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OPINION PIECE

Sustainable management of transboundary pests requires holistic and inclusive solutions

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Abstract
Globalization and changing climates are aggravating the occurrence and impacts of transboundary pests, and driving the emergence of new threats. Most of the low- and middle-income countries in Africa, Asia and Latin America are not fully prepared in terms of surveillance, diagnostics, and deployment of plant health solutions due to several factors: adequate investment is lacking; knowledge is inadequate; and connections from the local to global, and global to local are insufficient. Effectively countering the current and emerging threats to plant health requires a holistic approach that includes: 1) globally coordinated diagnostic and surveillance systems; 2) epidemiological modelling, risk assessment, forecasting and preparedness for proactive management and containment; and 3) implementation of context-sensitive, eco-friendly, gender-responsive and socially inclusive integrated disease and pest management approaches to reduce the impacts of devastating transboundary pests and diseases. Despite several success stories where major pests and diseases have been brought to control through integrated approaches, further multi-institutional and multi-disciplinary efforts are necessary. Plant health management requires stronger interface between the biophysical and social sciences, and empowerment of local communities. These reflections derive from the proceedings of a webinar on "Transboundary Disease and Pest Management," organized by CGIAR (Consultative Group on International Agricultural Research) on March 3, 2021, in recognition of the United Nations designated International Year of Plant Health.

Keywords Plant health · Pests · Global surveillance · Integrated management · Gender

1 Introduction

Robust and resilient agri-food systems begin with healthy crops. Healthy crops are indeed key to ensuring food security and livelihoods for millions of smallholder farmers in the world's poorest countries. For this reason, the United Nations declared 2020 as the International Year of Plant Health. The recent years have seen a major increase in the spread of transboundary pests and pathogens of crops. International agricultural trade has seen sharp growth since 1990 (FAO, 2017). Besides air-borne, seed-borne and insect-vector channels, increasing agricultural trade, especially since 1990 (FAO, 2017), travel (although affected in the last two years due to COVID19), and weak phytosanitary systems in some developing countries (Day, 2013; Kumar et al., 2021) are accelerating the global spread of devastating crop pests and pathogens, threatening global agri-food systems and food security (Youm et al., 2011). Each year, plant diseases are estimated to cost the global economy over $220 billion, and invasive insects at least

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$70 billion (IPPC Secretariat, 2021). Recent analyses showed that the highest losses due to pests and pathogens are associated with food-deficit regions with fast-growing populations (Savary et al., 2019; Savary & Willocquet, 2020). The situation is aggravated by the effects of changing climate, driving the emergence of new threats (Deutsch et al., 2018; Burdon & Zhan, 2020; IPPC Secretariat, 2021; Skendžic et al., 2021).

The combination of modern science, global partnerships, and knowledge may enable the farming communities to be better prepared to counter threats to plant health. Integrated approaches should capacitate the farmers to effectively address the challenges of transboundary pests, and thus, threats to their food security and livelihoods. However, a truly integrated and holistic approach should also ensure sustainable integration of plant health innovations into the agri-food systems and in social landscapes, including gender-responsiveness, so that: a) the technologies indeed reach all those who are in need of them; b) resource-constrained women and men farmers who adopt the innovations are able to increase their incomes; and c) the technologies are congruent with community norms and values as well as with the preferences and needs of the weaker/marginalized sections of the societies.

This opinion piece is derived from presentations and discussions held during a webinar on "Transboundary Disease and Pest Management" (March 3, 2021), as a part of the International Year of Plant Health (IYPH) webinar series organized by the Consultative Group on International Agricultural Research (CGIAR). The webinar was attended by over 170 participants from Asia, Africa, Europe, and the Americas, with expertise in crop protection, breeding, biotechnology, agronomy, social sciences, and farming systems.

2 Prevention is always better than cure

Infected seeds or planting materials, pathogen-contaminated field equipment, insect-vector movement, the strong migratory capacity of some of the insect-pests (e.g., plant hoppers, locusts, fall armyworm), conductive environments, changing climate, and intensive crop production, besides global air and sea traffic, are all major causes of the rapid spread of pests and diseases. Preventing the incursion/introduction and outbreaks/establishment of pests and diseases to new areas is always better than scrambling to find a cure (Kumar et al., 2021). In recent years, reports of the introduction of non-indigenous pests into new territories have increased globally, driven by (1) agricultural intensification (Bernal & Medina, 2018), (2) international trade (Day, 2013; Youm et al., 2011), and (3) climate change (IPPC Secretariat, 2021; Skendžic et al., 2021). Introduction of exotic pests through seed and vegetative propagation material is a major pathway for the spread of devastating pests (Kumar et al., 2021). To reduce this risk, nations have established plant quarantine procedures in accordance with the multilateral treaty on plant protection (FAO-International Plant Protection Convention, IPPC); Kumar et al., 2021). These quarantine procedures are enforced by national plant protection organizations (NPPOs) and provide a frontline defence to contain transboundary pest invasions.

Preventing the spread of transboundary pests across countries and continents is difficult. Many factors, such as informal seed movement, make prevention extremely challenging. Several low- and middle-income countries (LMICs) are unable to implement adequate quarantine measures due to poor technical capacity and lack of resources to adequately test and monitor biological material. Containing the spread of invasive pests requires a holistic, multi-institutional strategy, including epidemiological modelling, risk prediction, diagnostic capacity, intensive surveillance, monitoring and early warning systems, adequate quarantine and phytosanitary regulations, timely communication, and the ability to enforce rapid containment actions whenever an invasion occurs. Alongside NPPOs, many organizations often work to support regulatory agencies' enforcement of quarantine rules and regulations. For instance, the CGIAR network has established Germplasm Health Units (GHUs) in each of its 11 centers to prevent the spread of seed-borne pests and pathogens through the global germplasm distribution activities of its international crop improvement programs (https://www.genebanks.org/the-platform/germplasm-health/). GHUs evaluate thousands of genetic materials, or germplasm, annually, which include evaluation of new breeding lines at multiple field sites, the majority of which are in LMICs (Kumar et al., 2021). GHUs work in close collaboration with NPPOs, act as a frontline defence, contributing to knowledge on pest and pathogen distribution, development, application of diagnostics for pest and pathogen identification and seed health certification, and application of phytosanitary methods to generate pest-and pathogen-free germplasm for safe international distribution.

There is a need to reinforce these efforts by establishing a global surveillance system (GSS) for crop pests and diseases (Carvajal-Yepes et al., 2019). This will strengthen the diagnostic and surveillance capacities of countries through the NPPOs, especially the LMICs in sub-Saharan Africa (SSA), Asia and Latin America. GSS is based on the foundation of networking and promotes the establishment of regional reference diagnostic labs to strengthen local technical capacity, knowledge sharing and global connectivity. This also requires platforms for data management, communication, and risk assessment (Fig. 1). A GSS diagnostic network in the LMICs should comprise GHUs and external partners located across Africa, Asia, and Latin America. While specific surveillance through national labs at entry and trade points, customs and border patrol, seed inspection and phytosanitary services continue to be important, new variants

Fig. 1 GSS concept: a network of diagnostic regional hubs, sharing pest- and pathogen-related data (depending on participating country-based agreements), with integrated data management, risk assessment, capacity development, and communications. Red circles: Regional diagnostic hubs mostly hosted by CGIAR centers; Green circles: NPPOs; Blue diamonds: Innovation partners or complementary hubs

of pests and pathogens often move across borders frequently bypassing specific surveillance measures (McCullough et al., 2006). Therefore, intensive efforts are needed to build the capacity of LMICs on lab and in-field diagnostics, specific and general surveillance capacity, and establish a platform to facilitate rapid exchange of data for regionally coordinated actions.

The role of communities in pest and disease surveillance, often referred to as "crowd-sourcing", has to be recognized. Investing in a mobile phone-based, farmer-centered large-scale e-surveillance and pest management system is important to capacitate the local communities (Awuor & Otanga, 2019). For example, the Scientific Animations Without Borders (SAWBO) platform has made low-cost animated videos on management of transboundary crop pests like fall armyworm (*Spodoptera frugiperda*; FAW), providing information about diagnostics, surveillance, and pest management using IPM (Bello-Bravo, Huesing, et al., 2018). Translated into many local languages, the SAWBO video on FAW management reached thousands of farmers in several countries in Africa and Asia. Learning gains from such SAWBO videos were found to be greater compared to traditional extension approaches (Bello-Bravo, Tamò, et al., 2018). Tambo et al. (2019) found that complementary ICT-based extension campaigns (particularly those that allow both verbal and visual communication) hold great potential to improve farmers' knowledge and trigger behavioural changes in the identification, monitoring and sustainable management of a new invasive pest. While ICTs have great potential, there are still challenges to overcome, especially in reaching remote areas, women, and less educated farmers. The high cost of internet and mobile phones, besides limited digital literacy, are also major constraints (Coggins et al., 2022). Therefore, social innovations are required to facilitate equitable access to digital extension.

3 Integrated management of transboundary crop pests and pathogens

The goal of integrated pest management (IPM) is to economically suppress pest/pathogen populations using techniques that support healthy crops, reduce the use of pesticides, and minimize harm to people and the environment. Host plant resistance and diversification of resistance genes, both in space and time, proved to be powerful way to proactively

tackle the impact of transboundary pest and pathogen invasions (e.g., Prasanna et al., 2020; Singh et al., 2016). An effective IPM strategy will integrate and employ an array of gender- and culturally appropriate approaches including clean seed systems, host plant resistance, biological control, cultural control or good agronomic practices and the use of safer pesticides only when absolutely needed (Fig. 2) to protect crops from economic injury.

Implementation of multi-disciplinary and multi-institutional plant health management strategies have enabled protection against some of the most devastating transboundary pathogens and insect-pests. The examples include wheat rusts (e.g., Singh et al., 2016), maize lethal necrosis in Africa (Prasanna et al., 2020), rice blast in Africa (Mutiga et al., 2021) and other pests globally (Mutiga et al., 2021; Norton et al., 2010; Teng, 2008), banana bunchy top virus in Africa (Kumar et al., 2011), and cassava mosaic viruses in Africa and Asia (Legg et al., 2015). These strategies have also facilitated scientifically-guided biological control of 43 exotic invertebrate pests in critical food, feed, and fibre crops in the Asia–Pacific, including banana, breadfruit, cassava, and coconut (Wyckhuys et al., 2020).

The fall armyworm (*Spodoptera frugiperda*; FAW) is one of the important examples that highlight the need for national, regional, and transcontinental coordination in effectively managing a highly destructive transboundary pest. The global spread of FAW within a very short timeframe has caused huge concern, especially in Africa (Otim et al., 2021; Prasanna et al., 2018) and Asia (Deshmukh et al., 2021), as the pest poses a serious threat to the food and nutrition security and livelihoods of hundreds of millions of farming households. Besides the economic damage, especially in maize, the FAW invasion has resulted in the heavy use of pesticides, increasing the cost of cultivation, while posing a serious threat to natural enemies (parasitoids and predators of FAW), human health, and the environment (Tepa-Yotto et al., 2021). A recent study (Yang et al., 2021) examining the response of farmers to FAW in the Yunnan province in China showed that the full cost of pesticide-based crop protection increased from US$81 per hectare per crop season in 2018 to US$276 in 2020. The study also showed that at the FAW infestation levels present, some farmers were applying, on average, as many as 6.4 pesticide applications per crop season in 2020. Although there is a wide range of proven technologies and practices available for management of FAW and other lepidopteran maize pests (Prasanna et al., 2018; Goergen et al., 2019; Van den Berg et al., 2021), these are not equally accessible, affordable, and acceptable to diverse farming communities across Africa or Asia. It is therefore critical that researchers design, validate and scale-up appropriate IPM packages suitable for smallholders'

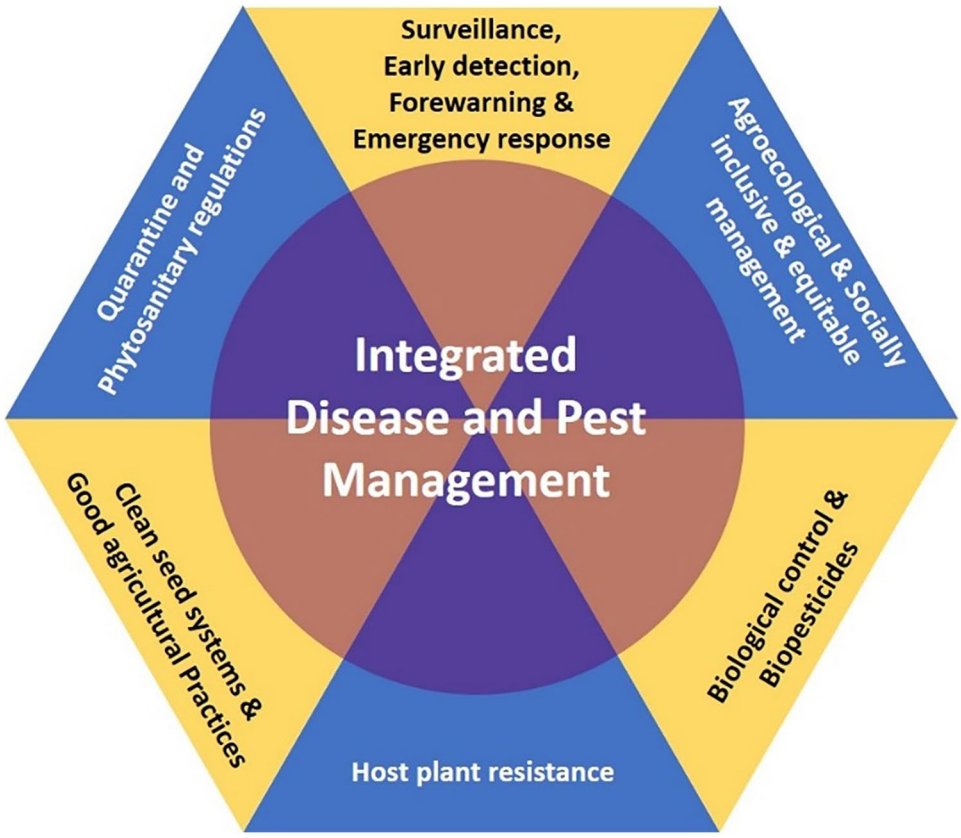

Fig. 2 Sustainable control of transboundary pests requires design and implementation of inclusive and equitable integrated management strategies that mobilize synergies of multiple disciplines, initiatives, and institutions

farming contexts in Africa and Asia, based on five criteria: cost, efficacy, safety, accessibility, and scalability (Prasanna et al., 2021).

At the IYPH webinar held on March 3, 2021, participants showed a keen understanding of the challenges facing IPM implementation and highlighted the key actions needed to address these challenges. When asked to identify the top investment priority for enhancing IPM of plant pests and diseases (Fig. 3), the same percentage of the 159 respondents (26%) answered "promote wider adoption of IPM by farmers" and "breeding and deploying pest- and disease-resistant crop varieties". Another 18% selected pest and disease surveillance and phytosanitary measures, 15% chose research on biocontrol solutions, and 15% selected predicting future pest and disease threats due to climate change.

The CGIAR Plant Health Initiative (https://www.cgiar.org/initiative/13-plant-health-and-rapid-response-to-protect-food-and-livelihood-security/), formulated in 2021, as a follow-up of the IYPH Webinar, and initiated in January 2022, focuses on a) strengthening the diagnostic and surveillance capacity of NPPOs and other national partners in the LMICs; b) undertaking epidemiological modelling, risk assessment, and guiding preparedness for rapid response against invasive pests; c) implementing integrated pest and disease management in targeted crops and cropping systems; d) developing and deploying tools and processes for protecting targeted food chains from mycotoxin contamination; and e) catalysing equitable and inclusive scaling of plant health innovations in target geographies.

4 Gender issues, and disciplinary gap between social and biophysical scientists

Women play significant roles in pest management in some regions, such as obtaining and planting healthy seed/planting materials, identifying pest symptoms, (Iradukunda et al., 2019; Nkengla-Asi et al., 2019; Upadhyay et al., 2018) and participating in crop protection activities, such as pesticide application (Schreinemacheres et al., 2017). However, the lack of gender and social perspectives in plant health surveillance, technology development, access to extension services, and impact evaluation has been one of the major impediments in improving the adoption of IPM strategies (Kawarazuka et al., 2020; Tambo et al., 2021; Terefe, 2020).

Women's constraints on technology adoption are diverse, including lack of financial resources, time, labour, and mobility (Peterman et al., 2010), and limited extension/information targeted for women's needs (Mudege et al., 2016). While the significance of understanding farmer perspectives has been well-recognized in the literature on pest and disease management (Alwang et al., 2019; Orr, 2003), gender is often forgotten and only added at the last stage of extension work when technologies are already developed, mostly in line with male farmers' perspectives. This approach resulted in not only low adoption rates of IPM, but also a widening of the gender gap. Equitable and inclusive innovations, therefore, need to start by involving women farmers in surveillance and technology development to learning from their rich experiences, observations, and knowledge. Research, extension and policy changes are

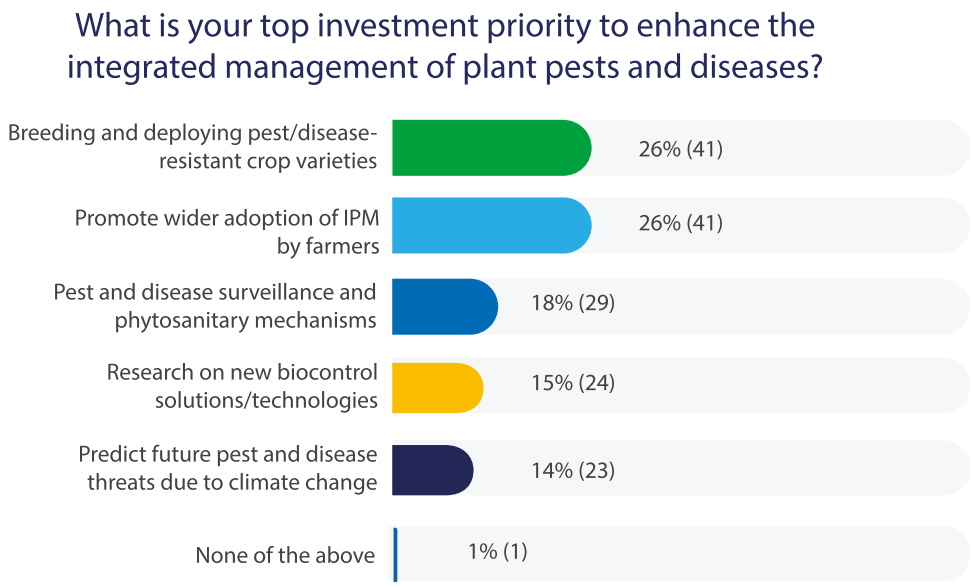

Fig. 3 Responses of 159 respondents of the IYPH webinar to the survey question related to the top investment priority (in their view) for enhancing the integrated management of plant pests and pathogens

needed to increase the efficiency, adoption and sustainability of IPM on resource-limited farms (Bottrell & Schoenly, 2018), together with innovative approaches to promote farmers' collective actions in plant health management (Garcia-Figuera et al., 2021; Graham et al., 2019) and farmer-to-farmer transfer of IPM knowledge (Yaguana et al., 2015).

To ensure that plant health innovations have equitable benefits to women and marginalized communities, some critical questions need to be considered while designing and implementing projects on plant health management: Which farming, ecological and socio-economic conditions do the plant health innovations best fit? Whose labour will increase or decrease due to application of the innovation? Who has digital literacy and access to ICTs within the community? What are the communication methods appropriate for resource-poor women in marginalized/remote communities? These questions need to be rigorously addressed through strong collaboration between social and biophysical scientists.

5 Conclusions

Effective plant health management requires holistic approaches that focus on preventing entry, establishment and spread of invasive pests and pathogens, to the extent possible, and mitigation of the impacts of the outbreaks through eco-friendly, socially inclusive, and sustainable management approaches. The reactive approach, followed in general by most institutions and countries, focusing on containment and management actions (in most cases using pesticides) after the occurrence of an outbreak, might have paid off in the short- and medium-term, but cannot be sustainable. The following are specific recommendations to improve transboundary pest management:

- Multi-institutional and multi-disciplinary efforts are required to curb the spread and impacts of transboundary crop pests and pathogens, including: a) proactive actions through globally coordinated surveillance, diagnostics, and deployment of plant health solutions; b) effective communication and data sharing among relevant stakeholders; c) epidemiological modelling, risk assessment, forecasting and preparedness for proactive management as well as rapid response and containment; and d) implementation of context-sensitive, and eco-friendly management approaches.
- It is important to recognize that IPM is not only about "Integrated Pest Management", but also "Integrating People's Mindsets" i.e., thinking beyond narrow disciplines and institutions, and working together to deliver holistic and sustainable solutions to the farmers' fields.
- Pest management decisions must be improved through evidence-based guidance frameworks, especially for identifying target countries/regions for risk management, and for deploying innovative management approaches, including resistant varieties and biological control, where available.
- Understanding gender and cultural influences, besides heterogeneous socio-economic impacts of plant health innovations, and intensively promoting farmers' collective action can aid in bridging the gender gap, and improving adoption of IPM by resource-constrained farmers.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Alwang, J., Norton, G., & Larochelle, C. (2019). Obstacles to widespread diffusion of IPM in developing countries: Lessons from the field. *Journal of Integrated Pest Management, 10*(1), 1–8. https://doi.org/10.1093/jipm/pmz008

Awuor, F. M., & Otanga, S. A. (2019). Farmer centered large scale e-surveillance and control of crop pests in Kenya. *Journal of Agricultural Informatics, 10*(1), 33–44.

Bello-Bravo, J., Huesing, J., Prasanna, B. M., Goergen, G., Eddy, R., Tamò, M., & Pittendrigh, B. R. (2018). IPM-based animation for Fall Armyworm: A multi-institutional and virtual international collaboration using the Scientific Animations Without Borders (SAWBO) platform. *Outlooks on Pest Management, 29*, 228–233. https://doi.org/10.1564/v29_oct_10

Bello-Bravo, J., Tamò, M., Dannon, E. A., & Pittendrigh, B. R. (2018). An assessment of learning gains from educational animated videos versus traditional extension presentations among farmers in

Benin. *Information Technology for Development, 24*(2), 224–244. https://doi.org/10.1080/02681102.2017.1298077

Bernal, J. S., & Medina, R. F. (2018). Agriculture sows pests: How crop domestication, host shifts, and agricultural intensification can create insect pests from herbivores. *Current Opinion in Insect Science, 26*, 76–81. https://doi.org/10.1016/j.cois.2018.01.008

Bottrell, D. G., & Schoenly, K. G. (2018). Integrated pest management for resource-limited farmers: Challenges for achieving ecological, social and economic sustainability. *The Journal of Agricultural Science, 156*(3), 408–426. https://doi.org/10.1017/S0021859618000473

Burdon, J. J., & Zhan, J. (2020). Climate change and disease in plant communities. *PLoS Biology, 18*(11), e3000949. https://doi.org/10.1371/journal.pbio.3000949

Carvajal-Yepes, M., Cardwell, K., Nelson, A., Garrett, K., Giovani, B., Saunders, D. G. O., Kamoun, S., Legg, J. P., Verdier, V., Lessel, J., Neher, R. A., Day, R., Pardey, P., Gullino, M. L., Records, A. R., Bextine, B., Leach, J. E., Staiger, S., & Tohme, J. (2019). A global surveillance system for crop diseases: Global preparedness minimizes the risk to food supplies. *Science, 364*, 1237–1239. https://doi.org/10.1126/science.aaw1572

Coggins, S., McCampbell, M., Sharma, A., Sharma, R., Haefele, S. M., Karki, E., Hetherington, J., Smith, J., & Brown, B. (2022). How have smallholder farmers used digital extension tools? Developer and user voices from Sub-Saharan Africa, South Asia and Southeast Asia. *Global Food Security, 32*, 100577. https://doi.org/10.1016/j.gfs.2021.100577

Day, R. K. (2013). More trade, safer trade: strengthening developing countries' sanitary and phytosanitary (SPS) capacity. CABI Working Paper 4, 33 pp.

Deshmukh, S. S., Prasanna, B. M., Kalleshwaraswamy, C. M., Jaba, J., & Choudhary, B. (2021). Fall armyworm (*Spodoptera frugiperda*). In Omkar (Ed.) *Polyphagous Pests of Crops*. Singapore: Springer, pp. 349–372. https://doi.org/10.1007/978-981-15-8075-8_8

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. *Science, 361*, 916–919. https://doi.org/10.1126/science.aat3466

FAO. (2017). *The future of food and agriculture – trends and challenges*. FAO.

Garcia-Figuera, S., Grafton-Cardwell, E. E., Babcock, B. A., Lubell, M. N., & McRoberts, N. (2021). Institutional approaches for plant health provision as a collective action problem. *Food Security, 13*, 273–290. https://doi.org/10.1007/s12571-020-01133-9

Goergen, G., Neuenschwander, P.M., & Coyne, D. (2019). Conserving and exploiting biodiversity in crop cultivation in sub-Saharan Africa. In: P. Neuenshwander, M. Tamo, *Critical Issues in Plant Health: 50 Years of Research in African Agriculture*. Cambridge, UK: Burleigh Dodds Science Publishing. https://doi.org/10.19103/as.2018.0043.04

Graham, S., Metcalf, A. L., Gill, N., Niemiec, R., Moreno, C., Bach, T., Ikutegbe, V., Hallstrom, L., Ma, Z., & Lubeck, A. (2019). Opportunities for better use of collective action theory in research and governance for invasive species management. *Conservation Biology, 33*(2), 275–287. https://doi.org/10.1111/cobi.13266

IPPC Secretariat. (2021). *Scientific review of the impact of climate change on plant pests – A global challenge to prevent and mitigate plant pest risks in agriculture, forestry and ecosystems*. FAO on behalf of the IPPC Secretariat. https://doi.org/10.4060/cb4769en

Iradukunda, F., Bullock, R., Rietveld, A., & van Schagen, B. (2019). Understanding gender roles and practices in the household and on the farm: Implications for banana disease management innovation processes in Burundi. *Outlook on Agriculture, 48*(1), 37–47. https://doi.org/10.1177/0030727019831704

Kawarazuka, N., Damtew, E., Mayanja, S., Okonya, J. S., Rietveld, A., Slavchevska, V., & Teeken, B. (2020). A gender perspective on pest and disease management from the cases of roots, tubers and bananas in Asia and sub-Saharan Africa. *Frontiers in Agronomy, 2*, 7. https://doi.org/10.3389/fagro.2020.00007

Kumar, P. L., Hanna, R., Alabi, O. J., Soko, M. M., Oben, T. T., Vangu, G. H. P., & Naidu, R. A. (2011). Banana bunchy top virus in sub-Saharan Africa: Investigations on virus distribution and diversity. *Virus Research, 159*, 171–182. https://doi.org/10.1016/j.virusres.2011.04.021

Kumar, P. L., Cuervo, M., Kreuze, J. F., Muller, G., Kulkarni, G., Kumari, S. G., Massart, S., Mezzalama, M., Alokonya, A., Muchugi, A., Graziosi, I., Ndjiondjop, M.-N., Sharma, R., & Negawo, A. T. (2021). Phytosanitary interventions for safe global germplasm exchange and the prevention of transboundary pest spread: The role of CGIAR Germplasm Health Units. *Plants, 10*, 328. https://doi.org/10.3390/plants10020328

Legg, J. P., Kumar, P. L., Makeshkumar, T., Tripathi, L., Ferguson, M., Kanju, E., Ntawuruhunga, P., & Cuellar, W. (2015). Cassava virus diseases: Biology, epidemiology, and management. *Advances in Virus Research, 91*, 85–142. https://doi.org/10.1016/bs.aivir.2014.10.001

McCullough, D. G., Work, T. T., Cavey, J. F., Liebhold, A. M., & Marshall, D. (2006). Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. *Biological Invasions, 8*, 611. https://doi.org/10.1007/s10530-005-1798-4

Mudege, N. N., Chevo, T., Nyekanyeka, T., Kapalasa, E., & Demo, P. (2016). Gender norms and access to extension services and training among potato farmers in Dedza and Ntcheu in Malawi. *The Journal of Agricultural Education and Extension, 22*(3), 291–305. https://doi.org/10.1080/1389224X.2015.1038282

Mutiga, S. K., Rotich, F., Were, V. M., et al. (2021). Integrated strategies for durable rice blast resistance in sub-Saharan Africa. *Plant Disease, 105*, 2749–2770. https://doi.org/10.1094/PDIS-03-21-0593-FE

Nkengla-Asi, L., Olaosebikan, O. D., Che, V. S., Ngatat, S., Zandjanakou-Tachin, M., Hanna, R., & Kumar, P. L. (2019). Gender norms and their implications for banana production and recovery in West Africa. In M. Segal, K. Kelly, & V. Demos (Eds.), *Gender and Practice: Knowledge* (pp. 61–75). Emerald Publishing Limited.

Norton, G. W., Heong, K. L., Johnson, D., & Savary, S. (2010). Rice pest management: issues and opportunities. In Pandey, S., Byerlee, D., Dawe, D., Dobermann, A., Mohanty, S., Rozelle, S., & Hardy, B. (Eds) Rice in the Global Economy: Strategic Research and Policy Issues for Food Security. International Rice Research Institute, Los Banos, Philippines, pp. 297–332.

Orr, A. (2003). Integrated pest management for resource-poor African farmers: Is the emperor naked? *World Development, 31*(5), 831–845. https://doi.org/10.1016/S0305-750X(03)00015-9

Otim, M. H., Fiaboe, K. K. M., Akello, J., Mudde, B., Obonyom, A. T., Bruce, A. Y., Opio, W. A., Chinwada, P., Hailu, G., & Paparu, P. (2021). Managing a transboundary pest: The fall armyworm on maize in Africa. *IntechOpen*. https://doi.org/10.5772/intechopen.96637

Peterman, A., Behrman, J. A., & Quisumbing, A. R. (2010). A review of empirical evidence on gender differences in nonland agricultural inputs, technology, and services in developing countries. In A. R. Quisumbing, R. Meinzen-Dick, T. L. Raney, A. Croppenstedt, J. A. Behrman, & A. Peterman (Eds.), *Gender in Agriculture* (pp. 145–186). Springer.

Prasanna, B. M., Huesing, J. E., Eddy, R., & Peschke, V. M. (Eds.). (2018). *Fall Armyworm in Africa: A Guide for Integrated Pest Management* (1st ed.). CIMMYT.

Prasanna, B., Suresh, L. M., Mwatuni, F., Beyene, Y., Makumbi, D., Gowda, M., Olsen, M., Hodson, D., Worku, M., Mezzalama, M., Molnar, T., Dhugga, K., Wangai, A., Gichuru, L., Angwenyi, S., Alemayehu, Y., Grønbech-Hansen, J., & Lassen, P. (2020). Maize

lethal necrosis (MLN): Containing the spread and impact of a devastating transboundary disease in sub-Saharan Africa. *Virus Research, 282*, 197943. https://doi.org/10.1016/j.virusres.2020.197943

Prasanna, B. M., Huesing, J. E., Peschke, V. M., Nagoshi, R. N., Jia, X., Wu, K., Trisyono, Y. A., Tay, T., Watson, A., Day, R., Eddy, R. (2021). Fall armyworm in Asia: invasion, impacts, and strategies for sustainable management. In Prasanna, B. M., Huesing, J. E., Peschke, V. M., & Eddy, R. (Eds). *Fall Armyworm in Asia: A Guide for Integrated Pest Management.* Mexico, CDMX: CIMMYT, pp. 1–20.

Savary, S., & Willocquet, L. (2020). Modeling the impact of crop diseases on global food security. *Annual Review of Phytopathology, 58*, 313–341. https://doi.org/10.1146/annurev-phyto-010820-012856

Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2019). The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution, 3*, 430–439. https://doi.org/10.1038/s41559-018-0793-y

Schreinemachers, P., Chen, H.-P., Nguyen, T. T. L., Buntong, B., Bouapao, L., Gautam, S., Le, N. T., Pinn, T., Vilaysone, P., & Srinivasan, R. (2017). Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia. *The Science of the Total Environment, 593–594*, 470–477. https://doi.org/10.1016/j.scitotenv.2017.03.181

Singh, R. P., Singh, P. K., Rutkoski, J., Hodson, D. P., He, X., Jørgensen, L. N., Hovmøller, M. S., & Huerta-Espino, J. (2016). Disease impact on wheat yield potential and prospects of genetic control. *Annual Review of Phytopathology, 54*, 303–322. https://doi.org/10.1146/annurev-phyto-080615-095835

Skendžic, S., Zovko, M., Živkovic, I. P., Lešic, V., & Lemic, D. (2021). The impact of climate change on agricultural insect pests. *Insects, 12*, 440. https://doi.org/10.3390/insects12050440

Tambo, J. A., Aliamo, C., Davis, T., Mugambi, I., Romney, D., Onyango, D. O., Kansiime, M., Alokit, C., & Byantwale, S. T. (2019). The impact of ICT-enabled extension campaign on farmers' knowledge and management of fall armyworm in Uganda. *PLoS ONE, 14*(8), e0220844. https://doi.org/10.1371/journal.pone.0220844

Tambo, J. A., Matimelo, M., Ndhlovu, M., Mbugua, F., & Phiri, N. (2021). Gender-differentiated impacts of plant clinics on maize productivity and food security: Evidence from Zambia. *World Development, 145*, 105519. https://doi.org/10.1016/j.worlddev.2021.105519

Teng, P. S. (2008). Integrated pest management in rice. *Experimental Agriculture, 30*, 115–137. https://doi.org/10.1017/S001447970002408X

Tepa-Yotto, G. T., Tonnang, H. E. Z., Goergen, G., Subramanian, S., Kimathi, E., Abdel-Rahman, E. M., Flø, D., Thunes, K. H., Fiaboe, K. K. M., Niassy, S., Bruce, A., Mohamed S. A., Tamò, M., Ekesi, S., & Sæthre, M. G. (2021). Global habitat suitability of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae): key parasitoids considered for its biological control. *Insects* 12, 273. https://doi.org/10.3390/insects12040273

Terefe, B. (2020). Gender assessment of Plantwise Programme. CABI Project Report. https://www.cabi.org/cabi-publications/gender-assessment-of-plantwise-programme/

Upadhyay, B., Burra, D., Nguyen, T. T., & Wyckhuys, K. A. G. (2018). Caught off guard: Folk knowledge proves deficient when addressing invasive pests in Asian cassava systems. *Environment, Development and Sustainability, 15*(5), 1–21.

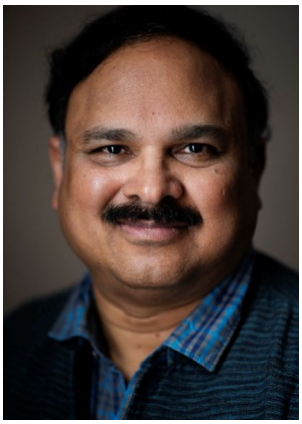
Van den Berg, J., Prasanna, B. M., Midega, C. A. O., Ronald, P. C., Carrière, Y., & Tabashnik, B. E. (2021). Managing fall armyworm in Africa: Can Bt maize sustainably improve control? *Journal of Economic Entomology, 114*, 1934–1949. https://doi.org/10.1093/jee/toab161

Wyckhuys, K. A. G., Lu, Y., Zhou, W., Cock, M. J. W., Naranjo, S. E., Fereti, A., Williams, F. E., & Furlong, M. J. (2020). Ecological pest control fortifies agricultural growth in Asia-Pacific economies. *Nature Ecology & Evolution, 4*, 1522–1530. https://doi.org/10.1038/s41559-020-01294-y

Yaguana, V. C., Alwang, J., Norton, G., & Barrera, V. (2015). Does IPM have staying power? Revisiting a potato-producing area years after formal training ended. *Journal of Agricultural Economics, 67*(2), 308–323. https://doi.org/10.1111/1477-9552.12140

Yang, X., Wyckhuys, K., Jia, X., Nie, F., & Wu, K. M. (2021). Fall armyworm invasion heightens pesticide expenditure among Chinese smallholder farmers. *Journal of Environmental Management, 282*, 111949. https://doi.org/10.1016/j.jenvman.2021.111949

Youm, O., Vayssières, J.-F., Togola, A., Robertson, S. P., & Nwilene, F. E. (2011). International trade and exotic pests: The risks for biodiversity and African economies. *Outlook on Agriculture, 40*, 59–70. https://doi.org/10.5367/oa.2011.0031



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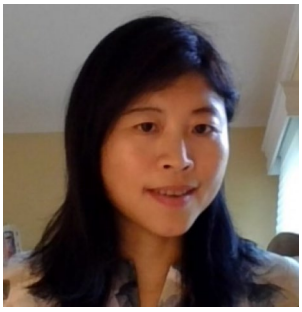

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