting the crop back, e.g., Colorado potato beetle on potato; feeding on the marketable portion of the crop, e.g. tomato fruitworm boring into tomato; feeding on leaves and reducing photosynthesis and hence yield, e.g., onion thrips on onions; contaminating the marketable portion of the crop, e.g., European corn borer inside snap beans; transmitting a plant pathogen, e.g. western flower thrips on many crops. How can we control insects that cause such diverse types of injury?



Conceptual diagram of integrated pest management emphasizing the importance of the underlying foundation of pest avoidance through components such as insect-resistant GM varieties and biological control.
Source: Romeis, J., A.M. Shelton, G.G. Kennedy. (2008) Integration of Insect-Resistant Genetically Modified Crops within IPM Programs. Springer, New York.

In most cases growers still rely heavily on frequent applications of insecticides, which has led to many cases of insecticide resistance, decimation of beneficial insects and contamination of soil and water. Surprisingly and unfortunately, the majority of all insecticides used are used on fruits and vegetables (Shelton, 2012), crops that are a requirement of a healthy diet, because these two crop groupings have a wide diversity of pests and high cosmetic standards (Shelton *et al.*, 2008; Shelton, 2012). In the illustration below, the amount of insecticides used on fruits and vegetables (45%) exceeds that used on corn, cotton and rice combined!
Is there a way to break this cycle of insecticide overuse, especially on crops needed for a healthy diet? As mentioned previously, the key to avoiding pests is to utilize host plant resistance. Plant breeders have a long and successful history of developing germplasm resistant to various pathogens and being able to incorporate the resistance into commercial varieties. However, there has been much less successful breeding of plants resistant to insects (Smith, 1989), especially to the largest insect orders whose members attack crops, Lepidoptera and Coleoptera.
Fischhoff *et al.* (1987) demonstrated the ability to genetically engineer a plant to express an insecticidal protein from the soil bacterium, *Bacillus thuringiensis* (Bt), which has been used for decades as a foliar insecticide and has a long history of safe use. There are many different strains of Bt that produce insecticidal crystal (Cry) proteins that, when ingested by susceptible insects, cause the insect to cease feeding and die (Schnepf *et al.*, 1998). Bt plants were first commercialized in 1996 and have been rapidly adopted by farmers as part of their IPM programs (Shelton *et al.*, 2002). It has been argued that Bt crops are simply another form of host plant resistance for IPM programs and provide the same benefits (e.g. pest control) and risks (resistance evolution) as host plant resistance developed through traditional methods (Kennedy, 2008).



In 2014, 78.8 million ha of Bt crops (cotton and maize) were planted in 28 countries (James, 2014). Additionally, smaller areas of Bt sweet corn are being grown for the fresh market in North America and they have provided excellent control of pest Lepidoptera (Shelton *et al.*, 2013). In 2014 Bt eggplant was first commercialized in Bangladesh and is rapidly being adopted by resource-poor farmers who normally would spray with broad-spectrum insecticides 2-3 times per week to control the eggplant fruit and shoot borer (Choudhary *et al.*, 2014). Besides host plant resistance using Bt crops, resistance to insect-transmitted viruses has been achieved through genetically engineering plants to contain part of the virus and thereby fight off infection through the process of ribonucleic acid interference (RNAi) (Shelton, 2015). Virus-resistant papaya and summer squash are commercially available (Shelton *et al.*, 2008).

Bt field corn and Bt cotton have been commercialized for 19 years and revolutionized insect pest management, but what have been their effects? Studies have reported that Bt cotton and Bt maize have provided substantial economic benefits and reduced the use of harmful insecticides with positive implications for biological control. For example, Klümper and Qaim (2014) report that Bt crops have, compared to non-Bt crops, globally increased yield by 21.6%, decreased insecticides by 36.9%, and increased grower profit by 68.2%. Moreover, widespread adoption of Bt cotton and Bt maize has suppressed regional populations of the cotton bollworm, *Helicoverpa armigera*, in China (Wu *et al.*, 2008), pink bollworm, *Pectinophora gossypiella* (Lepidoptera: Gelechiidae), in the US (Carriere *et al.*, 2003), and the European corn borer, *Ostrinia nubilalis* (Lepidoptera: Crambidae), in the US (Hutchinson *et al.*, 2010).

Besides the economic benefits and reduced use of insecticides, numerous studies have shown that the Bt proteins expressed in commericalized Bt crops do not harm important natural enemies that help suppress pest populations (Lu *et al.*, 2012; Romeis *et al.*, 2013; Comas *et al.*, 2014; Su *et al.*, 2014; Tian *et al.*, 2014; Tian *et al.*, 2015). This is in stark contrast to studies with synthetic or organic insecticides that have deleterious effects on natural enemies (Naranjo *et al.*, 2009; Lu *et al.*, 2012).

With the widespread use of Bt crops, there is justified concern that insects would rapidly evolve resistance to the Bt proteins. Insects have a long history of evolving resistance to other insecticides (Whalon *et al.*, 2015), so why not to Bt plants? Surprisingly to some, there have been few cases of resistance to Bt crops in the field. The reasons for this appears to be the high and consistent expression of Bt proteins in plants compared to foliar insecticides, and the use of refuges to maintain susceptible alleles in the population (Tabashnik *et al.*, 2003; Tabashnik *et al.*, 2013). The conservation of natural enemies by substituting Bt proteins for harsher synthetic or natural product insecticides also appears to contribute to the minimal number of cases of resistance to Bt plants (Liu *et al.*, 2014). But vigilance and proper management to delay resistance continues to be a priority to preserve this valuable technology.

While the widespread adoption of Bt corn and Bt cotton (globally, 30% and 68% of each crop, respectively, was Bt) should be applauded, it is unfortunate that these benefits have largely not been realized for fruits and vegetables, which traditionally receive such high insecticide loads, as shown in the figure above. Shouldn't genetically engineering be promoted as a tool to create host plant resistance to key insect pests as part of an IPM strategy?

CONCLUSIONS

IPM is a philosophy and set of practices to manage pest populations using a number of different and synergistic strategies. Host plant resistance is the foundation for IPM, and genetic engineering has allowed scientists to create plants that are resistant to insects and the pathogens they transmit, without disrupting the agroecological setting in which the crops are grown. The environmental and economic benefits of genetically engineered crops that control insects and pathogens they transmit, have been well documented. As these benefits are more widely realized, more countries will adopt genetically engineered crops for pest management to benefit farmers, consumers and the environment.

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