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12

Eco-Efficient Research to Provide Safe, Profitable, and Environmentally Sustainable Production of Fruits and Vegetables

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Abstract

Fruits and vegetables have a major role in ensuring that the world is not only fed but also nourished. They supply many of the micronutrients that combat malnutrition and contribute to balanced diets required for good human health. However, because of the large number of pests and diseases that challenge these crops, current crop-management practices may often be deleterious to the health of the farmer, the consumer, and the environment. There is an urgent need to develop technologies that will enhance production of common fruit and vegetable crops in a more ecologically sustainable manner. If such opportunities are to be exploited effectively they need to build on the foundations of strong local knowledge and a comprehensive understanding of the real needs of resource-poor farmers and their communities. For the less-known crops, for which the potential for development opportunities are high among smallholder farmers, it is appropriate to consider new strategies to increase production, open markets, and increase incomes in ways that minimize negative environmental impacts, thus helping to maximize the longer-term sustainability of production systems. To properly formulate such strategies requires a wide range of partners, from both the public and the private sector, to be brought together to address whole value chains, and sufficient financial resources to accomplish the research and development required.

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This chapter highlights the importance of fruits and vegetables in combating world malnutrition. We examine the major constraints to production and consumption in the developing world, and various eco-efficient approaches to enhance production efficiency, produce quality, and safety. We stress the value of improved, resilient germplasm, safer pest- and disease-management practices, more appropriate water and soil-fertility management, and ways in which technology dissemination might be made more effective. The chapter includes examples of eco-efficient interventions in production of fruits and vegetables, the risks of such interventions and opportunities to enhance their impact, and key lessons for research, development, and policy.

Fruits and Vegetables to Alleviate Global Malnutrition and Improve Livelihoods of the Rural Poor

Fruits and vegetables are highly nutrient-dense. They contain vitamins, fiber, minerals, antioxidants, and other micronutrients essential for human health, and thus are excellent food sources to combat malnutrition. Micronutrient malnutrition, resulting from an imbalanced diet, is prevalent globally regardless of age, location or income category, and is often the main cause of various debilitating chronic and fatal diseases. While 925 million people currently suffer from hunger, approximately 1.6 billion are malnourished (FAO, 2010; WHO, 2011). This high prevalence of micronutrient malnutrition is mainly the result of an insufficient intake of vitamins and minerals (WHO and FAO, 2006). Among the poor, the cause of malnutrition can be linked directly to their limited access to adequate amounts of appropriate food to satisfy their nutritional requirements for good health. Examples of the effects of malnutrition that are common in developing countries include maternal mortality and premature birth caused by iron deficiency, and night blindness and an impaired immune system caused by insufficient vitamin A. Being malnourished does not necessarily mean hungry, as a result of consuming excess carbohydrates and fats, thus bringing the accompanying medical effects of high body mass index. In the developed world, malnutrition can be attributed to an unwise diet choice and a pronounced tendency to consume an excessive amount of fats, carbohydrates, and protein. Obesity (which often leads to diabetes) and consequent cardiovascular and other chronic diseases are the prime silent manifestations of malnutrition caused by inappropriate consumption, in both developing and developed countries. The resulting cost to national health services is very large and growing steadily.

More investment is needed to increase availability and consumption of fruits and vegetables worldwide if we are to both feed the world and also nourish its population to the level needed to assure good health, and thus deliver improved livelihoods. Under-consumption of fruits and vegetables is among the top 10 risk factors leading to micronutrient malnutrition and is associated with the prevalence of chronic noncommunicable diseases (Ezzati et al., 2002). Noncommunicable diseases such as hypertension, cardiovascular diseases, cancer, diabetes, and obesity may be the causes of a high proportion of untimely deaths, for example, in some African countries (Ganry, 2011). In these countries the availability of fruits and vegetables is often far below the World Health Organization's recommended per capita intake of 400 g/day. Currently the agricultural research community's main goal is the increased production off grains and other staple crops to feed a growing world population. However, for a development strategy to be effective and sustainable it is necessary to ensure that both food and nutritional security are delivered simultaneously and at the same time the environment and enterprises in which production occurs are not chronically degraded.

Fruits and vegetables can also fight hunger, malnutrition, and environmental degradation indirectly. Their high market value contributes to generating income through direct sales and added value, thus alleviating rural poverty and providing additional opportunities to purchase nutritious foods. Profitable fruit and vegetable production systems can take place even in smallholdings (due to limited economies of scale). Some of these crops can be grown with relatively low capital investment (Shackleton et al., 2009). Even with restricted but judicious inputs there can be quick returns to investment for the poor in both rural and urban areas. Moreover, investing in suitable inputs to prevent mining of soil nutrients and adoption of better land-management practices have the potential to be extremely environmentally beneficial within a resource-poor farmer context. Fruit and vegetable production tends to be labor intensive and therefore provides employment and generates income across the community; it also empowers women, who often have a major role in fruit and vegetable value chains. Indigenous fruits and vegetables are regularly sold in local markets and, in some cases, can achieve a sufficient level of quality and consumer acceptance to permit commercial cultivation by smallholder farmers.

Constraints to Fruit and Vegetable Production and Consumption in the Developing World

Enhanced per capita consumption of fruits and vegetables among all sectors of society would help fight malnutrition and poverty along the value chain from field to table. Fruit and vegetable enterprises need to ensure availability and affordability for consumers to maximize the benefits for both consumers and producers. Producers in developing countries have to overcome various constraints in sustaining sufficient product availability. These constraints include: lack of access to improved, superior-quality seeds; limited knowledge of effective production practices, particularly with reference to using available water resources efficiently; and ensuring that soil health is not compromised by either nutrient mining or excessive use of fertilizer. In addition, ineffective and harmful pest- and disease-management practices may threaten not just the profitability of the farm enterprises but the very health of the farmer, the family, the consumer, and the surrounding environment.

Climate uncertainty, manifested by unpredictable, harsh weather events has exacerbated the constraints that smallholder farmers face. This includes increased pest and disease pressure, and the resulting challenge of producing residue- and contaminant-free products. In the case of fruit growers, for instance, increases in relative humidity that occur as a result of unpredictable rain near harvest carry the risk of fungal infections that become evident only after the fruit is sold to the markets. Temperature fluctuations are increasingly accompanied by changes of population dynamics in both pollinators and insect pests. For example, increases in temperatures have meant that insects such as the fruit fly (*Anastrepha fraterculus*) are now found where they were normally absent, such as areas where Andean blackberry (*Rubus glaucus*) is cultivated. Events like these have caught growers off guard and have resulted in loads of fruit being rejected at processing facilities (A. González 2010, pers. comm.). Unexpected rains may cause temporary flooding, which can have disastrous effects on tomato (*Solanum lycopersicum*) and many other crops.

Most vegetables and some annual fruit species are particularly susceptible to drought, even when experienced for very short periods of time. Drought is especially challenging in highland landscapes, where irrigation is usually not available. Even with the use of irrigation, however, unexpected lack of water will cause severe losses.

There are many opportunities for growing underutilized or indigenous fruit and vegetable species, which are often less susceptible to climatic events than are introduced species. Unfortunately, historically there has been very little investment in research on the physiology and other attributes of these species despite the fact that they provide very tangible alternatives to the more widely grown crops in improving nutrition and income for the rural poor.

An Eco-Efficient Approach to Enhance Production Efficiency, Produce Quality, and Safety

As described in Chapter 2, eco-efficient agriculture aims to increase productivity while reducing associated negative environmental impacts. It must be profitable, competitive, sustainable, and resilient while meeting the economic, social, and environmental needs of the rural and urban poor. Producing enough food to assure both food and nutritional security for the global population while preserving or enhancing the environment and minimizing health risks requires more efficient and ecologically friendly production systems.

An eco-efficient approach can be pursued and applied at each step, from seed production to postharvest value addition. These approaches could include ecologically appropriate practices in seed production and in the seedling nursery, utilization of cover crops that enhance mulching and fertilizer effectiveness, more efficient irrigation systems, low-ecological-risk pest- and disease-management techniques, diversification of production systems, and efficient preharvest and postharvest management methods. The following sections describe some examples of eco-efficient production practices. Their practical application and research results on them are described in the case studies section.

Improved, resilient germplasm

Improved, superior lines of fruits and vegetables are one affordable tool that smallholder horticultural producers can use to address the ever-increasing challenges of biotic and abiotic stresses linked to climatic changes (de la Peña and Hughes, 2007). Many wild relatives of cultivated varieties possess genes that make them more adaptable and tolerant to harsher environments in which they can thrive. For example, *S. chilense*, a wild relative of the cultivated tomato, is indigenous to the desert areas of northern Chile and is adapted to extreme aridity, soil salinity, and to low temperatures (Chetelat et al., 2009). Two wild nightshade species from the same region (*S. sitiens* and *S. lycopersicoides*) share such traits. Gene transfer from these wild species could facilitate the development of drought- and salt-tolerant traits in standard tomato varieties. The genetic factors that are responsible for these traits have been identified and efforts are being made to transfer them into cultivated tomato by hybridization and introgression.

Unfortunately, the search for tolerance to biotic and abiotic stress is occurring mainly in highly commercial vegetables and temperate fruit species. The underutilized species, which are consumed and marketed by, and help to nourish, many families in developing countries, remain very much understudied and are at risk of being lost to deforestation and land use changes (Keatinge et al., 2010). Many indigenous vegetable species, such as amaranth (*Amaranthus* spp.), kangkong (*Ipomoea aquatica*), and Malabar spinach (*Basella alba*), are infested by very few pests and infected by only a few diseases. Thus they can thrive with very limited external production inputs. However, in the case of some of the underutilized fruit species, such as the Andean fruit species naranjilla or lulo (*S. quitoense*), resistance to biotic stresses (e.g., nematodes and root rot) has not been found. Naranjilla is economically important to smallholders in several Latin American countries, but is highly susceptible to many pests and diseases. A closely related species, *S. hirtum*, has fruits that are not appealing to consumers but has shown resistance to the main root nematode pest, *Meloidogyne incognita*. *Solanum hirtum* was used in hybridization programs in Colombia and a tri-hybrid variety has been released out of this cross (Bernal et al., 1998).

Given the large potential diversity of fruits and vegetables, cultivation of traditional species adapted to different agroecological environments offers an opportunity to improve production and increase incomes for smallholders. Increased production and utilization of these traditional species need to be promoted. Expansion of the current cultivated crop range with indigenous species would not only enhance the resilience of these crop production systems but increase the diversity of fruits and vegetables available to consumers.

The search for genes controlling those characteristics that can facilitate adaptation to changing ecological and climatic conditions is becoming urgent. Consequently, efforts to collect, conserve, and utilize genetic diversity are assuming critical importance. Collections of fruit and vegetable germplasm are important reserves of genes to confer pest and disease resistance, tolerance to flooding, improved nutritional content, longer shelf life, better yield and market quality, and other desirable traits. For example, screening of accessions from the genebank of the AVDRC - The World Vegetable Center has resulted in the identification of pepper (*Capsicum annuum*) lines tolerant to anthracnose (*Colletotricum acutatum*), cucumber lines resistant to powdery mildew (*Podophaera xanthii*), and pepper lines with resistance to aphids (*Myzus persicae*) and broad mites (*Polyphagotarsonemus latus*), among others.

Unfortunately, no such intensive and targeted institutional efforts have taken place to search for genes of interest in tropical fruit collections. Efforts to conserve genetic resources of tropical fruits, if they exist within a country, tend to be diffused between the national research organizations, local universities, and local farmers. Screening of germplasm of Andean blackberry from the national collection held in Colombian Corporation of Agricultural Research (Corpoica), resulted in identification of accessions tolerant to anthracnose (Kafuri, 2011). Many other examples of evaluation of national collections have shown that efforts should be devoted to characterizing existing collections rather than further collecting. There is a risk that valuable genes could be lost if the collections are not well maintained, and the collections may not represent the full genetic variability of the species.

Safer pest and disease management practices

Horticultural production systems in the tropics and subtropics are often strongly affected by pests and diseases. As a result, sustainable production is not easily attainable without proper management strategies. Unfortunately, the majority of smallholder producers in developing countries have only limited access to technologies, information, financial resources, and professional services to deal with pest and disease problems. The pressure to maintain high levels of production pushes them towards misuse and/or overuse of pesticides. Some work among fruit and vegetable producers has shown that farmers often rely on calendar-based pesticide applications, often using mixtures of products and without a clear underlying rationale for their use. A study conducted by a non-governmental organization (NGO) in India showed that out of five internationally banned pesticides, four were found to be commonly in use or being tested on vegetables and fruits in New Delhi (Garg, 2011). In a participatory survey among passion-fruit growers in Colombia, 47% of growers interviewed applied a mixture of pesticides up to four times a month rather than basing their applications on a damage threshold (Romero and González, 2010).

Although larger enterprises often have some access to technologies and professional services that permit them to be more judicious in the chemicals and application rates used, this is not always the case. While large-scale producers may have better capacity to maintain the yields of their production systems, the pressure to satisfy the preferences of higher-end consumers for unblemished produce may still encourage them to overuse crop protection agrochemicals to assure market acceptability. When combined with inappropriate pesticide applications prior to harvest, this excessive use of inputs can result in considerable levels of harmful residues in the harvested produce. These residues have the potential to offset the nutritional benefits of vegetables and fruits. Not only does pesticide misuse affect consumers' health, it can also be hazardous to the health of farm workers if protective measures are not taken during application, which is often the case in developing countries. Overuse of agrochemicals can also dramatically increase production costs, eroding smallholder farmers' profits and thus their ability to create sustainable enterprises. The health of consumers and producers must not be jeopardized by harmful agricultural practices used to produce nutrient-laden fruits and vegetables.

Studies show variable concentrations of chemical residues on and in fruits and vegetables. For example, 21 pesticide residues were detected in the cabbage samples at the farm-gate in Cape Coast, Ghana (Armah, 2011). Out of those, two were at exceedingly high levels (allenthrin at 9.57 mg/kg and phorate at 2.08 mg/kg) and three were potentially carcinogenic compounds although at toxicologically acceptable levels (cypermethrin at 0.31 mg/kg, permethrin at 0.15 mg/kg and parathion at 0.019 mg/kg). In Germany, the Federal Office of Consumer Protection and Food Safety (BVL)—management authority for health related consumer protection—reported that out of 65% passion fruit samples containing pesticides residues, 35% were above the acceptable levels (BVL, 2008). When pesticides are used appropriately their residues in harvested crops are below maximum residue levels (MRLs)—the maximum concentrations legally permitted in or on food commodities entering a country—and the crops are considered to be toxicologically acceptable. Bayoumi et al. (2006) compared chemical residues in cucumbers sprayed only once, as recommended by the product label, with those on cucumbers that received numerous applications, following the growers' practices. The results indicated that the numerous applications resulted in pesticide residues above the MRLs. Measurement of pesticide residues is mandatory only for fruits and vegetables exported from their country of origin, in order to comply with importing country regulations. However, having little or no pesticides in fruits and vegetables is equally important for domestic consumers.

The ability of fruit and vegetable cropping systems in developing countries to tolerate, and adapt to, climate uncertainty will undoubtedly determine their viability in the future (FAO, 2001). Researchers are developing technologies to help smallholder farms and farmers be more resilient to the increasing frequency and intensity of biotic and abiotic stresses associated with climate change. As smallholder farmers are usually resource-limited, these technologies must be affordable, simple to use, and accessible.

Integrated pest and disease management (IPM) is one environmentally sound approach to manage biotic stresses in fruit and vegetable production systems. IPM practices enhance the role of natural enemies, of plant defense systems, and of environmental factors to reduce pest and disease incidence in a sustainable way. Should chemical inputs be deemed necessary, the selection of appropriate chemicals and the dosage and frequency at which they are applied must be done with careful consideration for the safety of the environment and human health, and to minimize negative impacts on the various interacting pest- and disease-management components. IPM not only provides a safer method to manage pests and diseases but also often reduces input costs due to the more judicious use of pesticides.

Water and soil fertility management

Informed soil and water management is an essential feature of eco-efficient systems. Failure to address such issues in a timely fashion will surely compromise system sustainability. Micro-irrigation systems, such as drip irrigation, can increase crop productivity per unit of water used compared with less efficient irrigation systems, and are now affordable for resource-poor farmers. In many arid or semi-arid locations such systems are the only solution, simply because there is too little water available to use less efficient systems. Nevertheless, many smallholder farmers are still unfamiliar with the concept and practicality of micro-irrigation techniques. Access to these technologies in some areas is still fairly limited, making it even harder to adopt and, where necessary, to adjust the technology to meet local, specific requirements.

Because drip irrigation avoids prolonged direct contact between the water and the upper part of the plants, it may also minimize the spread of soil-borne microbial contamination to fruits and leafy vegetables. Using the same logic, use of grey water for irrigation may be safer when applied using micro-irrigation methods. However, recent occurrences of contaminated vegetables in Europe are putting these practices under the spotlight. Authorities and farmers should be aware of the danger of biological contamination in irrigation systems. Irrigation water runoff, which may contaminate groundwater and other water resources with fertilizer and pesticide residues, is also minimized in production systems using micro-irrigation.

Smallholder fruit producers currently use multi-strata and multi-species production systems to boost water productivity. However, while the farmers have built on traditional knowledge, their production systems have been devised with very little technical information or access to new technologies. Research is needed to provide more sound alternative production practices, such as the growing and incorporation of cover crops that can help boost water-holding capacity in fruit orchards as well as contribute to soil fertility and structure, which helps the main crop withstand climate extremes. These alternative production practices need research and validation and could prove very useful to reduce herbicide application, ensure soil water retention, mitigate the effects of short-term droughts, and control erosion in high rainfall areas. However, when selecting cover crops farmers need to consider carefully the cover crops' effect on insect diversity, as this could increase the number of crop pests. Conversely, the cover crop selected could be beneficial to the biological control agents of the insect pests (Wood et al., 2011).

In some vegetable species, the issues of flooding and the presence of soil-borne diseases may be addressed by using grafting. This practice has been used for centuries in temperate fruit production, and is becoming more prevalent in some tropical and subtropical fruits, e.g., avocado, citrus (*Citrus* spp.), mango, and soursop (*Annona muricata*). The scion (upper part) of superior cultivated crop plants can be grafted to rootstocks of plants with important characteristics such as resistance to flooding and/or certain soil-borne plant diseases. Grafting tomato or pepper varieties to bacterial-wilt-tolerant eggplant rootstocks can drastically reduce the incidence of the wilt caused by *Ralstonia solanacearum*. Flood-tolerant eggplant rootstocks also enable farmers to produce tomatoes during rainy seasons in the tropics, ensuring production and availability of the crop all year round. *Ralstonia solanacearum* is also the causal agent of moko disease, which is responsible for severe losses in plantain in Latin America and the Caribbean. Unfortunately, no grafting is possible in monocotyledonous species like banana or plantain (*Musa* spp.) and thus alternative solutions are needed.

Because fruits and vegetables are among the most input-responsive of crops, they are often cultivated in intensive production systems with high fertilizer input. This can lead to an over-reliance on inorganic fertilizers to increase yields, but failure to apply enough nutrients will lead to mining of soil nutrients. An appropriate balance of input and offtake of nutrients is required for good soil health. Injudicious use of fertilizer may, however, contribute to the deterioration of soil quality. Accumulation of salts and nitrates from fertilizers in vegetable cropping systems in the North China Plain, for example, has resulted in reduced soil pH, higher electrical conductivity, and raised cadmium concentrations, contributing to rapid soil deterioration (Ju et al., 2007). Leaching of inorganic fertilizer into groundwater may also contaminate water sources used for human and animal consumption, possibly compromising human and animal health. There have been few attempts to investigate nutrient budgets of fruit and vegetable production, but such studies are required to optimize nutrient use and reduce the energy cost of fruit and vegetable production.

Research is under way on the use of "biochar"—charcoal created by pyrolysis of plant biomass—as one alternative or adjuvant to fertilizer. Biochar may enhance soil physical, chemical, and biological properties. In contrast to the burning and natural decomposition of trees and agricultural matter, which releases a large amount of carbon dioxide to the atmosphere, biochar sequesters carbon. Tropical soils are commonly low in organic matter and available nutrients due to high soil temperatures and severe leaching caused by high rainfall. Application of biochar to the soil may improve soil water retention, fertility, and overall quality, thus improving agricultural productivity.

Effective technology dissemination

For agricultural research and development to achieve societal impact it is imperative that the results are delivered to, disseminated among, and adopted by the target beneficiaries. Smallholder farmers need to be better advised on the availability of potentially affordable eco-efficient production systems, on what other alternatives may be available and appropriate, and what technologies are available for adoption or adaptation. Therefore the participation of farmers, as ultimate users of new or adapted agricultural technologies, is crucial when designing research and development activities. An understanding of the constraints and opportunities that farmers encounter and of their assessment of the type of intervention they are willing to adopt and level of risk they are prepared to take is essential to ensure that any innovations are properly targeted to generate effective uptake. Because a sense of ownership is created through the active involvement of the intended users, the outputs of participatory research and development are more likely to be adopted by the target beneficiaries. Information, technical advice, and market price data can be effectively disseminated using popular information technology tools such as mobile phones and the internet. Videos posted on the internet can potentially reach thousands of growers and are cheap to make. Agricultural extension services also play an important role in technology dissemination. NGOs, when provided with appropriate technologies and information, can also deliver important support to smallholder farmers.

Case Studies

Controlling the eggplant fruit and shoot borer in South Asia

This case study is based on Alam et al. (2006).

Eggplant is very common in the South Asian diet. It is an economically important vegetable, and one of the very few that are available throughout the year at prices generally affordable to everyone. Its intensive cultivation provides a valuable source of income for farmers with small land holdings. Nutritionally, eggplant is a rich source of vitamins B6, C, and K. It also contains dietary minerals such as magnesium, phosphorus, potassium, manganese, and copper, as well as dietary fiber and folic acid. The eggplant fruit and shoot borer (*Leucinodes orbonalis*) causes damage to the plant by boring into and feeding on both the plant shoots and fruits. It can substantially reduce yields and marketable eggplant fruit harvest and can decrease farmer income significantly. Yield losses of up to 75% are reported in India.

Eggplant farmers in Gujarat state, India, have attempted to control the borer by relying exclusively on pesticide sprays. As the borer gradually developed resistance to the commonly applied pesticides, farmers were forced to spray more and more frequently. They started spraying pesticides one month after transplanting and sprayed more than 40 times over the 5- to 6-month growing season. A study in Bangladesh has suggested that farmers may have sprayed up to 90 times during the winter cropping season and 110 times during the summer cropping season. This increased the cost of production significantly, reducing farmer net income.

Most farmers adopted some personal protective measures while spraying, thus demonstrating their awareness that pesticides can be harmful to human health. Protective measures ranged from covering their faces with cloth to wearing full protective clothing and washing their hands with soap after spraying. The majority stated that they harvested their eggplants within 2 days of spraying, thus considerably increasing the exposure of both the farmer and the consumer to hazardous pesticide residues both by contact and in the diet. At these spray application intensity levels pesticide residue can potentially contaminate local drinking water through runoff and seepage.

Based on knowledge of the eggplant fruit and shoot borer's biological characteristics, the type of damage to the plants, the agronomy and production requirements of the eggplant, and the local environment; research trials were conducted to develop an intervention strategy to control the borer. This resulted in a simple and affordable IPM strategy that consisted of four parts:

1. Sanitation of the planting area by judiciously disposing of eggplant crop residue from the previous season.
2. Prompt cutting and disposal of all damaged shoots and fruits throughout the growing season.

3. Installation of traps baited with the borer sex pheromone at the first flush of flowering.
4. Withholding use of pesticides for as long as possible to allow survival and proliferation of native predators and parasitoids attacking the borer.

This approach was simple to apply and very affordable since it withholds use of pesticides for as long as possible and only one component (the borer pheromone) needs to be purchased by the farmers.

This IPM intervention technology was first disseminated in Jessore district of Bangladesh, in Gujarat and Uttar Pradesh states of India, and in the Central Province of Sri Lanka. After the pilot project demonstrated the success of the intervention in reducing pest damage to an economically tolerable level, the technology was widely implemented in other intensive eggplant cultivation areas in South Asia. Distribution of extension brochures in local languages, publicity through print and electronic media coverage, local documentary screenings, and dramas encouraged widespread uptake and adoption by farmers.

Subsequent yield losses caused by the eggplant fruit and shoot borer were reduced to 10–15% from an average 34–40%. A preliminary impact study conducted in Bangladesh at the end of the fourth year of the dissemination effort showed a drastic reduction of pesticide use—down from 90 applications to only 21 pesticide applications in the winter season and from 110 applications to 33 applications during the summer season. In India, interviews indicated that 146 farmers sprayed their eggplant crop more than 50 times in the growing season prior to the project. After the project had been implemented, only 27 farmers still continued this intensive spraying regime. The increased yield and decreased expenditure on pesticides resulted in a substantial increase in the farmer incomes. Farmers who adopted the technology achieved a mean net rate of return for eggplant cultivation estimated at 150–240% greater than that of those who continued with their old pesticide application regime.

Another significant benefit from this intervention was the growth of small and medium-sized enterprises selling the sex pheromone lure. At the beginning of the project, the sex pheromone was not commercially available. Within 3 years, three entrepreneurs had started selling the product, and at the end of the project there were nine such businesses in India alone. The combined sales of the two pioneering companies had tripled in two years. In turn, this also benefitted the farmers as it further reduced the cost of eggplant production using the IPM technology. Other benefits from the success of the intervention, which were inferred rather than measured, were less pesticide residue on eggplants in the market, reduced health hazards faced by farmers as a result of spraying pesticides less frequently, and better environmental quality in the eggplant production areas.

Breeding for resistance to tomato yellow leaf curl disease

This case study is based on Muniyappa et al. (2002) and NRI (2008; 2009).

Tomato yellow leaf curl disease (TYLCD) first became a problem on tomato in the eastern Mediterranean region in the mid 1960s. The disease is caused by a begomovirus, Tomato yellow leaf curl virus (TYLCV), transmitted by the whitefly (*Bemisia tabaci*). The disease can cause total crop loss and is a serious constraint to tomato production globally. Because few varieties can withstand the disease, tomato farmers had no other choice than to control the whitefly with intensive pesticide use, thus encouraging pesticide misuse. The farmers' overreliance on pesticides has spurred the emergence of new, aggressive biotypes of whitefly that are highly mobile and resistant to pesticides. The spread of these more efficient whitefly biotypes with a wide host range has resulted in TYLCD gradually becoming a worldwide problem.

Host-plant resistance is the ideal cornerstone of control against TYLCD in tomato. It is cost-effective and very simple to use as it is incorporated in the seeds that the farmer plants. Thus, research was conducted to develop tomato varieties resistant to the disease. The first resistance gene, *Ty*-1, conferred resistance to the then prevalent species of the virus and was identified in the wild tomato species, *S. chilense*. This was bred into commercial varieties, but it soon became apparent that this resistance was ineffective against some emerging species or variants of the virus in some regions. The search then began for other resistance genes. The *Ty*-2 resistance gene was identified in another wild tomato species, *S. habrochaites*, and since then a further three resistance genes (*Ty*-3, *Ty*-4, and *Ty*-5) have been identified in other wild species and used in various areas of the world. A 10-year breeding program involving international and advanced agricultural research institutions, the University of Agricultural Sciences, Bangalore, India, and national agricultural research and development systems incorporated these resistance genes into domesticated lines. Three tomato varieties resistant to TYLCV were released in Karnataka state, India: 'Sankranthi', 'Nandhi', and 'Vybhav'. These varieties are high yielding, tolerate high ambient temperatures, and are also resistant to bacterial wilt caused by *R. solanacearum*.

Farmers who grew the resistant varieties were able to harvest a much higher yield of tomatoes than non-adopters, even during the peak seasons of disease incidence. Their income levels were seven times as much as those of farmers who grew susceptible varieties; the extra income was used by the households to improve their diet, education, and health care.

The resistant germplasm has now been distributed to more than 26 public and private institutions in 13 countries. Private seed companies have started to utilize the germplasm in their breeding programs to produce hybrids, encouraging the scaling out of the benefits of using TYLCV resistance genes.

In addition to planting resistant varieties, farmers were also trained in IPM and encouraged to use it in their production systems to protect the tomato crop from whitefly infestation without overuse of pesticides. Nets were erected over the tomato seedlings to protect them from the disease vectors. The reduced use of pesticides has enabled the development of value-added products such as tomato juice and sauces that are almost free of pesticide residues.

Grafted naranjilla benefits smallholders in Ecuador

This case study is based on CIAT (2010).

Naranjilla (*S. quitoense*) is found in several countries in Latin America, but is economically important mainly in Colombia and Ecuador where more than 30,000 rural families rely on it for their income. It is grown between 700 and 2200 m.a.s.l. on small hillside plots. Naranjilla produces marketable fruits after just 8 months, and continues to produce fruits for 2 to 3 years depending on the health of the plants. The market price of fruits remains fairly stable throughout the year as there is little seasonality of production. Local and international demand is growing, but the crop can be difficult to grow without the use of pesticides, which can result in fruits contaminated with pesticide residues.

Naranjilla is highly susceptible to fungal diseases and to pests, including nematodes and fruit borers. Farmers have managed the nematode problem by planting the crop in new plots cut from primary forest to provide land that is free of nematodes and soil-borne diseases that could infect the crop. The alternative is to apply large amounts of chemicals. Both Colombia and Ecuador have developed hybrid varieties of naranjilla with pest and disease resistance. In Ecuador, the interspecific hybrids 'INIAP Puyo' and 'INIAP Palora', developed by the country's National Autonomous Institute for Agricultural Research (INIAP), have been widely grown by smallholder farmers. However, their fruit quality, with respect to fruit size and aroma, is inferior to the almost-extinct local varieties.

To address this problem, INIAP scientists searched for and identified disease resistance in closely related species and selected some resistant populations for use as rootstocks. Between 2006 and 2009 field experiments were used to test the performance of the preferred naranjilla variety grafted onto two related, highly compatible species. The resulting cultivar/rootstock combination was named 'INIAP Quitoense 2009', and was distributed to farmers under an agreement with a commercial nursery. The field data showed a large significant increase in productivity when compared with the interspecific hybrids. In addition, the grafted plants require less chemical input because of their resistance to nematodes and diseases. More than 115 ha were planted with the grafted plants within a year, and farmers are receiving a greater economic return (290%) as a result of the greater consumer appeal of better flavor. As the fruits are less likely to be contaminated with toxic pesticides there are also now possibilities to address potential export markets.

Tackling passion fruit pest problems in Colombia

This case study is based on Wyckhuys et al. (2010) and Rengifo et al. (2011).

Throughout the developing world, minor tropical fruits generate income and employment opportunities, sustain local livelihoods, and constitute the basis for an emerging agro-industry. In stark contrast with major crops such as mango, pineapple, papaya (*Carica papaya*), avocado, banana, and citrus, minor fruits still receive comparatively little research attention. However, they are being consumed and traded to an increasing extent. In Colombia, 95% of minor fruit production is in the hands of smallholder farmers, who have few financial resources and are commonly bypassed by government extension programs where they exist. Despite bright market prospects for these fruit crops, stagnant yields, poor management systems, and phytosanitary impediments prevent smallholder producers from fully benefiting from current market opportunities. Phytosanitary issues affect minor fruit production in several ways: directly impacting yield, triggering costly pesticide applications, or subjecting the crops to strict quarantine restrictions on foreign markets.

In Colombia, several passion fruit species (*Passiflora* spp.) are commercially exploited. Most are grown by small-scale, resource-poor farmers in some of the country's most deprived and socially volatile rural areas. Lance flies (Diptera: Lonchaeidae) are key pests of these crops, but little information exists regarding their biology, ecology, and management. Incomplete information on the crop's susceptibility to Tephritid fruit flies has resulted in restrictions on exports of fresh fruits to the lucrative US market. Local farmers experience considerable yield losses due to pest attack. They lack the necessary knowledge to properly manage pests and suffer financial losses as a result of pest damage and infestation.

A research consortium involving international organizations, local universities, and farmers' associations was formed to devise cost-effective, sustainable, and environmentally sound pest-management options for local passion fruit producers. Field surveys from 2008 to 2010 in the major passion fruit production regions shed light on the pest complex, its population dynamics, and geographical infestation patterns. A broad complex of lance fly species was associated with the passion fruit crop, affecting flower buds, flowers, or fruits, and attaining regional infestation levels up to 40%. Repeated field surveys involving more than 200 farmers were unable to find evidence of attack by quarantinable pests such as Tephritid fruit flies. Field studies complemented with laboratory assays were used to investigate the host status of passion fruit crops with respect to one of the most notorious quarantine pests, the Mediterranean fruit fly (*Ceratitis capitata*). Until now, there is no evidence that purple passion fruit is a host for *C. capitata* and thus quarantine restrictions for this pest–fruit complex for the US market may have to be revised.

Next, a national farmer survey was conducted to gain insights into the agroecological knowledge and pest-management behavior of local farmers. Aside from the almost universal use of calendar-based insecticide sprays, farmers experimented to a considerable extent with bait traps and low-cost bait types. A few farmers also invented toxic bait sprays and sanitary practices. Using participatory research approaches in five farming communities, some of these local innovations were compared with scientifically defined management tools. Through this approach, farmers discovered for themselves that some of their management tactics were futile while others were much more effective and less costly than their current pesticide use patterns. Farmer experiences were documented using film, and these are currently being shown in multiple communities. Farmers are often eager to try out the practices that are promoted by their peers.

Given continuing incidences of injudicious use of insecticides by farmers to manage pests in their crops and the unrelenting importance of pest problems to farm enterprises, research was conducted in collaboration with the National University of Colombia to quantify the susceptibility of passion fruit to attack by lance flies. Lance fly attack was mimicked by removing a different number of flower buds per plant, and the resultant crop yield was recorded. Results showed that passion fruit plants effectively compensated for flower bud loss and only showed sharp drops in yield at relatively high injury levels (K. Wyckhuys 2011, pers. comm.). These findings are currently being used to formulate threshold levels at which insecticide use is justified. This may help farmers move away from current pest-management schemes that are costly and harmful to the environment and to the health of farmers and consumers alike.

Through this research project the partnering institutions elucidated the key pest complexes associated with passion fruit, clarified the crop's susceptibility to quarantinable pests, and laid the basis for IPM in the crop. The joint social and ecological project focus proved highly effective in identifying pest-management alternatives and further promoting those with local smallholder farmers. In the meantime, the absence of Tephritid fruit flies in these crops could generate tangible market opportunities for smallholder passion fruit producers in Colombia and beyond.

Case studies: conclusions

In summary, it appears that the examples of eco-efficient management interventions for resource-poor farmers given in this paper can be profitable and sustainable. Nevertheless, such systems tend to be quite knowledge-intensive and need to be well-understood by farmers if their rate of adoption is to be sufficient to create widespread impact. Failure to address such knowledge needs may result in a second generation of problems; it is thus necessary to be sensitive to the additional risks that may be caused by such changes in management systems.

Risks Associated with Eco-Efficient Interventions

One major challenge when using resistance traits to manage pests and diseases is how to ensure the durability of the resistance. The composition and structure of pest and disease populations can evolve rapidly. For example, viruses are notorious for having the ability to recombine and mutate into a wide range of highly diverse variants, which can overcome plant resistance genes and defense mechanisms. In many cases the change is spurred by selection pressures created by the resistant germplasm. In the case of TYLCV, for example, it is becoming apparent that if only one or two *Ty* resistance genes are present in a tomato variety there is a strong selection pressure for the virus to overcome the resistance. Thus the challenge to the breeders is to incorporate several disease resistance genes in one variety to provide higher levels of resistance to a broad range of variants of the pathogen. Stacking or pyramiding resistance genes in various combinations reduces the possibility of encountering a pathogen species or strain that can overcome the combined resistances, thus improving the chances of durable resistance. The performance of resistant lines in different geographical locations demonstrates that different combinations of resistance genes need to be evaluated locally for durable resistance.

An integrated approach, combining various methods to overcome constraints to fruit and vegetable production systems, can raise the resilience of eco-efficient interventions. The sustainability of TYLCD management could, for example, be enhanced by combining host-plant resistance to begomoviruses with resistance to the virus vector and IPM practices to control the whitefly vector. Research is underway to attempt to pyramid genes for whitefly resistance into existing tomato lines with multiple begomovirus resistance genes. Combinations of host-plant resistance against these viruses and IPM against the whitefly vectors have been implemented successfully in various cropping systems and regions of the world: on tomato-based mixed cropping in Southeast Asia, on common bean (*Phaseolus vulgaris*) production in Central America and the Caribbean, and on cassava (*Manihot esculenta*) and sweet potato (*Ipomoea batatas*) production in sub-Saharan Africa (CIAT, 2008; Nweke, 2009).

The IPM intervention to control eggplant fruit and shoot borer is relatively resilient because several methods are being used to disrupt the insect's lifecycle at various points. A potential risk to the impact of the intervention arises if the pests move from field to field or encroach from surrounding areas. An active network of community-based organizations and policymakers can provide substantial support by encouraging farmers across wider areas to implement agreed intervention practices. Pest and disease management over wide areas is important to ensure impact, as it has been demonstrated by using male sterility to control fruit flies in several countries.

Although plant breeding can be used to confer pest and disease resistance in many species, efforts to breed for disease resistance in underutilized vegetables and tropical fruits are almost nonexistent. The focus on tropical fruit production and export in developing countries is relatively new (except in a few specific cases, such as banana and pineapple), and the appearance of these crops in international markets dates back only perhaps a generation or so. The visibility of these crops was based on the selection of particular germplasm that suddenly become the prevalent variety in a given region, as was the case for the Gros Michel banana. Multiple examples in avocado, mango, and citrus also exist. Development of pest and disease resistance by breeding programs is likely to have more immediate impact in species with short production cycles than in perennial tropical fruit species. Fruit consumers prefer particular varieties that combine particular color, shape, aroma, and flavor, combinations that are not easy to achieve quickly through breeding. Given the low current investment and research efforts in tropical fruits, it is wise to consider the expertise and knowledge of fruit growers as experimenters, rather than necessarily applying formulaic research-station-based technologies.

Opportunities to Enhance Impact

Participatory research should be promoted and supported to ensure that the science-based technologies are combined with farmers' and fruit-growers' experiences and needs and hence deliver technologies that are adapted and adopted. It is also critical to stakeholders along the value chain, from seed or seedling production through to consumption and the health sector, as well as policymakers, national agricultural research and extension services, the private sector, NGOs, and community-based organizations, all of which influence the eventual uptake and potential success of new technologies.

One of the key drivers of success of the TYLCV project in India was the active participation of the target beneficiaries from the start of the project (NRI, 2009). The disease had already been documented as a severe constraint to growers through the national media and farmers' fora. Farmers were consulted to identify their perceived constraints and their target markets and to describe the production and value chains in which they were involved. Farmers and other project participants developed a sense of ownership and pride in the new technology, resulting in increased levels of adoption and multiplying the positive impacts of the intervention. The private sector often has an extended sales and farmer network, and thereby has an advantage in the efficient dissemination of information and improved agricultural technologies. Private seed companies, for example, are important partners in increasing the availability and rate of dissemination of improved, high-quality vegetable seeds. Local communication networks and traditional methods of mass communication (especially rural radio) can also be utilized to promote dissemination of information about new technologies. Film and drama performances, mobile telephones, and other social communication media need to be harnessed to enhance the spread, uptake and impact of eco-efficient technologies.

A further major issue for fruit and vegetable products is that generally they are highly perishable. A recent study in Africa, India, and other developing countries indicated that postharvest losses in fruits and vegetables are probably in the range of 30–40%. The persistently high postharvest losses in the tropics are due to incorrect harvesting times, mishandling, poor packing, lack of temperature management, difficulties in transportation to markets, and the tendency for horticultural crops to have a definite peak period of production. This production peak, which can saturate markets and decrease the market value of the crop, may force growers to abandon their produce before sale (Kitinoja, 2010). If postharvest losses are not reduced they may wipe out the gains from eco-efficient production systems. Postharvest management and processing of fruits and vegetables are opportunities to reduce losses, add value, and thus increase net returns. Simple technologies, such as using ice to cool harvested leafy greens prior to transportation to the market and better packaging to reduce losses (e.g., modified-atmosphere packaging), can add value and reduce risk along value chains. Careful targeting of products (e.g., juice, dried fruit, pickled products) helps ensure a consistent market for produce.

Key Lessons for Research, Development, and Policy

There are numerous opportunities to enhance the productivity of fruits and vegetables using eco-efficient methods that will promote consumer safety, reduce risks to farmers, and ensure sustainable and profitable production systems. Building farmers' ability to navigate the future uncertainty of climate change is one of the main strategies in the development of climate-smart production systems. It is therefore imperative to actively involve the farmers themselves in the process. Farmers have a wealth of knowledge and many coping strategies. Their assessment of interventions needed, opportunities, and the level of risk they are willing to bear must be taken seriously in any research and development activity intended to benefit those farmers and their communities. Strong collaboration between the stakeholders along the whole value chain is essential to ensure the development of production systems that are competitive, resilient, and sustainable in the face of future uncertain conditions, be they environmental or economic.

Engaging the private sector and development agencies effectively can have benefits for development-oriented research. Although many small and medium-sized enterprises do not have the capacity to conduct their own research and development activities, they may be willing to provide some financial resources for research that will benefit themselves as well as the public domain. Likewise commercial seed companies can multiply and market fruit and vegetable varieties bred by the public sector, helping ensure that they reach as many farmers as possible. Large NGOs that seek adapted and effective technologies to accomplish their goals also can provide substantial funding for research and development activities on issues identified by themselves and their target communities. Such research and development activities are likely to address neglected and underutilized species that receive little research attention through more formal channels.

Development of eco-efficient interventions in fruit and vegetable production will only be possible if dependable, long-term funding is available. Currently, however, research on vegetables and fruits is severely underfunded. Fruits and vegetables have a vital role in ensuring human health; policymakers worldwide should recognize this and provide resources for research and development efforts on behalf of resource-poor farmers. They should be made aware of other benefits likely to be associated with a greater consumption of fruits and vegetables, such as reduced medical expenditures and improved environmental health. Climate-smart and ecologically sound fruit and vegetable production systems will be a key tool in helping smallholder, resource-poor farmers to grow themselves permanently out of poverty, allowing them not only to feed themselves and their communities but also to better nourish the world. If the Millennium Development Goals are to be achieved, such products will need to be available and affordable worldwide. Much good knowledge is already available as a foundation on which to build but political commitment is essential if the world is to benefit from more eco-efficient fruit and vegetable production technologies and systems.

References

Alam AN; Hossain MI; Rouf FMA; Jhala RC; Paterl MG; Rath LK; Sengupta A; Baral K; Sylesha AN; Satpahty S; Shivalingaswamy TM; Cork A; Talekar NS. 2006. Implementation and promotion of an IPM strategy for control of eggplant fruit and shoot borer in South Asia. Technical Bulletin 36. AVRDC – The World Vegetable Center, Shanhua, Taiwan. 74 pp.

Armah FA. 2011. Assessment of pesticide residues in vegetables at the farm gate: Cabbage (*Brassica oleracea*) cultivation in Cape Coast, Ghana. Research Journal of Environmental Toxicology 5:180-202.

Bayoumi AE; El-Zemaity MS; El-Megeed MIA; Hamad MA. 2006. Traditional practices of using pesticides on vegetables and its impacts on residue levels of fenitrothion on cucumber under Egyptian conditions. Annals of Agricultural Science, Cairo 51(2):581–589.

Bernal J; Lobo M; Londoño M. 1998. Documento de presentación del material “Lulo La Selva”. Corpoica, Rionegro, Antioquia, Colombia. 77 p.

BVL (Federal Office of Consumer Protection and Food Safety). 2009. Reports on food safety 2008. Berlin, Germany.

Chetelat RT; Pertuze RA; Faundez L; Graham AB; Jones CM. 2009. Distribution, ecology and reproductive biology of wild tomatoes and related nighshades from the Atacama Desert region of northern Chile. Euphytica 167:77–93.

CIAT (Centro Internacional de Agricultura Tropical). 2008. Dissemination of validated integrated pest management technology in developing countries affected by whitefly pests and whitefly-transmitted viruses that hinder food production and socio-economic development in the tropics. Final project report submitted to UK Department for International Development. CIAT, Cali, Colombia.

CIAT (Centro Internacional de Agricultura Tropical). 2010. CIAT Annual Report 2010: from the New World to the whole world. CIAT, Cali, Colombia.

de la Peña RC; Hughes Jd’A. 2007. Improving vegetable productivity in a variable and changing climate. SAT eJournal 4:1–22. (Available at ejournal.icrisat.org/SpecialProject/sp1.pdf; accessed 17 February 2012).

Ezzati F; Lopez AD; Rodgers A; Hoorn SV; Murray CJL. 2002. Selected major risk factors and global and regional burden of disease. The Lancet 360(9343):1347–1360.

FAO (Food and Agriculture Organization of the United Nations). 2001. Climate variability and change: a challenge for sustainable agricultural production. COAG/01/5. FAO, Rome, Italy. (Available at ftp://ftp.fao.org/unfao/bodies/coag/coag16/X9177e.doc; accessed 17 February 2012).

FAO (Food and Agriculture Organization of the United Nations). 2010. News release: Global hunger declining, but still unacceptably high. Rome, Italy.

Ganry J. 2011. More fruits and vegetables. Fruits 66:1–2.

Garg A. 2011. High court sets up panel to probe pesticide levels in fruits and veggies. The Times of India [online]. Available at http://timesofindia.indiatimes.com/city/delhi/HC-sets-up-panel-to-probe-pesticide-levels-in-fruits-and-veggies/articleshow/7665505.cms

Ju XT; Kou CL; Christie P; Dou ZX; Zhang FS. 2007. Changes in the soil environment from excessive application of fertilizers and manures to two contrasting intensive cropping systems in Northern China Plain. Environmental Pollution 145:497–506.

Kafuri AL. 2011. Antracnosis de la mora de castilla (*Rubus glaucus* Benth): variabilidad del agente causante e identificación de fuentes de resistencia en germoplasma de *Rubus* spp en Colombia. Dissertation. Universidad Nacional de Colombia. 158 p.

Keatinge JDH; Waliyar F; Jamnadass RH; Moustafa A; Andrade M; Drechsel P; Hughes Jd'A; Kardirvel P; Luther K. 2010. Re-learning old lessons for the future of food: by bread alone no longer – diversifying diets with fruit and vegetables. Crop Science 50:51–62.

Kitinoja L. 2010. Identification of appropriate postharvest technologies for improving market access and income for small horticulture farmers in sub-Saharan Africa and South Asia. World Food Logistic Organization Grant final report. (Available at http://ucce.ucdavis.edu/files/datastore/234-1847.pdf; accessed 29 February 2012).

Muniyappa V; Padmaja AS; Venkatesh HM; Sharma A; Chandrashekar S; Kulkarni RS; Hanson PM; Chen JT, Green SK; Colvin J. 2002. Tomato leaf curl virus resistant tomato lines TLB111, TLB130, TLB182. HortScience 37(3):603–606.

NRI (Natural ResourcesInstitute). 2008. Promotion and impact assessment of tomatoes resistant to tomato leaf curl virus disease. www.nri.org/docs/tomato_leaf_curl_india.pdf (accessed 17 February 2012).

NRI (Natural Resources Institute). 2009. Malle roga: tomato leaf curl virus disease [video]. www.youtube.com/watch?v=kWQAL51evTY. (accessed 17 February 2012).

Nweke F. 2009. Resisting viruses and bugs: cassava in sub-Saharan Africa. In: Spielman DJ; Pandya-Lorch R, eds. Millions fed: proven successes in agricultural development. International Food Policy Research Institute, Washington, DC, p 41–46.

Romero AC; González A. 2010. Análisis de residualidad de plaguicidas en el cultivo de maracuyá (*Passiflora edulis* var. *flavicarpa*). Centro Internacional de Agricultura Tropical, Cali, Colombia. 1 p.

Rengifo JA; Garcia JG; Rodriguez JF; Wyckhuys KAG. 2011. Host status of purple passion fruit for the Mediterranean fruit fly (Diptera: Tephritidae). Florida Entomologist 94:91–96.

Shackleton CM; Pasquini M; Drescher AW. eds. 2009. African indigenous vegetables in urban agriculture. Earthscan, London. 169 p.

Tomley, S. 2009. The 12 most contaminated fruits and vegetables: how to lower your intake of pesticides through eating different food. www.suite101.com/content/the-12-most-contaminated-fruits-and-vegetables-a173744 (accessed 17 February 2012).

WHO; FAO (World Health Organization; Food and Agriculture Organization of the United Nations). 2006. Guidelines on food fortification with micronutrients. WHO; FAO, Geneva, Switzerland.

WHO (World Health Organization). 2011. News release: New online nutrition initiative can help protect lives and health of millions of children. www.who.int/mediacentre/news/releases/2011/nutrition_20110810/en/ (accessed 29 February 2012).

Wood,G., Glatz, R., DeGraaf, H., Siekmann, G., Stephens, C. 2011. Revegetation by design: Promoting the 'on-farm' use of native vegetation as agents for 'natural pest control'. Publication No. 11/002. Project No.PRJ-000568. Rural Industries Research and Development Corporation. Barton, Australia.

Wyckhuys KAG; Lopez F; Rojas M; Ocampo JA. 2010. Do farm surroundings and local infestation pressure relate to pest management in three cultivated *Passiflora* species in Colombia? International Journal of Pest Management 57:1–10.