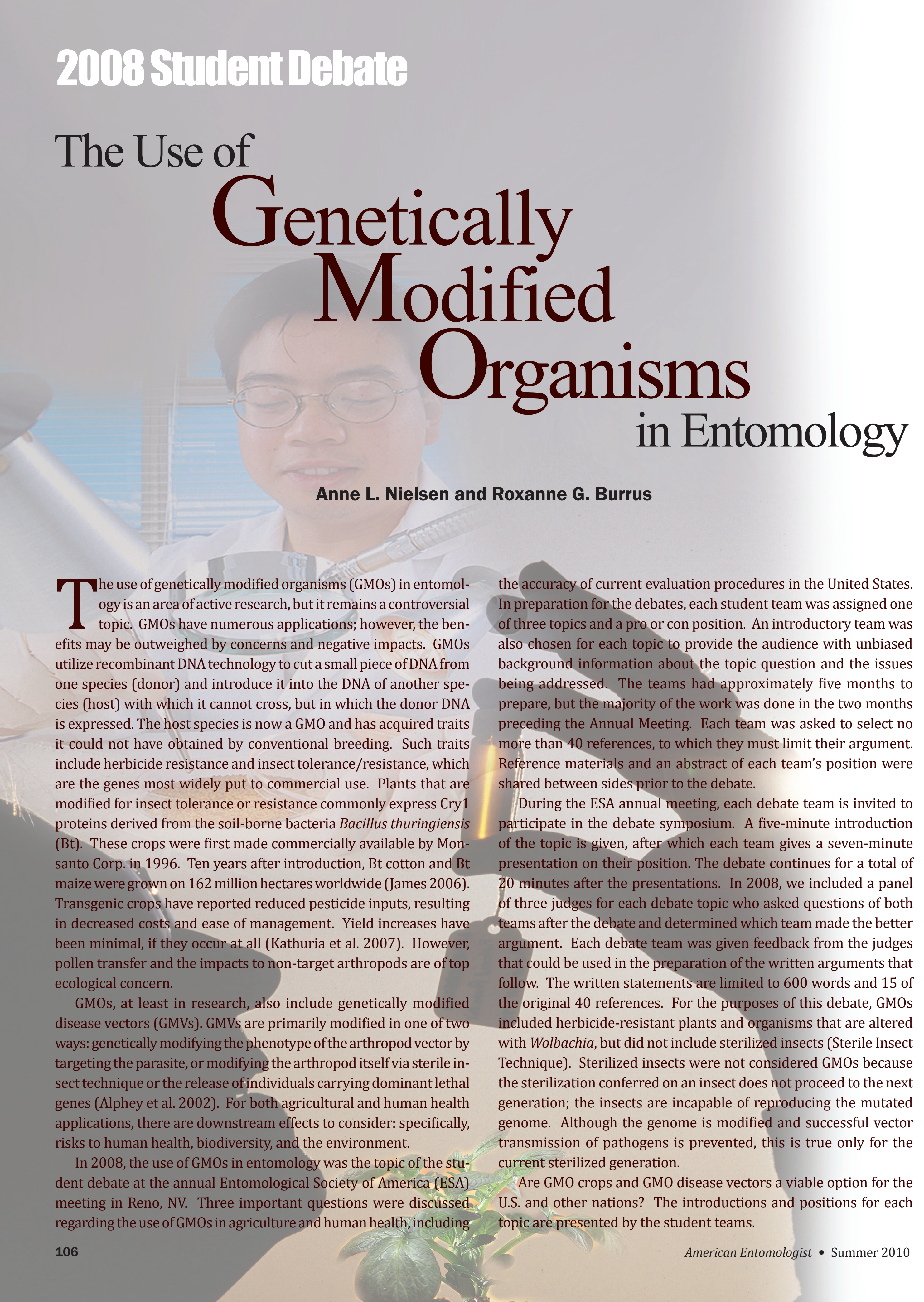

2008 Student Debate

The Use of Genetically Modified Organisms in Entomology

Anne L. Nielsen and Roxanne G. Burrus

The use of genetically modified organisms (GMOs) in entomology is an area of active research, but it remains a controversial topic. GMOs have numerous applications; however, the benefits may be outweighed by concerns and negative impacts. GMOs utilize recombinant DNA technology to cut a small piece of DNA from one species (donor) and introduce it into the DNA of another species (host) with which it cannot cross, but in which the donor DNA is expressed. The host species is now a GMO and has acquired traits it could not have obtained by conventional breeding. Such traits include herbicide resistance and insect tolerance/resistance, which are the genes most widely put to commercial use. Plants that are modified for insect tolerance or resistance commonly express Cry1 proteins derived from the soil-borne bacteria *Bacillus thuringiensis* (Bt). These crops were first made commercially available by Monsanto Corp. in 1996. Ten years after introduction, Bt cotton and Bt maize were grown on 162 million hectares worldwide (James 2006). Transgenic crops have reported reduced pesticide inputs, resulting in decreased costs and ease of management. Yield increases have been minimal, if they occur at all (Kathuria et al. 2007). However, pollen transfer and the impacts to non-target arthropods are of top ecological concern.

GMOs, at least in research, also include genetically modified disease vectors (GMVs). GMVs are primarily modified in one of two ways: genetically modifying the phenotype of the arthropod vector by targeting the parasite, or modifying the arthropod itself via sterile insect technique or the release of individuals carrying dominant lethal genes (Alphey et al. 2002). For both agricultural and human health applications, there are downstream effects to consider: specifically, risks to human health, biodiversity, and the environment.

In 2008, the use of GMOs in entomology was the topic of the student debate at the annual Entomological Society of America (ESA) meeting in Reno, NV. Three important questions were discussed regarding the use of GMOs in agriculture and human health, including the accuracy of current evaluation procedures in the United States. In preparation for the debates, each student team was assigned one of three topics and a pro or con position. An introductory team was also chosen for each topic to provide the audience with unbiased background information about the topic question and the issues being addressed. The teams had approximately five months to prepare, but the majority of the work was done in the two months preceding the Annual Meeting. Each team was asked to select no more than 40 references, to which they must limit their argument. Reference materials and an abstract of each team's position were shared between sides prior to the debate.

During the ESA annual meeting, each debate team is invited to participate in the debate symposium. A five-minute introduction of the topic is given, after which each team gives a seven-minute presentation on their position. The debate continues for a total of 20 minutes after the presentations. In 2008, we included a panel of three judges for each debate topic who asked questions of both teams after the debate and determined which team made the better argument. Each debate team was given feedback from the judges that could be used in the preparation of the written arguments that follow. The written statements are limited to 600 words and 15 of the original 40 references. For the purposes of this debate, GMOs included herbicide-resistant plants and organisms that are altered with *Wolbachia*, but did not include sterilized insects (Sterile Insect Technique). Sterilized insects were not considered GMOs because the sterilization conferred on an insect does not proceed to the next generation; the insects are incapable of reproducing the mutated genome. Although the genome is modified and successful vector transmission of pathogens is prevented, this is true only for the current sterilized generation.

Are GMO crops and GMO disease vectors a viable option for the U.S. and other nations? The introductions and positions for each topic are presented by the student teams.

TOPIC

Genetically modified insect disease vectors should be incorporated into vector-borne disease control programs because they decrease disease transmission and spread to humans and livestock with fewer environmental risks than conventional control methods.

Introduction

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Arthropod-transmitted diseases such as malaria, leishmaniasis, trypanosomiasis, dengue fever, yellow fever, and West Nile encephalitis have emerged as serious health risks, imposing an overwhelming burden on world populations. These emerging and resurgent vector-borne diseases cause millions of new infections and incidences of mortality annually, particularly in developing countries (WHO 2004).

Historically, vector control programs have utilized an integrated approach with a combination of traditional control methods, preventive measures and pharmaceutical regimes (Lacey et al. 2001). The limited success of these approaches combined with developing resistance has brought about an interest in the use of alternative control methods, as stated by Knols and Bossin (2006): "The continued threat of vector-borne diseases calls for both reactive and proactive efforts to mitigate the significant morbidity and mortality they cause."

At a 1991 meeting of the World Health Organization's Special Programme on Research and Training in Tropical Diseases and the MacArthur Foundation, researchers evaluated current disease control strategies and formulated a plan to evaluate promising alternatives (Christophides 2005). Genetically modified disease vectors (GMV) are currently being considered as one such alternative for inclusion within comprehensive control programs (Beaty 2000, Christophides 2005).

The goal of GMV programs is to perturb the ability of insect vectors to transmit pathogens (Christophides 2005, Curtis 2006). In reaching this goal, researchers have explored two approaches: creating GM vectors that are refractory to disease transmission by altering their physiology and/or behavior, or by disrupting pathogen development (Riehle et al. 2003, James 2005, Jacobs-Lorena 2006). Methods utilized in these approaches include the use of dominant lethal genes, the use of bacterial symbionts that disrupt pathogenesis or transmission, and the use of effector genes, whose products interfere with pathogen development.

Evaluation of GMV agents as a control strategy requires consideration of all potential complications and issues before release within control programs. Vector and pathogen life cycles, pathogenesis, and disease transmission must be amenable to the use of genetically manipulated refractory vectors (Marrelli et al. 2007, Lambrechts et al. 2008). Ecological, epidemiological, economic, social, and ethical concerns must be carefully considered (Macer 2005, Knols and Bossin 2006, Lacey 2001). Additional issues include the effects of biotic and abiotic parameters, environmental impacts, and the burden of cost on developing nations (Lacey et al. 2001). Because of the highly mobile nature of insect vectors, international collaboration is critical, as is education of stakeholders (Kapuscinski 2002, Macer 2005).

Given the potential impacts and the range of these issues, there is considerable controversy surrounding the incorporation of genetically modified organisms into disease control programs.

▲ Pro Position

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Vector-borne diseases cause an enormous burden on human health worldwide. These diseases cause significant economic losses, increase health care costs, and decrease productivity, mostly in countries that can least afford this (Jacobs-Lorena 2006). Traditional pest control techniques alone have not provided adequate control, as evidenced by over one million deaths and 300 million cases annually for malaria alone (Boëte and Koella 2003). Other vector-borne diseases are also expected to increase as climate change, rapid global transportation, and increased immigration spread exotic vectors and diseases into new areas (Abraham et al. 2007). The two main traditional chemical control tactics, application of pesticides and administration of pharmaceutical drugs, are of limited effectiveness, respectively due to resistant insects and parasites (Riehle et al. 2003). Despite decades of intense research on malaria and dengue, a third strategy, vaccination, is only available for yellow fever, and even in this case the disease has not yet been eradicated. (Jacobs-Lorena 2006). Because these methods of control are only partially effective, we argue that genetically modified vectors (GMVs) should be incorporated into disease control programs.

Germ-line transformation in insects of medical importance is already feasible in *Aedes*, *Anopheles*, *Culex*, *Rhodnius*, and *Glossina* spp. (Jacobs-Lorena 2006, Beard et al. 2001, Aksoy et al. 2001). The most promising strategy to date is paratransgenesis, in which an arthropod's symbiotic bacteria is genetically modified to kill the parasite, altering the arthropod host's ability to transmit the pathogen (Beard et al. 2001). Paratransgenesis could be used to control both African and American forms of trypanosomiasis (sleeping sickness and Chagas disease) (Beard et al. 2001, Aksoy et al. 2001). Laboratory and greenhouse experiments have been successfully conducted for one of the principal vectors of Chagas disease, *R. prolixus*, and for *Trypanosoma cruzi*, using a synthetic material called CRUZIGARD that contains transgenic bacteria (Beard et al. 2001). Due to the effectiveness of CRUZIGARD as a driving mechanism, field trials are warranted as the next step (Beard et al. 2001). The initial steps for the transformation of malaria mosquitoes (*Anopheles* spp.) have already led to identification of the promoters, effectors, and reporter genes affecting malaria in mice. The effectiveness of these transgenes needs to be tested for *Plasmodium* species that cause malaria in humans (Riehle et al. 2003). The driving systems being investigated for mosquitoes include genetic phenomena (e.g., competitive displacement, reduced heterozygous fitness, under-dominance, and meiotic drive) and other systems based on exploitation of infectious and infectious-like agents (extracellular and intracellular symbiotic microorganisms, viruses, and transposons) (James 2005). Researchers are optimistic that these strategies can be further improved (Moreira et al. 2004).

Although there is speculation about possible problems associated with GMVs (e.g., the creation of a super-parasite), the estimates of these risks have not been supported by lab trials (Rodriguez 2006). Unfortunately, no control method or strategy can be considered risk-free. Even pharmaceutical drugs and pesticides have risks associated with their use (Atkinson and Handler 2005).

Ongoing field studies of insect behavior and ecology in potential release sites afford an unprecedented opportunity to develop novel vector control strategies that incorporate GMVs (Knols and Bossin 2006, Willem and Boëte 2003). Furthermore, the use of GMVs has the potential to reduce the negative environmental impact of insecticides (Abraham 2007).

Educational programs that integrate local communities and scientists are crucial; this process needs to be completely open to all involved (Macer 2005). Ethical, social, and legal implications should be resolved to ensure public acceptance and successful implementation of GMVs (Toure and Manga 2006). As responsible scientists, it is incumbent upon us to continue searching for new ways to mitigate the devastating impact of these diseases. The use of GMVs is one avenue that we must explore; after all, every single human life is precious.

Acknowledgements

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▼Con Position

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Genetically modified insect disease vectors (GMV) should not be incorporated into vector-borne disease control programs. In addition to low expectations regarding the efficacy of the GMV strategy, there are epidemiological, ecological, and ethical reasons why this is a poor approach to vector-borne disease control.

GMVs are less fit than their wild type (WT) counterparts (Rasgon 2008); therefore, genetic drivers are necessary to increase the proportion of GMV in the population (James 2005). It is estimated that a 10:1 ratio of GMV to WT is needed to establish GMV traits in a population (Christophides et al 2006). Rearing and releasing GMVs into a population in such numbers is expensive and logistically improbable.

Even if it were possible to release GMVs at these levels, gene linkage is necessary to successfully drive desired traits into a population (Christophides 2005). Because the driver and gene are mutagenic in nature, unpredictable effects in GMV populations could arise if the linkage breaks down between them. If the driver becomes associated with a non-target gene, it could result in undesirable phenotypes and failure of the proposed control method. Most importantly, the gene drive system is irreversible once released.

James (2005) and Rasgon (2008) independently created models that predict that a 100% refractory GMV population is required for disease control, meaning that 100% efficacy is required 100% of the time. Furthermore, disease vector interactions are complicated by the fact that diseases can be vectored by multiple species and one species can vector multiple diseases. Novel ecological situations can lead to acquisition of a new vector. For example, Chikungunya virus was introduced to Mauritius, where it acquired a new vector (*Aedes albopictus)* in the absence of its native vector (*Aedes aegypti)* (de Lamballerie et al. 2008). These factors make it difficult to saturate an environment with the 100% refractory GMV necessary for successful disease control.

Release of GMVs may also select for more virulent pathogens (Snow et al. 2005). Potential shifts in co-evolved vector-pathogen relationships could drive changes in disease virulence. Mackinnon et al. (2004) reared several generations of malaria-immunized and non-immunized mice and found that the immune-experienced malaria lines were significantly more virulent to both immunized and naïve mice. These findings suggest that resistant hosts, like GMVs, can promote virulence evolution.

Unlike genetically modified plants, GMVs are incredibly mobile, which greatly enhances the ecological dynamics of vector species and interferes with the dynamics of released GMV. Given the uncontrollable and unpredictable nature of GMVs, it is impossible to contain them within sovereign political borders. It is also unethical to release GMVs without acquiring informed consent from all potentially affected countries and individuals (Macer 2005). It is our position that tactical implementation of GMV for disease control is incompatible with traditional control methodologies (e.g. insecticides, bed nets, habitat reduction) (Spielman 1994). Because indigenous vector populations have experienced selective pressure due to traditional control methods for extended periods, GMVs are more likely to be severely affected.

In summary, we cannot support the incorporation of GMVs into vector-borne disease control. They cannot be controlled by the safety and management practices legally mandated for genetically modified organisms. The release of GMVs is inherently unpredictable, uncontrollable, unsustainable, and potentially unsafe to humans and the environment. Existing vector-borne disease control programs “fail” primarily in areas that lack the adequate infrastructure to maintain them. Vector-borne disease control is a humanitarian problem that will not be solved by compromising the ecology of a region and the ethics of science.

Acknowledgements

We would like to thank Michael Saunders and the Department of Entomology at Penn State for their contributions.

TOPIC

Genetically modified organisms (GMOs) should be incorporated into management programs for insect crop pests to reduce insecticide use while providing acceptable levels of damage against all pests and improve crop yield.

Introduction

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The world’s population is approaching 7 billion people, yet the proportion of cultivatable land continues to decline. Biotechnology, both urban and rural, is a significant part of our culture, and genetically-modified organisms (GMOs) are a significant component of global agriculture. As such, GMOs are a very contentious issue in both agriculture and ecology. Are GMOs safe to both humans and the environment? Is it feasible to use them as tools in food production? Are they effective in controlling pests and increasing yield?

Various traits can be altered during the creation of GMOs. Plant architecture can be changed to create dwarf varieties that show elevated productivity (Sakamoto and Matsuoka 2004). In the case of wheat and rice, for example, increased nitrogen fertilization via soil amendments not only results in increased seed production, but also in stem elongation. However, dwarf varieties will convert nitrogen into additional seeds instead of vegetative growth, thus increasing productivity. Plant defense can be enhanced, as in the case of the many crop cultivars using *Bacillus thuringiensis* (Bt) as a management tool (Romeis et al. 2006). At least 52 different plant species have been altered with Bt, including crops such as corn, rice, potatoes, canola, soybean, and cotton (Dunwell 2000). Plant physiology can also be altered, and GMOs that show increased photosynthesis rates, improved foliar sugar and starch ratios, altered senescence, and tolerance to environmental stress have been tested (Dunwell 2000). With all the potential benefits of GMOs, one might think their usage would be both assumed and accepted as an integral part of global food production. However, there is considerable controversy surrounding the use and benefits of GMOs.

From an agronomic perspective, GMOs are an integral part of global food and fiber production, and when properly used, they require reduced pesticide inputs, benefiting both the environment and the farmer. Carpenter et al. (2001) reported a reduction of ~1.2 million kg of insecticides per year in cotton alone. However, insects, with their short generation times and voracious appetites, often find a way to circumvent GMO technologies, forcing companies to continually develop new pest management tactics (Carvalho 2006). Yield increases have been shown in some but certainly not all crops. Research in rice, for example, has generated many promising technologies; however, none of these have translated into real yield increases. In contrast, there have been some significant yield increases in other grain crops (Kathuria et al. 2007).

From an ecological perspective, GMOs are safe only in certain circumstances. In such cases, they have been shown to be detrimental to non-target species while not always reducing pesticide inputs into the environment. For example, green lacewing (*Chrysoperla carnea*) larvae showed increased mortality when fed prey reared on Bt corn, and in choice tests preferred prey that had not fed on Bt corn (Hilbeck 2001). GMO plant residue takes longer to decompose, and contaminates soil with toxicological properties even after breaking down (Flores et al. 2005). GMOs are unnatural, yet to date have not been shown to be unhealthy (Peterson et al. 2000), nor have they been proven to be ecologically damaging. They have, however, not been proven to actually be healthy or ecologically *un*damaging. This reflects the current state of science in that we simply do not yet know enough about the long-term effects of GMOs to make informed decisions (Wolfenbarger and Phifer 2008).

The perfect GMO crop would show increased yield, require fewer pesticide inputs and applications, have zero effect on the ecological food chain, and disappear at the conclusion of the growing season. Unfortunately, no such GMO exists, and until it does, the debate will continue.

▲ Pro Position

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Pesticide management is a priority in agriculture as it relates to both maintaining pest damage at or below acceptable levels and to the relatively recent push for more environmentally friendly crop production. New management techniques are implemented with the expectation that these approaches will provide suitable levels of pest control. The advent of new technologies provides an opportunity to refine management programs in an attempt to further reduce pest damage. Genetically modified organisms (GMOs) are a pest management tool that has seen a significant increase in usage during the last decade (James 2007, Fernandez-Cornejo 2008). We assert that the integration of GMOs into management programs will result in reduced insecticide use, provide sufficient protection against pest damage, and increase crop yield.

Crop losses caused by insect pests represent one of the greatest limiting factors to crop production (Sharma et al. 2003). This potential for loss is one of the reasons crop producers are eager for new technologies that can reduce the loss caused by pests. One of the potential benefits of GMO usage is the reduction in the amount of insecticides applied (James 2007, USDA 2008). Reduction in insecticide use can be attributed to pest-resistant genes incorporated in many GMO products, which provide insect control and alleviate the need to apply insecticides (James 2007).

Another potential benefit of GMOs is the increase in crop yields, in part due to lower levels of crop damage. United States cotton growers reported a 260 million-pound increase in cotton yield when using genetically modified Bollgard® cotton (Singh et al. 2006). Also, a 3.5 billion-pound increase in corn yields was reported by the NCFAP with the use of *Bacillus thuringiensis* (Bt) maize (Singh et al. 2006). Ultimately, these higher crop yields translate into a higher profit margin for the individual producer.

One of the major concerns associated with the use of GMO products is the development of resistance to Bt. The Bt resistance gene in insects is typically recessive, which allows for the use of a refuge strategy to manage resistance (Gujar et al. 2007). Additionally, a high-dose refuge strategy can be utilized and has shown to be effective at reducing survivorship (Cerda et al. 2006). Employing either of these strategies is effective at combating Bt resistance development in crop systems.

The initial cost for GMO seeds is higher than that of conventional seeds; however, this will be balanced by reduced costs associated with pest management. The long-term economic benefits from using GMOs will outweigh the increase in startup costs. While some cases have shown that crop yield did not increase significantly or that there were still problems with pests, these instances do not appear to be the standard. The use of GMOs in pest management programs can be a powerful tool in the battle against pests. Given current evidence of reduction in insecticide use, successful pest damage control, and increased crop yield, we maintain that GMOs should be incorporated into management programs.

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We would like to thank our faculty advisor Dr. Craig Coates, and the Texas A&M University Department of Entomology.

▼ Con Position

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Although insecticidal GM crops have been promoted under the premise of reducing pesticide use and increasing yields, we contend that:

- reliance on GMOs for pest management is inconsistent with the principles of ecologically based IPM as defined by Kogan (1998);
- most comparisons in insecticide use have failed to note that Bt itself is classified and regulated as a pesticide (EPA 1998), and therefore GM crops represent substitution of one pesticide for another (Hurley 2005);
- increases in yield do not represent economic benefit when additional economic outlays are taken into account (Raney 2006);
- current regulations for the safe deployment of GM crops are insufficient to prevent flow of transgenes to other crops and wild plants; and

- the regulations are voluntary and unenforceable.

In contrast to IPM, in which insecticides are applied according to pest density relative to injury threshold, genetically incorporated toxins are expressed persistently and independently of pest populations (Jayaraman 2005). This prophylactic use of insecticides results in stronger selection pressure for resistant pest genotypes, increased risks of non-target effects leading to secondary pest outbreaks, new pest complexes, and environmental contamination (Hurley 2005). For example, successful suppression of *Helicoverpa armigera* (Hübner) with Bt cotton in China has reduced organophosphate use (Wu et al. 2008), but has been accompanied by the emergence of mirid bugs (Hemiptera: Miridae) as a new cotton pest complex (Lu et al. 2008).

The effectiveness of high-dose/refuge strategy deployed by EPA to allay Bt resistance has been supported (Onstad et al. 2001) under the following potentially false assumptions: a) resistant individuals are rare, b) resistance alleles are recessive, c) random mating occurs among individuals in Bt crops and refuges, and d) a high dose of the toxin is expressed in Bt crops (EPA 1998). However, exceptions to these assumptions have been found in the field. The mean initial frequency of 0.16 for Bt resistance alleles in some populations of *Pectinophora gossypiella* (Saunders) was unexpected and considered comparatively high (Tabashnik et al. 2000). Resistance to Bt toxins in a lab-selected strain of *Ostrinia nubilalis* (Hubner) was inherited as an incompletely dominant autosomal gene (Huang et al. 1999). Random mating may not occur because Bt delays the development of insects such as *Leptinotarsa decemlineata* (Say), leading to unsynchronized emergence times between populations from Bt and refuge crops (Nault et al. 2000). The levels of the Bt toxin can vary among different Bt varieties and within different parts of individual plants, and they decline over time (Karanthi et al. 2005). Recently observed increases in the frequency of resistance alleles in some populations of *Helicoverpa zea* (Boddie) suggest the potential for failure of existing resistance management strategies (Tabashnik et al. 2008).

With the current transgenic crop technology, transgenes cannot be contained in fields where the crops are grown. The flow of transgenes threatens identity preservation for various cultivars of conventional and organic crops and their introgression cannot be easily reversed (Mercer and Wainwright 2007). Current EPA containment strategies (buffers) are ineffective in preventing pollen-mediated gene flow, particularly with regards to insect-pollinated crops (Pasquet et al. 2008). Although chloroplast modification offers future hope, the risk of pollen-mediated gene transmission cannot be eliminated. The inability to restrict flow of transgenes violates the interests of other stakeholders, which is another break from the mandate of IPM (Kogan 1998). In developing countries, containment of transgenes is further complicated by cultural practices such as seed trading, which is a critical component of rural farming. In summary, all of the potential effects of currently registered Bt crops described herein are incompatible with the principles of IPM that enjoins the use of all the resources of ecology to manage pests while doing less harm to the environment.

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TOPIC

Current evaluation procedures of GMOs are adequate to determine their long-term impacts on the environment and human health.

Introduction

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Since the application of *Bacillus thuringiensis* as an insecticide in 1961 (Milner 1994) and the availability of genetically modified organisms (GMOs) for cultivation, the effects of GMOs on the environment and humanity have fostered a highly polarized debate worldwide. Currently there are two groups of GMOs: plants such as soybean, cotton, canola, and corn, which have increased in worldwide cultivation for at least 12 years (Brookes and Barfoot 2006); and insects such as honey bee, silkworm, mosquitoes, pink bollworm, and med fly, among others, which are awaiting field trials and future release for commercial and beneficial purposes (Pew initiative on food and biotechnology 2004). Empowering plants against herbicides, insect pests, and pathogens sounds promising, but the possibility of ecological disaster causes alarm. GMO proponents argue that GMO crops result in healthier foods, higher farm income, and greater profits. On the other hand, GMO food crops foster fear in the general public (Ando and Khanna 2000). Allegations have been made that humanity may somehow receive some mutation through consumption of GMOs due to horizontal or vertical gene transfer or the creation of "genetic monsters" made under the guise of good intentions (Ando and Khanna 2000). As a result, stricter measures have been suggested to make sure that these fears are alleviated (Ando and Khanna 2000).

Current evaluation techniques, standardized by the World Health Organization and Food and Agricultural Organization and implemented by the Environmental Protection Agency, the Food and Drug Administration, and the United States Department of Agriculture, screen GMOs for possible adverse effects before products come to market (FDA 1992). These regulations, which were formulated prior to the technological advancements that we are now poised to achieve, are constantly being reviewed. So far, there have been no reported environmental catastrophes related to GMOs. The pre-market safety review Section 402 (a) (1) of the act (21 USC 342 (a) (1)) acts as a safeguard to prevent the release of a harmful GMO (FDA 1992). In the twelve years of GMO crop production, higher farm incomes and positive environmental impacts have been reported, as measured by environment impact quotients (Brookes and Barfoot 2006). However, the National Research Council Committee has recently concluded that "the effects on the environment were considered to have the greatest potential for long-term impact" and identified aquatic organisms and insects to be of the highest concern for negative effects of GMOs due to their mobility (Pew initiative on food and biotechnology 2004).

With increasing technology and genetically modified insects waiting for field releases, many questions arise. Do we need stricter measures by national and international regulatory bodies before releasing a GMO into the market? Should we wait for scientific evidence regarding the inadequacy of existing measures before we revamp them? Although the current standards have been successful in preventing the release of GMOs that would cause increased damage to the environment, are they still adequate or should standards and policies be increased? Are we clear on the jurisdiction with our regulatory bodies as GM insects are awaiting field trials? Are the policies for hazard identification, hazard characterization, exposure assessment, and risk characterization adequate, and do they justify the stand of the United States that GMOs are safe with their current evaluation procedures? As with any new technology, are we just reluctant to embrace this boon of science in spite of our success to date in preventing any negative impact on the environment?

Until these questions are more clearly answered, the debate over GMOs rests in whether or not the current evaluation methods are adequate to protect the environment and consumers.

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▲ Pro Position

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University of Georgia

Following their commercialization in 1995, 308.75 million acres (39.34% of global total crop acreage) of GM crops have been planted worldwide (James 2007). Such widespread adoption of this revolutionary technology reflects a high degree of conviction about the benefits and safety of GM products. There have been no scientifically documented cases of adverse effects on human health or the environment from any product of recombinant DNA technology approved by United States regulatory procedures (McHughen and Smyth 2008). The successes and associated benefits of GM crops are a result of rigorous and effective evaluation.

Insect-resistant GM plants are derived primarily from *Bacillus thuringiensis* (Bt)-based technology. Bt is a naturally occurring and ubiquitous soil bacterium and its δ-endotoxin has been labeled for pesticide application on food crops since 1961 (Milner 1994). Since its discovery in 1901 and the utilization of its insecticidal properties, the environmental and human health aspects of Bt have been widely investigated. Over 100 years of scientific evidence suggest that the efficacy and non-target effects of Bt products are highly predictable (Sayre and Seidler 2005).

The most publicized incident related to negative consequences of GMOs was the release of Starlink™ corn into the human food market when it had been approved only for animal consumption. Although negative media coverage generated widespread public concern, no adverse quantifiable health consequences were documented (Chassy 2002). This event spurred improvements in evaluation and enforcement procedures in the United States.

Evaluation procedures are designed not only to illuminate the desirable aspects of GM crops, but are also intended to look for potential negative characteristics. When negative characteristics are excluded from the marketplace, the evaluation process has served its purpose. For instance, voluntary cancellations of products undergoing evaluation are common, and conditional or time-limited registrations indicate that products are still under an additional level of control or scrutiny. These types of registration ensure that evaluation is ongoing and facilitate active observations that address product quality and safety at regular time intervals. The fact that very few pesticides are under time-limited registration indicates the elevated level of scrutiny for GM products, demonstrating that they are not indiscriminately approved (EPA 2008a). Exclusion of some products with undesirable characteristics should not condemn all recombinant DNA technology.

In general, DNA alterations by recombinant technology are far more predictable and controllable than those in conventionally bred plants that have been used for centuries. However, GMO evaluation procedures are more rigorous than the accepted and established procedures used to evaluate pesticides and products of conventional plant breeding (EPA 2008b). A lack of knowledge about how recombinant DNA technology works or how it is evaluated makes consumers more wary and skeptical about such products.

Industries have a tremendous incentive to ensure that there are no unacceptable long-term impacts of their products. Consequently, additional internal evaluations build upon the requirements defined by various regulatory agencies. In fact, it is our contention that risk assessments for most GMOs tend to be excessive, going well beyond the data required, which amounts to “overkill.” Such redundancies in regulatory frameworks mainly arise because of case-by-case evaluation of GM products. Some redundancy benefits the regulatory system, but it comes at a cost. When additional data are demanded, it neither increases available information about the safety of a GM product nor improves public confidence (McHughen 2007).

Thus, we argue that GMO regulation is dynamic; its procedures vary spatially and temporally on a case-by-case basis and reflect growing knowledge and experience (Conner et al. 2003). Stringent evaluations with numerous components and integration of extensive efforts by multiple agencies and industries assure adequate long-term protection of human health and the environment.

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▼ Con Position

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Currently, to deliberate optimum mechanisms for evaluating the long-term impact of genetically modified organisms (GMOs) on human health and the environment, we address the procedures of the Environmental Protection Agency, the United States Department of Agriculture, the Food and Drug Administration, and other countries’ counterpart agencies and international organizations influencing homeland practices. Continuous efficacy review of universities, private industry, the farming community, and national and international regulatory bodies as they contribute to the development of GMOs for the global market is as crucial a priority action as ever. The consequences of recombinant DNA technology have an ecological impact on suburban, urban, rural, wilderness, and aquatic environments worldwide. Revolutionizing the pesticide industry, GMOs became a part of an arsenal of tools available to integrated pest management systems intended to enhance food and fiber yields. Globally, food crops modified through recombinant methods comprise an increasing part of daily diets. We reviewed the existing regulatory procedures which inadequately take into account various biological risk factors and concluded that the current evaluation procedures are not sufficiently extensive enough to appropriately assess the impact of GMOs on human health and the environment.

Substantial equivalence is the current standard to measure the safety of GMOs. This methodology persists as a standard measurement despite improper evaluation of unexpected downstream gene expression events (Levidow et al. 2007). Microarray data testing expression levels of MON810 insertion events of Cry1Ab Bt toxin demonstrated that transgenic modified lines were more similar to each other than other non-trans gene lines used to compare gene expression (Coll et al 2008). Substantial equivalence as an evaluation parameter allowed the GMO industry to flourish, but the advent of new technologies creates the need for new evaluation procedures (Domingo 2007).

Unintentional gene expression events do occur, creating digestive and morphological consequences. In the case of corn modified to produce Bt Cry1Ab in three different insertion events vs. non-Bt isolines, the Bt lines were found to be higher in lignin content, which can lead to decreased digestibility (Deepak and Stotzky 2001). Feeding trials with Roundup-ready soybean performed on Wistar rats resulted in a higher rate of stillbirths and lower birth weights. These mice also showed cellular modifications to the liver, pancreas, and testes (Moch 2006). Another study using Snowdrop lectin, a protein with insecticidal capabilities engineered into potato, caused growth stunting and damage to the kidney, thymus, intestine, and immune system. Such studies illustrate the need to reevaluate the current evaluation procedures.

Another concern raised by the presence of GMOs in the environment is transgene crossover to wild relatives of GMOs. A case of gene drift occurred in a Bt strain from a cultivated sunflower line to a wild sunflower strain, which led to increased fecundity and reduced herbivory by insects (Snow et al. 2003). Spread of Bt genes to wild relatives would reduce natural refuge areas that limit increase of resistance emergence in insect pest populations.

GMOs have risen to the forefront of international agriculture, and as important commodities, they require safe utilization to preserve market share and human health and to protect non-target organisms interacting in a shared ecosystem. The arrival of new genetic monitoring techniques provides the opportunity to continually increase our safety standards. The aforementioned cases illustrate the need to modify the evaluation procedures to adequately measure the long-term effects of GMOs on the environment and human health.

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The three separate judge panels, each comprised of three professional scientists, all independently determined that the con position for each topic made the better argument. We would like to thank our judges Dina Fonseca, George Hamilton, Edwin Lewis, Jerome Hogsette, Marc Fisher, Ulrich Bernier, Thomas Reagan, Nina Alphey, and Eileen Cullen for volunteering their time and efforts.

Oregon State University

Kimberly M. Skyrm is a Ph.D. student working with Sujaya Rao on the foraging behavior of native bumble bees in agricultural ecosystems.

Jennifer E. Bergh is an M.S. student studying native bee ecology in wetland and agricultural ecosystems with Sujaya Rao.

Purdue University

Gladys K. Andino is a Ph.D. student in Greg Hunt's lab, where she studies the genetics of honey bees.

Victoria Caceres is a Ph.D. student in Doug Richmond's lab, where she studies the effect of varying ratios of nitrogen, phosphorus and sulfur on trophic interactions in turfgrass ecosystems.

Gloria I. Giraldo-Calderón is a Ph.D. student in Dr. Catherine Hill's lab, working on mosquito vision.

Julia Prado is a Ph.D. student in Cliff Sadof´s lab, where she develops an integrated approach to managing red maples to avoid outbreaks of secondary pests.

Kapil Raje is a Ph.D. student in both Dr. Jeffrey Holland and Dr. Virginia Ferris' labs, where he works in molecular phylogenetics of Cerambicidae.

Janice Van Zee is a Ph.D. student in Dr. Catherine Hill's lab, working with tick cytogenetics and genomics.

Pennsylvania State University

Dan Schmehl is a Ph.D. student in Jim Frazier's lab, where he studies the sublethal effects of pesticides on the European Honeybee.

Beth Irwin is a Ph.D. student in Consuelo De Moraes and Mark Mescher's laboratory, where she studies plant-symbiont interactions.

Tom Bentley is a Ph.D. student in Mark Mescher's lab, where he studies interactions between plant viruses, host plants, and insect vectors.

Rob Anderson is a Ph.D. candidate in Matt Thomas' lab, where he studies the effects of entomopathogenic fungi on the vector competence of medically important insects.

Amanda Bachmann is a Ph.D. candidate working with Shelby Fleischer on field crop pest population movement.

University of Wisconsin

David Coyle is a Ph.D. student with Dr. Kenneth Raffa, where he studies the ecology and impact of invasive root-feeding weevils on forest composition and fine root dynamics.

Texas A&M University

Aubrey M. Colvin is a Masters student in the laboratory of Dr. Robert Wharton. The focus of her research is the phylogenetic systematics of *Metopius* (Hymenoptera: Ichneumonidae).

Therese A. Catanach is a masters student in that laboratory of Dr. Jim Woolley; the focus of her research is the phylogenetic systematics of *Xyphon* (Hemiptera: Cicadellidae).

Jordan M. Coburn is a Masters student in the laboratory of Dr. Pete Teel; the primary focus of his research is medical entomology.

Andrew W. Boswell is a Masters student in Dr. Spence Behmer's laboratory, focusing on insect nutritional ecology and physiology.

Washington State University

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Nik Wiman is a Ph.D. student in Dr. Vincent P. Jones laboratory at the WSU Tree Fruit Research and Extension Center, where he works on Tachinidae as natural enemies of leafroller spp.

Jeremy L. Buchman is an M.S. student in Dr. Joseph E. Munyaneza's laboratory at USDA Yakima Agricultural Research Laboratory Wapato, WA, where he works on viruses vectored by insect pests of potato.

Bonnie Ohler is an M.S. student in Dr. Peter Landolt's laboratory at USDA Yakima Agricultural Research Laboratory, Wapato WA, where she studies chemical ecology of insect pests of tree fruits.

Mississippi State University

Cheri Abraham completed his M.S. at Mississippi State University working with Dr. David Held on *Larra bicolor*, the parasitoid on *Scapteriscus* mole crickets. He is currently at the University of Georgia studying in Dr. Kris Braman's lab.

University of Georgia

Jaime Fuest is a Ph.D. student working under the direction of D. Horton on the ecology and management of peach tree borers (Sesiidae) in peach systems.

Shakunthala Nair is a Ph.D. student working with S. Kristine Braman on the pest status of lace bugs on ornamental plants.

Krishna Bayyareddy is a Ph.D. student in M. Adang's lab and studies the Bt toxin receptors in the mosquito midgut that determine mosquitocidal specificity.

Shimat V. Joseph is pursuing a Ph.D. and his research focuses on management strategies to reduce hemlock woolly adelgid, *Adelges tsugae* (Adelgidae) damage under the direction of S. K. Braman and J. L. Hanula.

University of Tennessee at Knoxville

Jonathan Willis is an M.S. student in Dr. Juan-Luis Jurat-Fuentes lab, identifying novel cellulolytic enzymes from insects.

Anais Castagnola is an M.S. student in Dr. Jurat-Fuentes insect physiology lab. Her project's focus is insect midgut epithelial cell interactions and the discovery of novel growth factors.

Paul Rhoades is an M.S. student studying the pollination biology of the flowering dogwood with Drs. John Skinner, Bill Klingeman, and Bob Trigiano.

Kristin Abney is an M.S. student in Dean Kopsell's lab, where she studies secondary plant metabolites and phytonutrients.

Dr. Anne L. Nielsen is a postdoctoral researcher in Edwin Lewis' lab at UC Davis, where her research focuses on abiotic factors impacting entomopathogenic nematodes used for biological control in greenhouses. She completed her Ph.D. in 2008 at Rutgers University on the population ecology of an invasive stink bug species. **Lt. Roxanne G. Burrus** is a Ph.D. candidate at the University of Florida, where her research focuses on isolating *Escherichia coli* O157:H7 human pathogenic bacteria from house flies at dairy farms, and determining the dispersal distances of house flies from dairies into town. These two factors will be considered together to estimate the potential role that house flies have in transmitting this disease to humans that live in close proximities to dairies.