













Global Plant Health Assessment

An international peer-reviewed evaluation of the state of plant health across ecoregions of the world, and of the effects of plant disease on ecosystem services

ISPP INTERNATIONAL SOCIETY FOR PLANT PATHOLOGY
OECD

Global Plant Health Assessment

An international peer-reviewed evaluation of the state of plant health across ecoregions of the world, and of the effects of plant disease on ecosystem services

Edited by Laetitia Willocquet, Manjari Singh, Sonam Sah, Federica Bove, Serge Savary, and Jonathan Yuen

The Global Plant Health Assessment (GPHA) is an initiative under the *aegis* of the International Society for Plant Pathology (ISPP)

Published by Jonathan Yuen (jonathan.yuen@telia.com) and Laetitia Willocquet (Laetitia.Willocquet@inrae.fr)

First Edition:

ISBN (epub) 978-91-988233-0-1

ISBN (pdf) 978-91-988233-1-8

ISPP INTERNATIONAL SOCIETY FOR PLANT PATHOLOGY

OECD

Acknowledgments

We are grateful to the Executive Committee of the ISPP for its continuous support over this 3-year effort. The Global Plant Health Assessment is grounded on the volunteer contributions of a large community of colleagues (see Table 1 in Section Background and Overall Approach to Assessing Global Plant Health). Financial support to organise the GPHA International Workshop and Conference held in Toulouse in October 2021 in Toulouse was provided by the OECD-CRP (Co-operative Research Programme: Sustainable Agricultural and Food Systems), by direct support of GPHA participant's institutions, and a small complement from INRAE. We wish to thank Ms. Janet Schofield (OECD-CRP Office, Paris) for her kind support and availability as this OECD-CRP project was materialising. We wish to thank Dr. Arnaud Reynaud (Director) and Ms. Aline Couratier (Administrative Assistant) of the Toulouse School of Economics - Research, Toulouse, Ms. Stéphanie Risser (Events Coordinator, TSE, Toulouse), and Ms. Sophie Collet (Administrative Assistant, IGEPP-INRAE, Rennes) for their kind and efficient support in organising these events.

The Scientific Secretariat of GPHA (L Willocquet, M Singh, S Sah, F Bove, S Savary) is supported by the GB Pant University of Agriculture & Technology, Pantnagar, India, and by the Università Cattolica del Sacro Cuore, Piacenza, Italy, which are gratefully acknowledged.

Credits and description of icons

representing Plant Systems on the cover page as well as on the section headings of reports for: Cereals; Roots, Tubers, Banana & Plantain; Perennial Crops; Peri-Urban Horticulture and Household Gardens; Urban Vegetation; and Forests.

All icons were drawn by Serge Savary, and are derived from copyright-free photos, mainly Wikipedia.

Description of icons for plant systems: **Rice**: Ifugao Sculpture, Philippines. The Louvre. **Wheat**: Demeter, goddess of harvest and agriculture, on a silver coin, 4th century BC, Middle-East. Demeter also presides over the sacred law, and on the cycle of life and death. **Maize**: Maya maize god. He also is the patron of scribal arts, which he invented. Classic Period (200-900 AD). **Potato**: Axomamma, goddess of potato. Inca mythology. **Cassava**: Head from Ife (Nigeria): 14th-15th century AD, bronze. Height: 36 cm. **Banana and Plantains**: Kifwebe mask; wood. Luba Kingdom, Democratic Republic of Congo. Royal Museum for Central Africa, Tervuren, Belgium. **Grapevine**: Dionysos in a ship, sailing among dolphins. Attic black-figure kylix, ca. 53 B.C. Vulci, Italy. **Perennial fruits and nuts**: Reputed descendant of Newton's apple tree at Trinity College, Cambridge. **Coffee**: Coffee (*Coffea Arabica*) originates from Ethiopia and the southern tip of Arabia, then the Saba Kingdom and later Arabia Petrae. Coffee was drunk in Arabia long before being known to Europe. Sidamo coffee is one of the best in the world. **Orange**: O Meu Pé de Laranja Lima (My sweet Orange Tree) was written by José Moro de Vasconcelos in 1968, in Brazil. **Peri-urban horticulture and household gardens**: Annapurna, Hindu goddess of food and nourishment. Anna means "food"; pūrna means "full, complete and perfect". **Urban trees**: The Pulitzer Fountain is an outdoor fountain located in Manhattan's Grand Army Plaza in New Yor, USA. **Softwood forests**: *Pinus contorta* needles and cones. Background: totem pole in Ketchikan, Alaska, in the Tlingit style of Pacific North-West. **Oak forests**: *The Big Oak*: Painting by Gustave Courbet (1843). **Eucalypts**: Aboriginal bark painting. Eucalypts were important ceremonial elements for Australian aborigines. **Amazon forest**: The Izapa stela 5 features a Mesoamerican World Tree. Olmec art, 300-50 BCE. Fragment redrawn. American *ceibas* are genetically close to African *fromagers* and Asian *Kapoks*. All these trees have profound spiritual value.

Foreword for *Global Plant Health Assessment*

Jan E. Leach

President, International Society of Plant Pathology

Agricultural Biology, Colorado State University, Fort Collins, CO 80523-1177

Our planet's health is in a precarious state, and the health of our planet is undeniably linked to plants, and, of course, the health of those plants. The *Global Plant Health Assessment* initiative was the vision of an international group of dedicated volunteers who have keen knowledgeable and deep insight into the global state of plant health and its implications for the planet and humanity. The group's proposal of the initiative and this book was enthusiastically endorsed by the International Society for Plant Pathology's Executive Committee in 2019.

The *Global Plant Health Assessment* provides a snapshot of plant disease impacts on diverse plant systems in defined ecoregions. Trends in effects on ecosystem services are described for each plant system X ecoregion. All evaluations are presented using standardized rating methods, which is particularly valuable as it allows for easy comparison of impacts across systems, and provides a baseline for comparison into the future. Undoubtedly, because of the careful planning, design, execution, and review of the study, the *Global Plant Health Assessment* will be widely cited. Furthermore, it will serve as a unique and important resource to guide international policy.

The International Society for Plant Pathology is deeply indebted to the coordinators and experts who contributed to the conception and accomplishment of the *Global Plant Health Assessment*. It was a herculean effort with an aggressive timeline. It involved the coordination of over 100 plant health experts from over 30 countries. A study of this scale is unprecedented and it could not have been accomplished without the vision, planning, organization, guidance, and determination of the Coordination group and the support of the Scientific Secretariat. The *Global Plant Health Assessment* clearly meets the goals of the authors; it provides the first science-based overall assessment of plant health in diverse ecosystems globally. Congratulations and thank you!

Jan E. Leach

Jan E. Leach
President, International Society for Plant Pathology

Contents

Background and overall approach to assessing global plant health

Global Plant Health Assessment context: the meaning of plants

The Global Plant Health Assessment (GPHA) is an initiative of the International Society for Plant Pathology (ISPP) involving an international, volunteered, peer-reviewed evaluation of the state of plant health across ecoregions of the world, and of the effects of plant disease on ecosystem services. The initiative was motivated by the International Year of Plant Health (IYPH, 2020), to which ISPP has contributed in various ways.

2020 was declared the International Year of Plant Health by the General Assembly of the United Nations in order to raise global awareness on the importance of plant health for humans, societies, and the world. This book reports volunteered efforts made by a community of scientists worldwide who are concerned by the global state of plant health, and by the implications of faltering plant health on the balance of world's human-made or natural ecosystems, on the state of global food security, and on the daily contribution of plants to the beauty of our world.

Plants play a key role, globally to locally, in climate, air quality and composition, soil biophysical properties, biodiversity, landscapes, water quality, food and feed, pollution as well as the biophysical environment in our cities. Plants also are essential to human well-being as a source of beauty, inspiration, and re-creation. However, these roles are overlooked in many ways, and are taken for granted. Recognising the role of plants in human health and well-being is needed to safeguard the sustainability of Earth ecosystems.

Plant systems in the biosphere are strongly impacted by their state of health, which is in turn importantly influenced by plant pathogens. Yet, there seems to be no scientifically-grounded statements on the current state of plant health globally, or on its evolution in recent years.

Aim of the Global Plant Health Assessment

The Global Plant Health Assessment aims to provide a first time-ever overall assessment of plant health in the natural and human-made ecosystems of the world. Plant health is assessed through the functions that plants ensure in ecosystems: "ecosystem services" (Millennium Ecosystem Assessment, 2005). The GPHA assesses plant health on the basis of published, science- and fact-based, expert evaluations. The GPHA considers plant health from the angle of infectious diseases, yet addresses plant health as a whole. Its goal is an overview of the current status and trends in plant health, and their outcomes on ecosystem services: provisioning (food, fibre, material), regulating (climate, water, soils), and cultural (re-creation, spiritual, beauty).

Policies must be grounded on scientific evidence. With the Global Plant Health Assessment, we hope to produce material that would help developing policies globally and locally which would strengthen the ability to ensure plant health in a sustainable manner.

The GPHA addresses four broad types of Plant-Systems: forests, agricultural systems, peri-urban horticulture and household gardens, and urban vegetation. Each Plant-System in each ecoregion is being addressed by a small team composed of a Lead Scientist and a group of 3-4 Experts. The initiative therefore involves some 100 scientists in the world.

Overall principles and organisation of the Assessment

The Assessment has been sanctioned by the Executive Committee of the ISPP in November 2019, so that this work would be conducted under its *aegis*. The efforts underpinning the GPHA are therefore not institutional.

The conduct of the GPHA is entirely based upon volunteered contributions of international experts in the field of plant pathology, most of them, members of the ISPP. Participants to the GPHA are contributing in three different ways: to the overall coordination of the GPHA, as Lead Scientists of a given team, or as Experts involved in one of the GPHA teams.

The GPHA work is led by a **Coordination group**:

Serge Savary (INRAE, France; GB Pant University of Agriculture & Technology, India; UC Davis, USA); Didier Andrivon (INRAE, France); Paul D. Esker (PennState University, USA); Pascal Frey (INRAE, France); Daniel Hüberli (U. Western Australia); J Kumar (GB Pant University of Agriculture & Technology, and Graphic Era Hill University, India); Bruce McDonald (ETH, Zürich, Switzerland); Neil D. McRoberts (UC Davis, USA); Andy Nelson (Twente University, the Netherlands); Sarah J. Pethybridge (Cornell University, USA); Vittorio Rossi (Università Cattolica del Sacro Cuore, Italy); Pepijn Schreinemachers (World Vegetable Center, Thailand); Laetitia Willocquet (INRAE, France; GBPUAT, India).

The Coordination group is supported by a **Scientific Secretariat**: Laetitia Willocquet; Federica Bove (Università Cattolica del Sacro Cuore, Italy); Sonam Sah (GB Pant University of Agriculture & Technology, India); Serge Savary; and Manjari Singh (GB Pant University of Agriculture & Technology, India).

Lead scientists, who are lead authors of reports in this book, as well as **Experts** associated to the report writing, are listed in Table 1.

Some **key features** of the GPHA are:

- All terrestrial ecosystems in the world are considered. These are referred to as "Plant Systems", which can be human-made (such as agricultural systems, household gardens, or again, urban forests) or not (that is, ecosystems where human perturbations are limited, such as tropical rain-forests).
- Among the human-made ecosystems considered, we address: (1) agrosystems, (2) peri-urban horticulture (3) household (kitchen) gardens, and (4) urban vegetation. The Assessment attempts to address all these different forms of Plant Systems. The Assessment also considers a range of forest systems across the world, which involve varying degrees of human intervention.
- Plant health is seen through the lens of infectious plant diseases. However, because plant health is not restricted to infectious diseases, attention is also paid when appropriate to factors, biological (e.g., insects), physical (e.g., droughts, fires, and floods), and chemical (e.g., pesticides, ozone), which may influence the course of healthy life of plants.

The **concepts and guiding principles** of the GPHA can be summarised in a few points:

- The Global Plant Health Assessment is entirely based on volunteered time, mainly from members of the ISPP.
- The Coordination group is interdisciplinary, involving expertise in, e.g.: Geography, Climatology, Sociology, Environmental Sciences, Systems Sciences, and in Plant Pathology: Integrated Pest Management, Molecular Plant-Pathogen Interactions, Epidemiology, and Crop Loss Analysis. Members of the coordination group come from very different parts of the world.
- The project uses the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) as a template in its construction and development: first, a series of Ecoregions of the world have been defined; and second, key "PlantSystems" have been identified, in each of these Ecoregions.
- For each identified [PlantSystem x Ecoregion] pair, teams have been established, involving a Lead Scientist mobilising a few (2-3) Experts.
- Each team produced a report on the state of plant health in a chosen [PlantSystem x Ecoregion]. These reports are standardised in format and size, and address a specified, limited set of questions.
- Standardisation of reports is a critical way to: (1) minimise the (volunteered) time inputs of every Lead Scientists and Experts; (2) produce homogeneous reports in their formats and sizes, which (3) enables comparisons of plant health. These comparisons may be made across Ecoregions for similar plant systems, or across plant systems within Ecoregions.
- Results of the Global Plant Health Assessment must be verifiable and transparent. Each report must therefore be grounded on scientific, published, evidence.
- The GPHA considers the health of plants from the angle of infectious diseases in their effects on plant health. It does not consider abiotic stresses. Non-infectious, biotic and abiotic factors, however, are considered as factors of infectious diseases and their consequences.
- The assessment therefore concentrates on viruses, bacteria, fungi, oomycetes, nematodes, as well as on organisms (e.g., parasitic plants) which behave (specialisation/adaptation) as plant pathogens. Vectors of plant pathogens are also full part of the GPHA.

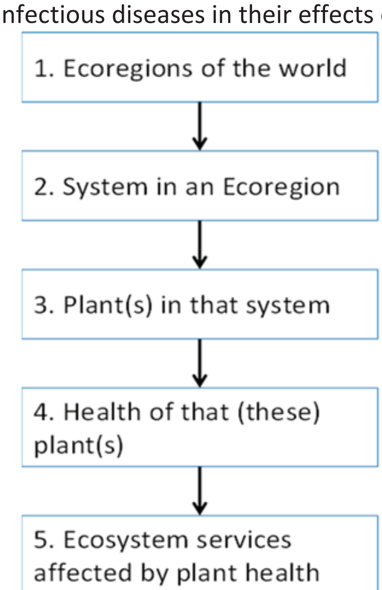

Figure 1. Steps in the Global Plant Health Assessment

Critically, the assessment considers plant health as a whole. The GPHA does not focus on individual, specific plant diseases, even though these are necessarily included in the assessment. Direct reference to specific plant disease or pathogen may occur when judged appropriate (as in the case of key diseases, major threats, or potentially grave and emerging diseases). As in the Millennium Ecosystem Assessment, plant health assessment is built from the collection of science- and fact-based expert opinions on the state of health of plants in specified plant systems within chosen ecoregions of the world.

The assessment does not attempt to address all plant species in the biosphere. Instead, the GPHA considers keystone plant species, the status of 'keystone' being assigned to plants that play a critical role in natural (including managed) ecosystems or in human-made agro-ecosystems. The approach therefore follows a series of steps as shown in Figure 1.

Recognising that plant health is an abstraction which cannot be quantitatively measured, the GPHA Project (1) is designed to produce qualitative assessments based on verifiable, published data, and (2) focuses on the consequences of plant health on ecosystem services (provisioning, regulating, and cultural), because these can be quantified.

As a result, 26 [PlantSystem x Ecoregion] reports were developed, considering 33 [PlantSystem x Ecoregion] (Figure 2), including: (1) cereal systems; (2) roots and tubers, banana and plantain systems; (3) fruit trees and grapes; (4) peri-urban horticultural systems and household gardens; (5) urban vegetation; and (6) forest systems in (a) North America, (b) Central and South America, (c) sub-Saharan Africa, (d) Europe, (e) South, East and Southeast Asia, and (f) Australasia.

Figure 2. Plant Systems assessed across Ecoregions of the world

Steps taken to develop and conduct the Global Plant Health Assessment

The conduct of the GPHA included two main groups of steps: first the conceptualisation, methodology development, and building of a network of contributors, and second the development of the reports.

Identification of Ecoregions, Plant Systems and Lead Scientists

1. The choice of Ecoregions is based on climatic and ecological environments, as well as on the social and economic context (10 Ecoregions defined).

2. Choice of PlantSystems: a selection of plant-based systems that matter most to human societies in terms of ecosystem services (8 major PlantSystems defined).

3. Prioritisation, among the (10 x 8 = 80) [PlantSystem x Ecoregion] resulting combinations, of those which are most relevant, based on human population, biodiversity, agriculture and food production, food consumption, and size of ecosystem services.

4. Within each prioritised [PlantSystem x Ecoregion] combination, identification of a reference (keystone) plant, or reference type of plants on which plant health is to be assessed.

5. Within each prioritised [PlantSystem x Ecoregion] combination, identification of a Lead Scientist who will co-ordinate the assessment of plant health in this specific [PlantSystem x Ecoregion] combination.

Development of reports

Reports were developed according to the following main steps:

1. Building of teams by Lead Scientists with Experts for each [PlantSystem x Ecoregion] combination.

2. Writing of reports according to a standardised procedure developed by the Coordination Group (**see Annex**). The metric to assess plant health is based on the ecosystem services generated by the Plant System, their increase, stability, or decrease. The considered ecosystem services belong to three broad groups: Provisioning (of food, fibre, materials), Regulating (of the climate, biodiversity, water, soils, pollutions), and Cultural (spiritual and cultural value, beauty, and re-creation).

3. Peer-review of reports: All reports are internally peer-reviewed. Peer review is led by one member of the Coordination as an Editor who identifies a Lead Scientist who acts as a Reviewer of a report she/he has not been involved into. Revisions are requested to each Lead Scientist by the Editor, and each report is revised accordingly to the Editor's satisfaction.

4. Presentation and discussion of reports during a Workshop held in October 2021 in Toulouse, France (see box below).

5. Final edition of reports.

ISPP Global Plant Health Assessment Workshop & International Conference held at the Toulouse School of Economics, France, 5 - 8 October 2021.

Both the Workshop (5-7 October 2021) and the Conference (8 October) were held in a hybrid format, with physically attending or remotely connected participants.

Participants to both events represented a diversity of facets in the plant sciences (plant biology, agriculture, forestry, ecology) and of institutions from academia, national institutes, NGOs, and international research.

The Workshop included presentations and discussions on 26 reports, as well as discussion sessions in workgroups, some of which had initiated exchanges prior to the Workshop: (1) Analysis and synthesis across reports, (2) Risks associated with plant health, (3) Initial work on policy recommendations, and (4) Dissemination of results from the GPHA.

The GPHA Conference (October 8) was open to the scientific public. It included keynotes and discussion panels on cross-cutting themes related to the GPHA: Climate change and plant health; Plant health and global food security; Plant health in a One Health world; The economics of plant health; Molecular plant pathology; State of plant diseases and their evolution across the world; Plant disease emergences; Population genetics and biodiversity; Plant disease risk assessment; Successes and failures in integrated pest management; Plant diseases in the networks of life and human societies; and Policies of plant health protection.

Further details of the Workshop and Conference are available on the GPHA website as well as in the ISPP Newsletter of December 2021 at: https://www.isppweb.org/newsletters/pdf/51_12.pdf

Other sources of information

Website for further details: The Global Plant Health Assessment is housed at: https://sites.google.com/view/global-plant-health-assessment/home

or, alternatively *via* the ISPP website newsletters: https://www.isppweb.org/

Reference

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

Table 1. Participants to the Global Plant Health Assessment

Name	Country	Affiliation	Role*
Ivette Acuña	Chile	Inst. de Invest. Agropecuarias, Osorno	E
Jorge Andrade-Piedra	Peru	International Potato Center (CIP), Lima	E
Didier Andrivon	France	INRAE, Rennes	C, KS
A. Elizabeth Arnold	USA	U. of Arizona	E
Jacques Avelino	France	CIRAD	L
R. Bandyopadhyay	Nigeria	International Institute of Tropical Agriculture	E
Clive Bock	USA	USDA ARS	L
Federica Bove	Italy	U. Piacenza	S
T. Brenes-Arguedas	Spain	UC Davis, California	L
Agnès Calonnec	France	INRAE, Villenave d'Ornon	E
Angus Carnegie	Australia	NSW Dept Primary Industries	L
Nancy P. Castilla	the Philippines	International Rice Research Institute	E
Xianming Chen	USA	USDA Washington	L
Helvecio Della Coletta-Filho	Brazil	Centro de Citricultura	E
Phyllis D. Coley	USA	U. of Utah	E
Kerik (Denton) Cox	USA	Cornell AgriTech	E
Triona Davey	United Kingdom	SASA, Edinburgh	E
Emerson Del Ponte	Brazil	U. Viçosa	L
Sandra Denman	United Kingdom	Forest Research, Alice Holt, Surrey	E
M-L. Desprez-Loustau	France	INRAE, France (Ret.)	L
Megan Dewdney	USA	U. of Florida	E
Annika Djurle	Sweden	SLU	E, KS
André Drenth	Australia	University of Queensland, Brisbane	E
Alexis Ducousso	France	INRAE, Cestas	E
Paul Esker	USA	PennState U.	C, L
Komi Fiaboe	Cameroon	IITA, Yaoundé	E
Josep Armengol Forti	Spain	U. Politècnica de València (UPV), Valencia	E
Sautua Francisco	Argentina	U. de Buenos Aires	E
Susan Frankel	USA	USDA	L
Pascal Frey	France	INRAE	C, L
Sara García-Figuera	USA	UC Davis, California	L
Paul Hendrik Fourie	South Africa	Citrus Research International & U. Stellenbosch	E
Karen Garrett	USA	U. Florida	L, KS
Maxime Guérin	France	Plante & Cité, Angers	E
Hans Hausladen	Germany	TUM School of Life Sciences, Freising	E
Daniel Hüberli	Australia	U. Western Australia	C
Jennifer Juzwik	USA	U.S. Forest Service, St. Paul	E
Zhensheng Kang	China	Northwest A&F U., Yangling	E
Lawrence Kenyon	Taiwan	World Vegetable Center	L, E
Jan Kreuze	Peru	Intl. Potato Center (CIP), Lima	E
Peter Kromann	The Netherlands	Wageningen University & Research	L
Jerome Kubiriba	Uganda	Nl. Ag. Research Organization (NARO), Kampala	E
Paulo Kuhnem	Brazil	Biotrigo Genética, Passo Fundo	E
Lava Kumar	Nigeria	International Institute of Tropical Agriculture	L, E
Jatinder Kumar	India	GB Pant U. of Agriculture and Technology	C, E
Marc-Henri Lebrun	France	INRAE, Grignon	KS
Anna Leon	USA	Weyerhaeuser Com	E
Wubutu Bihon Legesse	Ethiopia	World Vegetable Center	L, E
James Legg	Tanzania	Intl. Inst. of Tropical Agriculture, Dar es Salaam	L
Zhanhong Ma	China	China Ag. U., Beijing	L
George Mahuku	Tanzania	Intl. Inst. of Tropical Agriculture, Dar es Salaam	E
Robert O. Makinson	Australia	Australia Network for Plant Conservation, Sydney	E

Carmona Marcelo	Argentina	U. de Buenos Aires	E
Cristina Marzachì	Italy	Instit. Protezione Sostenibile delle Piante, Torino	E
Bruce McDonald	Switzerland	ETH, Zürich	C, KS
Neil McRoberts	USA	UC Davis, California	C
Abebe Menkir	Nigeria	Intl. Inst. of Tropical Agriculture	E
Alexey Mikaberidze	United Kingdom	U. of Reading	KS
Isabel (Alvarez) Munck	USA	USDA Forest Service	E
Andy Nelson	The Netherlands	Twente U.	C, KS
Emer O'Gara	Australia	Parks and Wildlife Service, Perth	E
Peter Ojiambo	USA	North Carolina State U.	E
Alejandro Ortega-Beltran	Nigeria	International Institute of Tropical Agriculture	E
Pierce Paul	USA	Ohio State U.	E
Sarah Pethybridge	USA	Cornell U.	C
Jean Pinon	France	INRAE, Champenoux (retired)	E
Srinivasan Ramasamy	Taiwan	World Vegetable Center	L, E
Tod Ramsfield	Canada	Natural Resources Canada	E
David M. Rizzo	USA	U. of California - Davis	E
Vittorio Rossi	Italy	U. Piacenza	C, L, KS, E
Irda Safni	Indonesia	Universiy of North Sumatra	E
Sonam Sah	India	GB Pant U. Agriculture & Technology (GBPUAT)	S, E
Alberto Santini	Italy	Nl. Research Council of Italy, Sesto Fiorentino	E
Serge Savary	France	INRAE, GBPUAT, UCDavis	C, L, S, E
Pepijn Schreinemachers	Thailand	World Vegetable Center	C, KS, E
Manjari Singh	India	GBPUAT	S, E, KS
Erin R. Spear	USA	Smithsonian Tropical Research Inst.	E
Giles E. St.J. Hardy	Australia	Murdoch U.	E
Nga Thi Thu Nguyen	Vietnam	Can Tho U.	E
Leena Tripathi	Tanzania	IITA, Dar es Salaam	L
Antonio Vicent	Spain	Instituto Valenciano de Investigaciones Agrarias	E
Altus Viljoen	South Africa	Stellenbosch U.	E
Laetitia Willocquet	France	INRAE, Toulouse	C, L, S
Alex Woods	Canada	BC Public Service British Columbia	L
Boming Wu	China	China Ag. U., Bejing	E
Xianchun Xia	China	Chinese Academy of Ag. Sciences	E
XiangMing Xu	United Kingdom	Nl. Inst. of Ag. Botany	L, E
Xiaoping Xu	China	Northwest A&F U., Yangling	E
Jonathan Yuen	Sweden	SLU	KS, e-book
Paul-Camilo Zalamea	USA	U. of South Florida	E
Changyong Zhou	China	Southwest University	E

* C: GPHA Coordination; L: Lead Scientist; E: Expert; S: GPHA Scientific Secretariat; KS: Keynote Speaker (8 oct 2021 Conference)

Reports

Banana and Plantain System in Sub-Saharan Africa

Lead Author: **Leena Tripathi**, L.Tripathi@cgiar.org; International Institute of Tropical Agriculture (IITA), Nairobi, Kenya

Contributing Authors:

- **Altus Viljoen**, altus@sun.ac.za; Stellenbosch University, South Africa
- **Lava Kumar**, L.Kumar@cgiar.org; International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria
- **George Mahuku**, G.Mahuku@cgiar.org; International Institute of Tropical Agriculture (IITA), Kampala, Uganda
- **Jerome Kubiriba**, jkubiriba@kari.go.ug; National Agricultural Research Laboratories (NARL), National Agricultural Research Organization (NARO), Kampala, Uganda

Background information

Banana (*Musa* spp.), including plantain, is one of the major staple food crops grown in 40 countries in sub-Saharan Africa (SSA), with an annual production of 44 million tonnes on 6.4 million hectares of land that feeds over 70 million people (FAOSTAT 2018). Africa produces a third of the world's bananas, East Africa being the largest banana-growing region, accounting for about 40% of aggregate production in Africa. Banana provides 30-60% of the daily per capita calorie intake in some of the East African countries such as Burundi, Rwanda, and Uganda with the greatest consumption at 220-460 kg per person annually (Abele and Pillay 2007; Kilimo Trust 2012). Banana and plantain are mainly cultivated by smallholder farmers for household consumption and for local or regional markets; only about 15% of the banana production enters international markets. It is a valuable component of food security and is also a cash crop, widely traded within countries from regions of sufficiency to areas of deficiency. Banana has a strong potential to provide raw material to the emerging agro-industry in SSA. Banana and plantain can be cultivated in diverse environments and produces fruits throughout the year in favourable weather conditions.

This report mainly covers the Provisioning Services for banana and plantain in sub-Saharan Africa.

PlantSystem considered in this report

Banana and plantain are non-woody herbaceous, perennial plants of the genus *Musa* under the family *Musaceae*. They are mostly a tropical plants that grow well in a temperature range of 15°C – 35°C with relative humidity of 75-85%. All cultivated bananas are either diploid or triploid hybrids between sub-species of *Musa acuminata*, or between *M. acuminata* and *M. balbisiana*. Banana and plantain originated from Southeast Asia. West-Central Africa is considered a

A banana plantation in Uganda (photo: George Mahuku) secondary diversification hub for plantain, and East Africa is a secondary hub for East African Highland bananas (EAHB). Hundreds of banana cultivars are grown and consumed worldwide, but large-scale banana farmers mainly grow the Cavendish type of dessert bananas for local and international commercialization. Plantain, however, is frequently grown in Central and West Africa, while East African Highland bananas are cultivated in east Africa. Other dessert banana varieties such as Sukali Ndiizi and Gros Michel are also grown at small scale in Africa. Plantain and EAHB represent approximately 70% of all bananas grown in Africa. Banana and plantain are rich source of carbohydrates, fibre, potassium, vitamins (vitamin B6, vitamin C), and various antioxidants.

Banana and plantain health in sub-Saharan Africa

State of banana and plantain health in the past 30 years

Banana yields are only 9% of the potential 70 $t.ha^{-1}$ per year. A major cause for low yields are diseases and pests. The most important pest and disease constraints of banana are Fusarium wilt, bacterial wilt, nematodes, weevil, black Sigatoka and Banana Bunchy Top Disease (BBTD) (Hauser et al 2019). Banana Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *cubense* (Foc), is most damaging to dessert varieties intended for fresh consumption, processing and export such as Gros Michel (AAA), Sukali Ndizi (Ney Poovan ABB), Kayinja (Pisang Awak ABB) and Cavendish bananas (AAA), as well as the cooking banana Bluggoe (AAB) (Blomme et al 2013). Foc race 1 is widely distributed in Africa on susceptible banana cultivars (Blomme et al 2013). A highly virulent Foc strain, called tropical race (TR4), was detected in Mozambique in 2013 (Viljoen et al 2020), and later in Mayotte Island off the east African coast (Aguayo et al 2020). Most bananas grown in SSA, such as the triploid EAHBs (called Matooke bananas) in East Africa, and the plantains and Cavendish bananas in West Africa, are not affected by Foc race 1. However, Cavendish bananas are severely affected by TR4 in northern Mozambique and by sub-tropical race (STR4) in South Africa.

Fusarium wilt symptoms on banana plants infected by Fusarium oxysporum f. sp. cubense (Foc), tropical race 4 (photo: George Mahuku)

Banana Xanthomonas wilt (BXW), caused by *Xanthomonas vasicola* pv. *musacearum,* is currently devastating banana production in East and Central Africa (Tripathi et al 2009). Yield losses can reach 100% in the infected fields, and its effects are worse during seasons of high rainfall. Losses to BXW have been estimated to be 2-8 billion US dollars (Abele and Pillay 2007). Because no highly resistant cultivars are available, the emphasis has been placed on cultural methods for containing the spread of the disease.

Yellow Sigatoka (caused by *Mycosphaerella musicola*) and Black Sigatoka (or Black Leaf Streak, caused by *Pseudocercospora fijiensis*) are widespread and maximum yield losses range between 33% and 80%. Yield losses from sigatoka have been increasing over the last few decades and are widespread. The adaptation range of *P. fijiensis* has been expanding into the cooler highlands, where the disease was previously absent (Kimunye et al 2020).

Important pests that may devastate banana plantations include weevils (*Cosmopolites sordidus*) and nematodes. Bananas are also affected by a combination of nematode species. The most damaging nematode species are *Radopholus similis* (burrowing nematodes), *Helicotylenchus multicinctus* (spiral nematodes) and *Pratylenchus* spp. (lesion nematodes). There is also evidence indicating that *Pratylenchus coffeae* is becoming more aggressive and widespread, replacing *R. similis* in importance. Maximum losses from nematodes range 25% to more than 80% (Jones 2009). The banana weevil (*Cosmopolites sordidus*) is the most important insect pest. Yield losses higher than 40% may occur in ratoon cycles (Gold et al 2004).

Four viruses have been reported on banana in SSA, the *Banana bunchy top virus* (BBTV), the *Banana streak virus* (BSV), the *Banana mild mosaic virus* (BanMMV) and the *Cucumber mosaic virus* (CMV) (Kumar et al 2015). With the exception of BBTV, all other three viruses are known to be widely distributed and are considered endemic. These three endemic viruses are not known to cause economically significant damage. No control efforts are implemented other than virus indexing for certification of planting material meant for domestic and international distribution. Of all these banana viruses, banana bunchy top disease (BBTD), caused by BBTV (genus *Babuvirus*), is the most critical and widespread viral disease of banana. Fruit production in infected plants are reduced by 70% to 100% within one season. All types of *Musa* cultivars grown in SSA are susceptible to BBTV. BBTV is transmitted by the banana aphid, *Pentalonia nigronervosa* and by vegetative propagation. BBTV disease is endemic in Central Africa since its appearance in the 1960s, contributing to production decline by 40% to 70% in the affected farms, and is emerging in West and Southern Africa. The banana bunchy top disease is considered invasive, which threatens the entire Eastern African sub-region. Over the last decade, BBTD has spread to at least eight countries (Benin, Cameroon, Mozambique, Nigeria, South Africa, Tanzania, Uganda and Zambia). The virus was also detected in Togo in 2018, but early detection and eradication prevented disease establishment.

Symptoms of banana plants infected by banana bunchy top virus (BBTV) (photo: Lava Kumar)

Reliable information on the general status of pathogens and pests in banana in the mainstream or informal literature is very limited. This hampers the understanding of changes in the banana health status during the past 30 years. However, the emergence of three major diseases (BXW, BBTD and Fusarium wilt TR4) in the various sub-regions of SSA has been documented to cause serious production losses in the past three decades. Empirical evidence suggests a decrease in production by up to 50% to 80% in the areas and farms affected by these diseases. Losses result from direct damage by the pathogens; indirect losses leading to decreased production results from farmers abandoning banana cultivation and shifting to other crops (e.g., to maize in BBTV affected central Malawi), an escape strategy which results from the lack of viable control measures to contain these diseases.

Evolution of banana and plantain health over the recent 10 years

Since the 2000s, the pest and disease levels and the damage they cause to the life-times of plantations and to banana yields have been increasing because (1) of the build-up in the population of endemic pathogens and pests, and (2) the emergence of pathogens, combined with (3) changes in climatic conditions, the increase of temperature, in particular (Erima et al 2017). Banana farming therefore faces multiple and increasing challenges in low altitude areas with weevils, nematodes, and Fusarium wilt (race 1). New diseases emerged as new threats since the 2000s, including the first report in Africa such as BXW in East Africa, BBTV in Eastern, Southern and Western Africa, and TR4 in Mozambique and Mayotte Island (Aguayo et al 2020).

Fusarium wilt can only be controlled by replacing susceptible with resistant banana varieties. A classical example is the replacement of Gros Michel (vulnerable to race 1) with Cavendish bananas in the mid-1900s. In the past decade, Sukali Ndizi, a popular and high-income dessert variety, is being replaced with Matooke bananas in East Africa when production is rendered impossible in small-grower fields. In northern Mozambique, TR4 susceptible Cavendish banana cultivars are also being replaced with Cavendish somaclones from Taiwan (Viljoen et al 2020). However, the response of cooking bananas and plantains against TR4 has not yet been extensively studied. TR4 may thus pose a significant threat to banana production on the entire continent. Where consumer preferences prevent the replacement of favoured susceptible varieties by less-favoured resistant ones, growers have no other choice than replace banana cultivation with less profitable crops. The threat of TR4 has caused panic among banana growers; its threat to smallholder farms in countries such as Tanzania is very real. TR4 was recently detected in a smallholder farmer's field in the Nampula province, —Mozambique. Given porous borders and the absence of effective quarantine systems, the threat of TR4 entering into smallholder production systems in East Africa is high.

The severity of sigatoka-like leaf spots have been on the increase. The pathogen (*P. fijiensis*) has expanded its range to new areas where it previously was not observed. A recent study revealed that the adaptation range of *P. fijiensis*, previously confined to elevation below 1350 m ASL, had expanded into the cooler highlands (at elevation higher than 1800 m ASL; Kimunye et al 2020). These highlands are the area where most of the susceptible EAHBs are grown by smallholder farmers. In addition, some of the previously sigatoka-resistant banana cultivars, such as Yangambi Km5 have been found susceptible, suggesting the emergence of new and virulent pathotypes of *P. fijiensis*.

Similarly, BBTV is spreading further in SSA. Its presence is confirmed in Southern Africa (Angola, Mozambique, South Africa, and Zambia) and West-Central Africa (Benin, Cameroon, and Nigeria). Presence of the virus is also confirmed in Tanzania and Uganda in 2020-21, which signifies incursion of the virus into East Africa. Within-countries expansion of BBTV has also been reported, as in Malawi, where it has reached both the banana-rich north and the southern regions, where it is a threat to banana diversity. Challenges in diagnosis, in containment, and in eradication efforts, resulted in unabated expansion of BBTV in SSA. BXW continues to cause large losses too. Complete losses and elimination of mats were reported recently in Burundi. BXW has however been brought under control, with incidence reduced from over 70% in 2005 to less than 5% today, in many bananas growing areas of Uganda using cultural control practices. Resurgences however have been recorded, and more may occur unless resistant varieties are developed and deployed.

Symptoms of Xanthomonas wilt (BXW) on banana plants (photo: Jaindra Tripathi)

Ecosystem services, as affected by plant disease

Provisioning **Regulating**

Level of ecosystem services generated by banana and plantain, as affected by plant disease, in the past 30 years

The overall increase in banana production since the 1960s in SSA has taken place despite a significant crop yield decline over the past 30 years. As indicated above, actual annual banana yields in farmer's fields are about 9% (range: 7.7 – 15.9 $t.ha^{-1}$) of the potential 60-70 $t.ha^{-1}$ (Van Asten et al 2005). Low banana yields result from multiple factors, including poor soil, low water availability, losses from pests, and diseases. Shocks from pests and diseases, especially BBTV, BXW, black Sigatoka and Fusarium can lead to 100% yield losses. Fusarium wilt is one of many diseases that led to a decline in production of banana in Africa. Once introduced into a field, the fungus cannot be eradicated, and production will decline until further production is not possible. There were major geographical shifts of banana cultivation in Uganda over decades from lowlands to highlands and this is in part the result of the build-up of multiple pests and diseases in the lowlands. This then lead to a shift of the provisioning ecosystem services; food, fibre and others, to new areas of banana production. BXW was reported to have disrupted ecosystems as it massively cleared plantations, especially in hilly areas of Burundi.

This degradation of the situation has not, so far, led to an overall decline of production, and we can assess the overall level of provisioning service as "fair".

Evolution of the level of ecosystem services generated by banana and plantain, as affected by plant disease, over the recent 10 years

Overall, the production of banana has been congruent with the rapid population growth of SSA. With respect to the provisioning ecosystem service, we can assess the current status as "stable".

Maintaining the overall banana production to acceptable levels concurrently with population growth in SSA has come at a very large cost: forests and natural ecosystems have been cleared for agriculture, thus eliminating services (water, soil, climate) that these ecosystems provided. The displacements of banana cultivation has also come at environmental costs as well, because of the very ecosystem services (soil conservation, soil moisture) that banana plantations, with their long term cycles, ensure, especially in small farms and household and kitchen gardens.

Although all these impacts have not been specifically analysed in relation with banana cultivation, the ecosystem services other than provisioning have declined during the period.

Complementary information

Banana production is seriously affected by combined biotic factors (pathogens and pests), abiotic stresses (drought and low soil fertility), genetic challenges (narrow genetic diversity in germplasm), and socio-economic and market challenges (inadequate availability of clean planting material) for smallholder farmers. Changes in climate has a significant impact on banana yields where the crop is grown with minimal or no irrigation. Extreme weather events may further reduce the basal resistance of banana against pathogens. The evaluation of disease-resistant varieties of banana under sub-optimal environmental conditions (i.e., under the pressure of abiotic yield limiting factors such as drought, low soil fertility) is required. This will enable the breeding of improved banana varieties which will resist combinations of abiotic and biotic constraints.

We are very confident with own assessment of the findings of the present report as many studies and publications support our views.

References

Abele S, Pillay M (2007) Bacterial wilt and drought stresses in banana production and their impact on economic welfare in Uganda: Implications for banana research in East African highlands. J Crop Improve 19:173–191 https://doi.org/10.1300/J411v19n01_09

Aguayo J, Cerf I, Folscher AB, Fourrier-Jeandel C, Ioos R, Matthews MC et al (2020) First report of *Fusarium oxysporum* f. sp. *cubense* tropical race 4 (TR4) causing banana wilt in the Island of Mayotte. doi: 10.1094/PDIS-06-20-1196-PDN

Blomme G, Ploetz R, Jones DR et al (2013) A historical overview of the appearance and spread of *Musa* pests and pathogens on the African continent. Highlighting the importance of clean *Musa* planting materials and quarantine measures. Ann Appl Biol 162:4–26 https://doi.org/10.1111/aab.12002

Erima R, Kubiriba J, Komutunga E et al (2017) Banana pests and diseases spread to higher altitudes due to increasing temperature over the last 20 years. Afr J Environ Sci Technol 11:601-608 https://doi.org/10.5897/AJEST2016.2173

FAOSTAT Agriculture Data (2018) Accessed online at: http://www.fao.org/faostat/en/#data/QC2

Gold CS, GH, Kagezi GH, Night G et al (2004) The effects of banana weevil, *Cosmopolites sordidus*, damage on highland banana growth, yield and stand duration in Uganda. Ann Appl Biol 145:263-269 https://doi.org/10.1111/j.1744-7348.2004.tb00382.x

Hauser S, Gold C, Pasberg-Gauhl C et al (2019) Identifying and managing plant health risks for key African crops: banana and plantain. In: Neuenschwander, Tamò (eds) Critical Issues in Plant Health: 50 years of Research in African Agriculture. Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp 229–258

Jones DR (2009) Diseases and pest constraints to banana production. Acta Hortic 828:21-36 DOI: 10.17660/ActaHortic.2009.828.1

Kilimo Trust (2012) Banana Value Chain(s) in the EAC: Consumption, Productivity and Challenges. http://www.kilimotrust.org/

Kimunye JN, Were E, Mussa F et al (2020) Distribution of *Pseudocercospora* species causing Sigatoka leaf diseases of banana in Uganda and Tanzania. Plant Pathol 69:50-59. DOI: 10.1111/ppa.13105

Kumar PL, Selvarajan R, Iskra-Caruana ML et al (2015) Biology, etiology and control of virus diseases of banana and plantain. Adv Vir Res 91: 229-269. https://doi.org/10.1016/bs.aivir.2014.10.006

Tripathi L, Mwangi M, Abele S et al (2009) Xanthomonas wilt: a threat to banana production in east and central Africa. Plant Dis 93:440–451. https://doi.org/10.1094/PDIS-93-5-0440

Van Asten PJA, Gold CS, Wendt J et al (2005) The contribution of soil quality to yield and its relation with other banana yield loss factors in Uganda. In: Blomme G, Gold CS, Karamura E (eds) Proceedings of a workshop held on farmer participatory testing of IPM options for sustainable banana production in Eastern Africa. Seeta, Uganda, 8–9 December 2003. International Plant Genetic Resources Institute, Montpellier, pp 100–115

Viljoen A, Mostert D, Chiconela T et al (2020) Occurrence and spread of the banana fungus *Fusarium oxysporum* f. sp. *cubense* TR4 in Mozambique. S Afr J Sci 116:1-11. https://doi.org/10.17159/sajs.2020/8608