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Roots, Tubers and Bananas

CGIAR

Workshop Report

Adaptation to Pest Risks under Future Climates in Africa

28–30 May 2014

Kampala, Uganda

CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY

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The workshop was conducted with the active participation of scientists from the following CGIAR centers as well as from international organizations and national agricultural research systems:

Workshop reports aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

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ACRONYMS

BMZ	German Federal Ministry for Economic Cooperation and Development
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Research
CIP	International Potato Center
CRP	CGIAR Research Programs
CRP-RTB	CGIAR Research Program on Roots, Tubers and Bananas
DLCO-EA	Desert Locust Control Organization for Eastern Africa
ERI	Establishment Risk Index
FAO	Food and Agriculture Organization of the United Nations
GI	Generation Index
GIS	Geographic Information System
ICIPE	International Centre of Insect Physiology and Ecology
IITA	International Institute of Tropical Agriculture
ILCYM	Insect Life Cycle Modeling (software)
IPPC	International Plant Protection Convention
NARO	National Agricultural Research Organization
NARS	National Agriculture Research Systems
NPPO	National Plant Protection Organizations
PRA	Pest Risk Analysis
RAB	Rwanda Agricultural Board

Abstract

A collaborative project, **Predicting climate change induced vulnerability of African agricultural systems to major insect pests through advanced insect phenology modeling, and decision aid development for adaptation planning**, funded by the German Federal Ministry of Cooperation and Development (BMZ), was implemented from 2010 to 2014 by the International Potato Center (CIP), Lima, Peru, with its partners at the International Centre of Insect Physiology and Ecology, Kenya, and the International Institute of Tropical Agriculture, Nigeria. The project further developed and extended the use and application of the free and open-source Insect Life Cycle Modeling (ILCYM) software. ILYCM was used to develop temperature-dependent pest phenology models for 19 important insect pests of agricultural and horticultural crops in Africa and to apply these models in Geographic Information Systems to understand better the impact of current and future climates on pest establishment, abundance, and spread potential. The objectives of the workshop were to inform stakeholders in plant health, plant quarantine, and pest management about future pest risks on global, regional, and local scales in Africa and to use this information for crop-specific adaptation planning and to define priorities in pest management. Climate change will aggravate the already serious challenges to food security and agricultural sustainability in Africa due to increasing pest problems, which was demonstrated for major pests of potato (potato tuber moth, *Phthorimaea operculella*; Guatemalan potato tuber moth, *Tecia solanivora*; Serpentine leafminer, *Liriomyza huidobrensis*; vegetable leafminer, *Liriomyza sativae;* Greenhouse whitefly, *Trialeurodes vaporarium*); sweetpotato (Sweetpotato whitefly, *Bemisia tabaci*); maize (Spotted stemborer, *Chilo partellus*; Maize stalk borer, *Busseola fusca*; African pink borer, *Sesamia calamistis*); cassava (Cassava mealybug, *Phenacoccus manihoti*; Cassava green mite, *Mononychellus tanajoa*); and fruits (Tephritid fruit fly, *Bactrocera invadens*). Owing to higher temperatures in future, pest incidence might also potentially decrease in certain regions. Detailed Pest Risk Analysis (PRA) results will be published in the forthcoming *Pest Distribution and Risk Atlas for Africa: Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates*. Participants discussed crop-specific adaptation plans and proposed five major recommendations for an action plan: (1) phenology modeling and pest risk mapping, including interactions with pests' natural enemies under current and future climates become important part of PRA implemented in the framework of International Plant Protection Convention; (2) establish a regional platform and network on pest risks under future climates, and create links and interactions with other climate change initiatives; (3) research needs identified during the workshop should be addressed in order to expand models to other major pests and to improve predictions of risks; (4) the capacity of National Plant Protection Organizations needs to be improved to adequately incorporate pest risk mapping results into adaptation planning to manage future pest risks on regional and country level; and (5) advocate for increased awareness of future pest risks under climate change and promote the inclusion of pest risk adaptation planning at country level under the relevant ministries.

Key words: *Pest risk analysis, pest modeling, climate change, adaptation planning, integrated pest management*

Acknowledgment

We gratefully acknowledge the financial support of BMZ for the project "Predicting climate change induced vulnerability of African agricultural systems to major insect pests through advanced insect phenology modeling and decision aid development for adaptation planning" in which the framework of this stakeholder workshop was conducted.

1. Workshop Background

Societies in Africa are highly dependent on agriculture, an activity traditionally vulnerable to unpredictable changes in climatic conditions. Any increase in temperature, caused by climate change, coupled with a decline in rainfall, will have direct and indirect drastic effects on crop production and hence food security. This will exacerbate existing vulnerabilities of the resource-constrained farmers who depend on agriculture for a living. On average, 30–50% of the yield losses in agricultural crops are caused by pests despite the application of pesticides to control them.

Climate, especially temperature, has a strong and direct influence on insect pest population development and growth. A rise in temperature, due to climate change, may both increase or decrease pest development rates and related crop losses. Further, an increase in temperature can potentially affect range expansion and outbreaks of many insect pests. Therefore, if adequate integrated pest management (IPM) strategies are not developed and made available to farmers, greater crop yield and quality losses could ultimately arise. Pesticides are out of reach for most subsistence farmers in Africa, causing them to rely on density-dependent suppression of pests provided by a range of natural enemies. Some of these natural enemies have been successfully naturalized in classical biocontrol programs for a wide range of crop pests. However, studies indicate that climate change can dissociate natural enemy-pest relationships, because of a higher sensitivity of natural enemies to climatic variability or of different temperature optima. This might negatively affect successful classical biocontrol programs.

The collaborative project "**Predicting climate change induced vulnerability of African agricultural systems to major insect pests through advanced insect phenology modeling, and decision aid development for adaptation planning**" is funded by the German Federal Ministry of Cooperation and Development (BMZ) and is being implemented by the International Potato Center (CIP), Lima, Peru, in collaboration with the International Centre of Insect Physiology and Ecology (*icipe*) and the International Institute for Tropical Agriculture (IITA). In the project pest risk assessments under potential future climates were conducted for a number of important insect pests of agricultural and horticultural crops in Africa using advanced pest phenology models and Geographic Information System (GIS) risk-mapping tools. The results of these investigations build a good foundation for understanding future pest risks on global, regional, and local scales and this information can be used for adaptation planning. To achieve food security in future and sustainable insect pest management under future climates, it is vital that all stakeholders work together to define priorities in pest management and adaptation planning.

2. Workshop Objectives

To inform stakeholders in plant health, plant quarantine, and pest management about future pest risks on global, regional, and local scales in Africa, and to use this information for crop-specific adaptation planning and to define priorities in pest management.

3. Methodology

The workshop was held on 28–30 May 2014, at the Royal Suites Hotel, Kampala, Uganda (see Annex 1). In total, 27 participants from 12 countries attended the workshop (see Annex 2). Participants included scientists and staff from the following: (1) CGIAR and affiliated centers—CIP, *icipe*, and IITA; (2) national agricultural research organizations (NAROs)—Rwanda Agricultural Board (RAB), Rwanda; NARO, Uganda; DLCO-EA, Ethiopia; Makota ARS, Malawi; (3) ministries of Agriculture—Burundi, DR Congo, Ethiopia, Malawi, Tanzania, Uganda; and (4) universities—Makerere University, Uganda.

The workshop program was divided into five major parts: (1) pest risk analysis (PRA) and modeling approaches to understand the impact of climate change on insect pests; (2) potential range expansion and abundance of pests in selected crops (potato and vegetables, maize, cassava, and fruits); (3) distribution and potential efficacy of pests' associated biocontrol agents under future climates; (4) country situation analysis on insect pests and changes due to climate change; and (5) adaptation planning and discussion of an action plan on "Adaptation to Pest Risks under future Climates in Africa."

Participants were introduced to objectives or programs of the workshop, which included the potential impact of climate change on insect pests, pest phenology modeling, and GIS approaches and methodologies used in the elaboration of a Pest Risk Atlas for Africa. This was followed by giving 12 pest-specific presentations all highlighting the impact of climate change on six, three, two, and one insect pests of potato and vegetable crops, maize, cassava, and fruits, respectively. Three other presentations followed to discuss the potential impact of climate change on beneficial insects (parasitoids). A synopsis on the current situation of insect pests in agricultural and horticultural crops and on priority pests under climate change for each country was presented by representatives of National Plant Protection Organizations (NPPOs) and NARS. These included the following aspects: (1) insect pests that have seemingly increased their prevalence, recurrence, and incidence during the past years probably due to climate change; (2) priority pests and main regions of incidence with respect to crops and cropping systems, extent and prevalence of damage, yield loss, and current control measures; (3) national capacities in terms of institutions/ laboratories dealing with insect pest management and climate change impacts, including diagnostics and surveillance; and (4) national adaptation plans in plant protection especially in insect pest management. In three parallel working groups, participants discussed and elaborated IPM adaptation plans for potato, maize, and cassava. In the plenary after presentations and discussions of the results by each working group, participants concluded the workshop with the formulation and adoption of workshop recommendations.

4. Results

4.1 Impact of climate change on insect pests

Climate change will aggravate the already serious challenges to food security and agricultural sustainability in Africa due to increasing pest problems and related crop yield and quality losses. Insect pests are exothermic organisms and cannot internally regulate their own temperature, instead they depend on the temperature of the environment to which they are exposed. Hence, any temperature increase (depending on a species optimal temperature of development) is expected to increase pest pressure in agricultural systems through:

- Range expansion of existing pests and invasion by new pests
- Accelerated pest development leading to more pest cycles per season
- Disruption of the temporal and geographical synchronization of pests and beneficial insects that increases the risk of pest outbreaks
- Promotion of minor pests to primary pests through reduced host tolerance and changes in landscape characteristics and land-use practices
- Increase of the susceptibility to pests in drought-stressed plants.

Climate change will affect temperatures differently at global and regional levels; agro-ecosystems and crops will have different vulnerability to pests under future climates. Further, temperature increases in already warmer tropical regions will increase insect abundance and activity proportionally more than in colder regions due to already higher metabolism rates of organisms. A scientific-based framework and tools to support a better understanding and predictions of climate change effects on pests and natural enemies on different scales will be crucial to adapt IPM.

4.2 Framework for PRA under future climates

The development and implementation of PRA is advocated by the International Plant Protection Convention (IPPC) (FAO 2007). But it does not yet provide and include a framework for assessing and predicting climate change impacts on insect pests (and diseases) (Fig. 1).

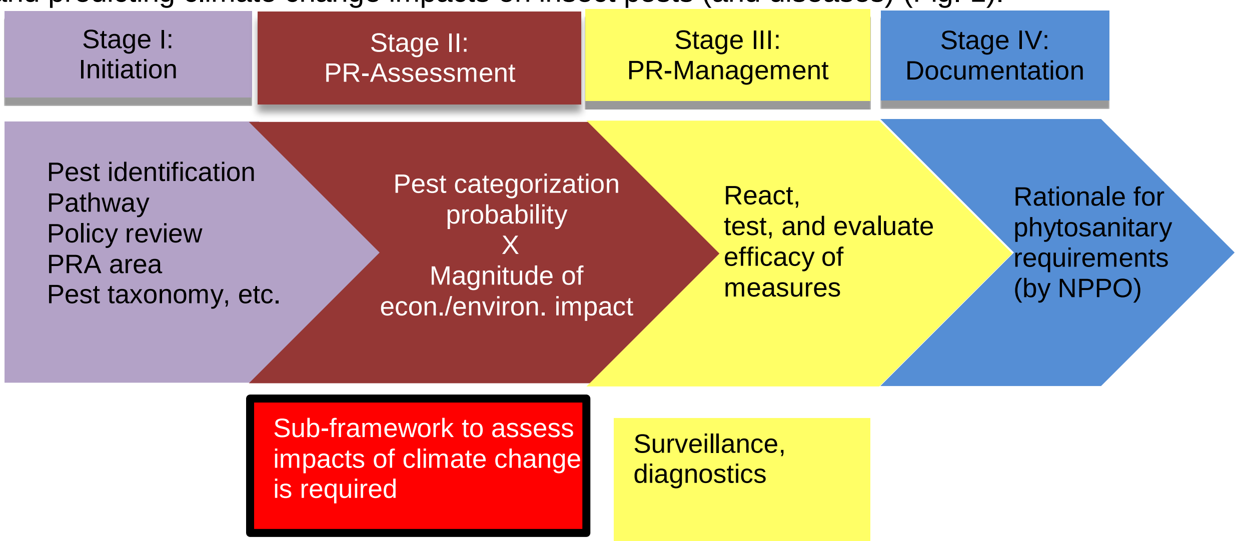

Fig. 1. Major stages of Pest Risk Analysis (adopted from FAO-IPPC 2007)

PRA is a science-based process that provides the rationale for determining phytosanitary measures for a specified PRA area. It is a process that evaluates technical, scientific, and economic evidence to determine whether an organism is a potential pest of plants and, if so, how it should be managed. The benefit of a PRA is to document all known information to help guide intervention strategies and to identify research gaps. New information that becomes available is used to update PRA document(s) to ensure that all appropriate knowledge is housed in a single location that is freely available to all in order to support the International Standards for Phytosanitary Measures of the IPPC.

4.3 The Insect Life Cycle Modeling (ILCYM) software as sub-framework for assessing the impact of climate on insect pests in PRA

A framework for assessing the impact of climate change on future pest risks must consider the establishment potential of an insect pest in a new environment, its potential spread after an introduction, and its economic impact in terms of pest abundance (Fig. 2). The ILCYM software, developed by CIP, allows a PRA to be conducted according to these criteria (Kroschel et al. 2013).

Likelihood of entry and establishment*	Consequences of establishment*
Entry potential	(3) Economic impact potential
(1) Colonization potential	Environmental impact potential
(2) Spread potential	Social impacts

*under current and future climates; 1–3 is considered in ILCYM Version 3.0 (www.cipotato.org/ilcym)

Fig. 2. Framework for a PRA under the aspect of climate change

Characteristics of ILCYM

ILCYM is a free, open-source computer-aided tool built on R and Java codes and linked to uDig platform, a GIS application that contains basic tools for mapping and managing geographic information (Sporleder et al. 2013; Tonnang et al. 2013). The software package comprises three modules:

1. The **model builder**, which facilitates the development of insect phenology models based on life table data derived from constant-temperature studies.
2. The **validation and simulation module**, which provides tools for validating the developed phenology model using insect life tables established at fluctuating temperature conditions.
3. The **potential population distribution and risk mapping module**, in which the phenology models are implemented in a GIS environment that allows for spatial global or regional simulations of species activities and mapping.

The relationship between aspects of insects' life-history (development, survival, reproduction, etc.) and environmental variables (temperature) can be well described by process-based phenology models. The **model builder** of the ILCYM software is a tool to support the development of process-based, temperature-driven, and age-stage–structured insect phenology models. ILCYM's model builder contains a library of empirical linear and non-linear models to define critical temperatures of insect development. Several statistical measures are provided for the estimation of parameters, the comparison and best selection of models. Further, phenology models can be applied for estimating insect population increase and abundance using deterministic and stochastic simulations under constant and fluctuating temperatures. Outputs of simulations are life table parameters that include net reproduction rate, mean generation time, intrinsic rate of increase, finite rate of increase, and the doubling time. Through these analyses, the biology and temperature requirements of insects in general (pest, natural enemies, etc.) can be defined. ILCYM also supports investigations to understand suitable release areas for natural pest enemies (e.g., parasitoids) and their potential efficiency to control pests in a given environment according to the prevailing temperature.

The **validation and simulation module** allows the evaluation of the ability of the developed phenology model to reproduce the insect species behavior under fluctuating temperature conditions. This is achieved by comparing experimental life table data obtained from fluctuating temperature studies with model outputs produced by using the same temperature records as input data. ILCYM stochastically simulates a user-defined number of life tables, each with a user-defined number of individuals, through rate summation and random determination for each individual's survival, development to the next stage, and sex.

In the ILCYM **potential population distribution and risk mapping module**, insect phenology models are simulated in a defined area according to grid-specific daily/monthly temperatures obtained from available climatic databases. From the estimated life table parameters, ILCYM calculates and maps three risk indices: (1) establishment risk (survival) index, *ERI*; (2) generation index, *GI*; and (3) activity index, *AI*. These indices are used to assess the potential establishment and population distribution, abundance, and spread of insect species.

ILCYM provides several GIS functionalities for vector and raster analysis—for example, to use shape files to map pest information only in those regions where target crops are grown (global crop maps). Additionally, a sub-module called "index interpolator" can be used to analyze the indices at high-spatial (pixel size of 90 m) and temporal resolution (daily data) for capturing and mapping small-scale population distribution and abundance of insects in, say, mountainous regions.

For spatial simulations under present climates, ILCYM uses temperature data obtained from WorldClim available at http://www.worldclim.org/. The database is a set of global climate layers (grids) with different spatial resolutions that contain monthly average minimum, maximum, and mean temperatures that were interpolated from historical temperature records worldwide (NOAA data) between 1950 and 2000. The data are well documented in Hijmans et al. (2005). For studying the effects of climate change on insects, the software provides downscaled future climate scenarios from different projections—for example, the SRES-A1B of the year 2050 (IPCC 2007), which was applied in all our presented studies included in the Pest Risk Atlas for Africa (see section 4.4). The predictions based on the WorldClim database are described by Govindasamy et al. (2003). The downscaling of data, which was conducted by Ramirez and Jarvis (2010), is freely accessible at http://gisweb.ciat.cgiar.org/GCMPage.

4.4 Pest distribution and Pest Risk Atlas for Africa

In the collaborative BMZ-funded project "Predicting climate change induced vulnerability of African agricultural systems to major insect pests through advanced insect phenology modeling, and decision aid development for adaptation planning," phenology models based on life table studies have been developed for a wide range of major pests of potato, sweetpotato, vegetables, maize, cassava, and fruit crops as well as for associated parasitoids used in classical biological control programs (33 species were considered). These models have been used to simulate life table parameters and to calculate and map their potential establishment and distribution, abundance, and spread under current (2000) and future (2050) climate change scenarios. These risk maps are being used for PRA of each of the pests. Results will be published in the *Pest Distribution and Risk Atlas for Africa: Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates* (see Annex 3). Advances in the risk mapping for selected pests and natural enemies have been presented and discussed at the workshop (see Annex 2).

Potential impact of climate change on major pests in target crops

In the workshop the potential range expansion and abundance due to climate change was presented for:

Potato and vegetable pests

Potato tuber moth, *Phthorimaea operculella*; Guatemalan potato tuber moth, *Tecia solanivora*; Serpentine leafminer, *Liriomyza huidobrensis*; vegetable leafminer, *Liriomyza sativae*; Greenhouse whitefly, *Trialeurodes vaporarium;* Sweetpotato whitefly, *Bemisia tabaci*

Maize pests

Spotted stemborer, *Chilo partellus*; Maize stalk borer, *Busseola fusca*; African pink borer, *Sesamia calamistis*

Cassava pests

Cassava mealybug, *Phenacoccus manihoti*; Cassava green mite, *Mononychellus tanajoa*

Fruit pest

Tephritid fruit fly, *Bactrocera invadens*

The analysis showed that climate change will affect the range expansion and abundance of pests; however, due to higher temperatures, pest incidence might also decrease in certain regions. Main shifts of the abovementioned pests are summarized in Tables 1–4 (pp. 11–12); detailed abstracts of the related presentations can be found in Annex 4.

4.5 Country synopsis

Annex 5 presents country synopses on important insect pests and aspects of climate change.

Table 1. Potential changes in range expansion and abundance of potato and vegetable pests in different regions, with special consideration of Africa, due to climate change for the SRES-A1B projection to the year 2050

Pest species	Change in establishment and abundance			
	Temperate	**Sub-tropical**	**Tropical**	**Africa**
Potato tuber moth, *Phthorimaea operculella*	Range expansion into temperate regions	Widely distributed; will increase its abundance and damage potential	Range expansion into tropical highland regions; increase of abundance and damage potential	Widely distributed; will increase abundance and damage potential
Guatemalan potato tuber moth, *Tecia solanivora*	No risk of establishment	Not yet infested. Likelihood for establishment is very low. Risk of establishment will be further reduced.	At low altitude risk of establishment and/or abundance decreases meanwhile at high altitudes risk or abundance increases	Not yet infested. Highland potato regions south of the equator are at risk of establishment. The risk will be further reduced.
Serpentine leafminer, *Liriomyza huidobrensis*	Range expansion into temperate regions, and increase of abundance and damage potential	Reduction of range expansion; will increase its abundance but decrease damage potential	Reduction of expansion; decrease of abundance and damage potential	Range expansion into southern countries; increase abundance and potential damage in central, eastern, and southern regions
Vegetable leafminer, *Liriomyza sativae*	Range expansion into temperate regions, and increase of abundance and damage potential	Slight range expansion; high increase of abundance and damage potential throughout the region.	Reduction of expansion, high increase of abundance throughout the region; reduction of damage potential	Range expansion into southern countries; high increase of abundance across region; damage potential will increase in eastern and southern countries
Greenhouse whitefly, *Trialeurodes vaporarium*	A slight range expansion	An expansion to south of Africa and south of Latin America; will increase its abundance and damage potential	A reduction in current high-risk areas in tropical regions; will decrease its abundance but its potential threat or damage potential remains	An expansion to southern countries of Africa; will increase its abundance and damage potential
Sweetpotato whitefly, *Bemisia tabaci*		An expansion to south of Africa and south of Latin America; will increase its abundance and damage potential	A slight expansion into tropical highland regions; will increase its abundance and damage potential	An expansion to southern countries of Africa; will increase its abundance and damage potential

Table 2. Potential changes in range expansion and abundance of maize pests in different regions, with special consideration of Africa, due to climate change for the SRES-A1B projection to the year 2050

Pest species	Change in establishment and abundance			
	Temperate	**Sub-tropical**	**Tropical**	**Africa**
Spotted stemborer, *Chilo partellus*	Range expansion into Mediterranean regions	Widely distributed in India, Southeast Asia and East and Southeastern Africa; will decrease abundance in dry lowland and increase abundance above 1,000 masl	Range reduction in dry lowland and expansion in mid- and high altitude; decrease in abundance in dry lowland and increase abundance above 1,000 masl	Distributed in East and southeastern Africa; will decrease abundance in dry lowland and increase abundance above 1,000 masl in East and Southeastern Africa
Maize stalk borer, *Busseola fusca*			Range reduction in lowland and expansion in higher altitudes;	Distributed in all sub-Saharan Africa; will decrease abundance and damage in

Pest species	Change in establishment and abundance			
	Temperate	**Sub-tropical**	**Tropical**	**Africa**
			decrease in abundance and damage in lowland and increase abundance and damage in altitude	lowland and increase abundance and damage in altitude areas.
African pink borer, *Sesamia calamistis*			Range reduction in lowland and expansion in altitude; decrease in abundance and damage in lowland and increase abundance and damage in altitude	Distributed in all sub-Saharan Africa; will decrease abundance and damage in lowland and increase abundance and damage in altitude areas and in Austral Africa

Table 3. Potential changes in range expansion and abundance of cassava pests in different regions, with special consideration of Africa, due to climate change for the SRES-A1B projection to the year 2050

Pest species	Change in establishment and abundance			
	Temperate	**Sub-tropical**	**Tropical**	**Africa**
Cassava mealybug, *Phenacoccus manihoti*	Slight range expansion given that the cassava crop also expands its range	Small range expansion with higher establishment and abundance in the highland areas	Decline in range and activity in much of the tropics but with higher abundance in highland areas	Decline in establishment and abundance in coastal western and eastern and southern Africa, but range expansion into southern Africa and highlands of other parts of tropical and subtropical Africa
Cassava green mite, *Mononychellus tanajoa*	Slight range expansion given that the cassava crop also expands its range	Decline in range in northern subtropics but range expansion with higher establishment and abundance in the southern subtropics and especially highland areas.	Decline in range and activity in much of the tropics but with higher abundance in highland areas.	Decline in establishment and abundance in coastal western and eastern and southern Africa and in inland Central Africa, but range expansion into southern Africa and highlands of other parts of tropical and subtropical Africa, except for much of interior Angola which will see a decline in range and abundance

Table 4. Potential changes in range expansion and abundance of fruit pests in different regions, with special consideration of Africa, due to climate change for the SRES-A1B projection to the year 2050

Pest species	Change in establishment and abundance			
	Temperate	**Sub-tropical**	**Tropical**	**Africa**
Tephritid fruit fly, *Bactrocera invadens*	Small range expansion in temperate zones with slight increase in abundance.	Range decline in the northern subtropics and range expansion and higher abundance in the southern subtropics.	Range decline in the northern tropics, and range expansion and higher abundance in the southern tropics; range expansion and higher abundance in all tropical highlands.	Range decline in Western African and coastal eastern and southern Africa; range expansion and higher abundance in all African highlands and in southern Africa.

4.6 Adaptation planning for IPM in potato, maize, and cassava

The working groups identified common areas to be addressed as part of adaptation planning.

4.6.1 Capacity building

Training of key focal persons of NPPOs, NARS, and quarantine services in PRA; and learning the use and application of modeling and mapping tools in ILCYM and the interpretation of risk maps. This should include training on pest diagnostics (taxonomy), building surveillance systems, and updating geo-referenced pest distribution maps.

4.6.2 Regional information networks

Establish information networks and platforms for PRA and surveillance systems (e.g., "African climate change pest network") that could be used to share and distribute information locally, regionally, and sub-regionally. The network could strengthen the regional collaboration by managing transboundary invasive pests and enforcing the implementation of the IPPC regulations.

4.6.3 Publication of the Pest Risk Atlas

The Pest Risk Atlas would be best available in a printed version, flexible to update, and include new information as well as electronically on the ILCYM webpage providing interactive risk maps with high resolution to analyze individual pest risks on country and regional scales. The potential risks need to be communicated and translated into a simpler form to be more easily understood by policy-makers or farmers.

4.6.4 Future research needs

Participants expressed the need to develop pest penology and risk maps for pests (e.g., aphids, different white fly biotypes) not yet considered but relevant locally and regionally in potato, maize, cassava, and other crops. This also includes phenology models of pests' natural enemies to better understand their importance and efficacy in pest control under changing climates. The modeling framework considers temperature as the main abiotic factor; the inclusion of other factors such as precipitation would be also important to better understand and predict population build up and abundance influenced by rainfall events. Finally, the risk indices do not provide predictions on potential yield losses and economic impacts, which is another important area of research to be addressed.

4.6.5 Crop-specific IPM adaptation

Potato

Building resilient systems through conservation and augmentation of biological control agents for native and invasive pests will build the basis to cope with the potential range expansion and increase of pest abundance under climate change. Introduction of biocontrol agents for invasive pests should be made in an early approach to keep pest populations low. Extension staff and farmers need to be informed about potential changes and trained in the use and application of new tools of pest control and best cultural practices. For already highly relevant pests, new innovative methods of control need to be introduced and distributed (e.g., sex pheromones, attract-and-kill, or biopesticides) for control of the potato tuber moth, which will conserve natural enemies but effectively control key pests. Variety selection for resistance against pests was not yet very successful for potato but should be further considered in research. Chemical pesticides with low toxic and less harmful effects on natural enemies should be tested and used as a last option, especially during pest outbreaks.

Cassava and banana/plantain

Reinforcing phytosanitary regulations for the movement of plant material (stakes, suckers) between regions and countries for limiting pest spread and distribution and use of resistant varieties built the basis of pest management. Further, classical biological control of invasive pests (mealybug, mite) and intercropping of banana-plantain and cassava for aphid and banana bunchy top disease management are important components for managing future pest risks.

Maize

Consider timing of planting, short-cycled plant varieties, intercropping and rotation systems, and crop residue management to avoid and reduce pest infestations.

4.7 Adaptation to pest risks under future climates in Africa: Recommendations for an action plan

1. **Phenology modeling and pest risk mapping (ILCYM), including interactions with pests' natural enemies under current and future climates become important part of PRA implemented in the framework of IPPC.**

2. **Establish a regional platform and network on pest risks under future climates and create links and interactions with other climate change initiatives.**

3. **Research needs identified during the workshop should be addressed in order to extend models to major pests and to improve predictions of risks.**

4. **The capacity of NPPOs needs to be improved to adequately incorporate pest risk mapping results in adaptation planning to manage future pest risks on regional and country levels.**

5. **Advocate for a better awareness of future pest risks under climate change and promote the inclusion of pest risk adaptation plans at country level under the relevant ministries' action plans.**

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6. ANNEXES

Annex 1. Workshop Program

Wednesday, May 28

Time	Topic	Responsible
08:30 - 09:30	Registration of participants at Royal Suites Hotel	J.S. Okonya
09:30 - 09:45	Welcome address	K. Bulegeyaby/MAAIF
09:45 - 10:00	Regional context of the workshop	Y. Baguma/NARO
10:00 - 10:15	Objectives, workshop approach and expected results	J. Kroschel
10:15 - 10:30	Self-introduction of participants	J. Kroschel
10.30 - 11.00	**Coffee break**	
Pest risk analysis (PRA) and modeling approaches to understand the impact of climate change on insect pests (Chair: B. Le Ru; Rapporteur: J.S. Okonya)		
11:00 - 11:20	Introduction into climate change impacts on insect pests and the development of a Pest Risk Atlas	J. Kroschel
11:20 - 11:50	Introduction into modeling approaches and the ILCYM software to assess and understand climate impacts on future pest distribution and abundance	H. Tonnang
11:50 - 12:10	Geographic Information System based risk mapping	H. Juarez
12:10 - 12:30	Discussion	
12:30 – 13:30	**Lunch**	
Potential range expansion and abundance of pests in selected crops **Potato and vegetable pests** **(Chair: E. Mohamed; Rapporteur: A. Arinaitwe)**		
13:30 – 13:55	Potato tuber moth, *Phthorimaea operculella*	J. Kroschel
13:55 – 14:20	Guatemalan potato tuber moth, *Tecia solanivora*	V. Canedo
14:20 – 14:45	Serpentine leafminer fly, *Liriomyza huidobrensis*	N. Mujica
14:45 – 15:10	Vegetable leafminer, *Liriomyza sativae*	N. Mujica
15:10 – 15:40	**Coffee break**	
15:40 – 16:05	Greenhouse whitefly, *Trialeurodes vaporarium*	H. Gamarra
16:05 – 16:30	Sweetpotato white fly, *Bemisia tabaci*	J. Kreuze
16:30 – 17:00	Discussion	
19:30	**Dinner**	

Thursday, May 29

Time	Topic	Responsible
Maize pests (Chair: R. Hanna; Rapporteur: F. Elias)		
08:00 – 08:25	Spotted stemborer, *Chilo partellus*	B. Le Ru
08:25 – 08:50	Maize stalk borer, *Busseola fusca*	N. Khadioli
08:50 – 09:15	African pink stem borer, *Sesamia calamistis*	N. Khadioli
09:15 – 09:30	Discussion	
Cassava pests (Chair: M. Otim; Rapporteur: N. Mujica)		
09:30 – 09:55	Cassava mealybug, *Phenacoccus manihoti*	R. Hanna
09:55 – 10:20	**Coffee break**	
10:20 – 10:45	Cassava green mite, *Mononychellus tanajoa*	R. Hanna
Fruit pests (Chair: M. Otim; Rapporteur: N. Mujica)		
10:45 – 11:10	Tephritid fruit fly, *Bactrocera invadens*	M. A. Kenfack
11:10 – 11:30	Discussion	
Distribution and potential efficacy of pests' associated biocontrol agents under future climates (Chair: H. Tonnang; Rapporteur: A. A. Koech)		
11:30 – 11:45	*Orgilus lepidus*, parasitoid of *P. operculella*	V. Canedo
11:45 – 12:00	*Cotesia flavipes*, parasitoid of *C. partellus*	B. Le Ru
12:00 – 12:15	*Fopius arisanus*, parasitoid of *B. invadens*	S. Nanga Nanga
12:15 – 12:30	Discussion	
12:30 – 13:30	Lunch	
Country situation analysis on insect pests and changes due to climate change (Chair: J. Kroschel; Rapporteur: J.S. Okonya)		
13:30 – 13:40	Synopsis from Burundi	E. Sakayoya
13:40 – 13:50	Synopsis from DR Congo	D. Mamba
13:50 – 14:00	Synopsis from Ethiopia	F. Elias
14:00 – 14:10	Synopsis from Kenya	E. Mohamed
14:10 – 14:20	Synopsis from Malawi	D. Gondwe
14:20 – 14:30	Synopsis from Mozambique	L. B. Uamusse
14:30 – 14:40	Synopsis from Rwanda	N. Nduwayezu
14:40 – 14:50	Synopsis from Uganda	A. Arinaitwe
14:50 – 15:00	Synopsis from Tanzania	K. Mdili
15:00 – 15:30	Coffee break	
Adaptation planning (working groups) (Chair: J. Kroschel; Rapporteur: J.S. Okonya)		
15:30 – 17:30	Working group session (3 parallel groups: potato, maize, cassava)	J. Kroschel
19:30	Cocktail and dinner	

Friday, May 30

Time	Topic	Responsible
Adaptation planning (working groups) (cont.) (Chair: J. Kroschel; Rapporteur: J.S. Okonya)		
08:00 – 08:30	Presentation of working group I (potato)	
08:30 – 09:00	Presentation of working group II (maize)	
09:00 – 09:30	Presentation of working group III (cassava)	
09:30 – 10:00	Discussion	
10:00 – 10:30	Coffee break	
Action plan: "Adaptation to Pest Risks under future Climates in Africa" (Chair: J. Kroschel; Rapporteur: J.S. Okonya)		
10:30 – 12:00	Final discussion, formulation and adoption of recommendations	J. Kroschel
12:00 – 12:30	Closing messages by participants and organizers	
12:30 – 14:00	Lunch	
14:00	**DEPARTURE**	

Annex 2. List of Participants

No.	Name	Affiliation	Country	Email
1	Heidy Gamarra	International Potato Center (CIP)	Peru	h.gamarra@cgiar.org
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4	Jürgen Kroschel	CIP	Germany	j.kroschel@cgiar.org
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6	Jan Kreuze	CIP	Peru	j.kreuze@cgiar.org
7	Norma Mujica	CIP	Peru	n.mujica@cgiar.org
8	Henri Tonnang	International Centre of Insect Physiology and Ecology (icipe)	Kenya	htonnang@icipe.org
9	Bruno Le Ru	icipe	Kenya	bleru@icipe.org
10	Nancy Khadioli	icipe	Kenya	nkhadioli@icipe.org
11	Rachid Hanna	International Institute of Tropical Agriculture (IITA)	Cameroon	r.hanna@cgiar.org
12	Samuel Nanga Nanga	IITA	Cameroon	snanga@cgiar.org
13	Michel Arnaud Kenfack	IITA	Cameroon	michelarnaud@yahoo.fr
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27	Lucas Benjamim Uamusse	Ministry of Agriculture, Plant Protection Department	Mozambique	uamusse5@gmail.com

Annex 3. Table of contents of the "Pest Distribution and Risk Atlas for Africa: Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates"

Annex 4. Abstracts of workshop presentations of impacts of climate change on the potential range expansion and abundance of pests in selected crops

Potato and vegetable pests

Potato tuber moth, *Phthorimaea operculella* (Zeller)

Kroschel, J, M. Sporleder, H. Juarez, P. Carhuapoma
International Potato Center (CIP), Lima, Peru

The potato tuber moth *Phthorimaea operculella* (Lepidoptera: Gelechiidae) is considered one of the most serious pests worldwide. Potato is the main host but other Solanaceae are also attacked. It is originated in the tropical mountainous regions of South America and is reported more than 90 countries. The moth occurs in almost all tropical and subtropical potato production systems in Africa and Asia, as well as in North, Central, and South America and it's adapted to wide range of different climates and agroecologies. Losses can reach up to 40% in the field and 100% in storage. *P. operculella* attacks all vegetative plant parts of potato, typical symptoms of leaf damage are mines caused by larvae feeding in the mesophyll. Tuber infestation caused by first instar larvae can be hardly noticed and characteristic piles of feces indicate infestation. Inside tubers, larvae bore irregular galleries which may run into the interior of the tubers or remain directly under the skin in field and storage conditions. Adults are brownish gray, with fraying on the posterior edge of the forewings and on both posterior and inner edges of the hindwings. The wings are folded to form a roof-like shape with a wingspan of 12-16 mm. They are nocturnal and all activity occurs in the evening. The future distribution and abundance of this pest will be affected by climate change by changes in temperature. Using the Insect Life Insect Modeling (ILCYM) software we applied three risk indices (establishment [ERI], generation [GI] and activity [AI] index) in a geographic information system (GIS) to map and quantify changes. Under the climate of the year 2000, an ERI>0.6 represents very well the current global distribution of *P. operculella*: Africa, Oceania, South America, and Asia. Under the year 2050 temperature scenario, the boundaries for *P. operculella* are indicated to shift further north in the northern hemisphere. The number of generations indicates pest abundance and is closely related to losses. In regions where potato tuber moth is established and losses occur, a minimum of >4 generations are developed; between 12-15 generations are developed in tropical production systems. For future scenario (2050), changes in a number of generations per year of >4 will be highest in Europe and Asia. In potato production areas of Africa, Asia and South America, *P. operculella* abundance and infestation is expected to become more severe, reflected in an increase of the area with >7 generations per year. The AI indicates the potential population growth throughout a year; an increase by 1 indicates a 10-fold higher increase rate. For 2050, an increase by a factor 5-10 is predicted for most potato growing regions worldwide especially in those regions where temperatures have not reached the upper temperature threshold. For Africa, establishment of *P. operculella* will potentially increase as well as number of generations (2-5 generations/year). There are only few regions that might become too warm for potato tuber moth and more likely also for potato production. Infestations in other Solanceaea crops such as tomato might increase. The activity will generally increase; only in regions where temperature may reach values of maximum temperature threshold for development, the population growth will be gradually reduced due to increasingly high temperature-induced mortality and reduced reproduction per female. *P. operculella* is already a cosmopolitan pest but climate change will support its further spread and abundance. Phytosanitary measures and inspections are important in those countries where the pest has not yet established.

Guatemalan potato tuber moth, *Tecia solanivora* (Povolny)

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International Potato Center (CIP), Lima, Peru

The Guatemalan potato tuber moth *Tecia solanivora* (Lepidoptera: Gelechiidae) is considered to be one of the most serious potato pests in Central and South America. It is a monophagous insect pest feeding

only on potato tubers under field and storage conditions. Losses of 100% and up to 40% are reported under storage and field conditions, respectively. Guatemala is supposedly the country of origin. It is however endemic in the whole of Central America, and has invaded Colombia, Venezuela, Ecuador and Tenerife (Canary Islands, Spain). Larvae make galleries in tubers; damage is first noticed when fully grown larvae leave tubers for pupation. The adult female is light brown and has three marks in the forewings and light brown longitudinal lines. In contrast, the male is dark brown with two marks on the first pair of wings and faint longitudinal lines. They are nocturnal. *T. solanivora* can adapt from subtropical zones in Central America at 1,000 m asl to colder zones at 3,500 m.a.s.l. The future distribution and abundance of this pest will be affected by climate change. Using the Insect Life Insect Modeling (ILCYM) software we applied three risk indices (establishment [ERI], generation [GI] and activity [AI] index) in a geographic information system (GIS) to map and quantify changes. Under the climate of the year 2000, an ERI [0.8-1] represents very well the current global distribution of *T. solanivora*: Central America, Venezuela, Colombia and Ecuador. Global predictions for 2050 indicate a reduction in the high-risk areas (ERI>0.8) in tropical areas of America, Africa and Asia, and a slight range expansion to more temperate areas. The number of generations in Central America, Venezuela, Colombia and Ecuador ranged from 3 to 10 generations per year and future scenario (2050) may potentially increase its abundance by 2 to 4 generations especially in subtropical regions. Currently, a high activity (AI) is shown (6 – 11.5) in Central America, Venezuela, Colombia and Ecuador and in the future, a marked potential population growth might occur in Mexico, south of South America, southern Europe and southern Australia. In Africa, the risks of establishment will potentially decrease in all potato-growing regions, but potato-growing regions of Angola, Rwanda and Tanzania remain at high potential risk (ERI >0.8). *T. solanivora* is an A2 quarantine pest for EPPO and its spread is not only limited by temperature but also depends on the year round presence of potato tubers. Phytosanitary measures and IPM help to control and reduce its dissemination and related yield losses.

Serpentine leafminer fly, *Liriomyza huidobrensis* (Blanchard)

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The leafminer fly, *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae) is a pest species from Central and South America, which had since the 1990s spread with plants to many parts of the world. In the tropics, subtropics and warmer parts of the temperate zone, *L. huidobrensis* has established itself in fields and has become greenhouse pest in colder climates of the northern hemisphere. *L. huidobrensis* has a wide host range. It causes direct damage to photosynthetic plant tissue due to larvae leaf mining, and damage by oviposition and feeding punctures (stipples) produced by adult females. Both crop yield and marketability are reduced, resulting in high economic losses to vegetable producers around the world. The polyphagous nature of *L. huidobrensis*, combined with high reproductive rates and rapid development of insecticide resistance, contributed to the success of *L. huidobrensis* as an invasive species. The life cycle is completed between 10 ºC (65.5 days) and 30 ºC (14.9 days), with the optimum temperature for overall population growth between 20-25 ºC. The establishment risk index (ERI), the generation index (GI), and the activity index (AI), allow to predict and explain the future distribution and damage potential of the pest under different climate change scenarios. An ERI of 0.8-1 reflects well the current global distribution of *L. huidobrensis* in the year 2000, as well as the high number of generations/year (GI>17) that develop in tropical and subtropical regions. Global predictions for 2050 indicate a potential reduction of high-risk areas (ERI>0.6) in these regions and a slight range expansion to more temperate regions, but still with a low establishment potential of the pest (ERI<0.6). Also, an increase of 2-4 generations/year can be potentially expected in Central and South America, Africa and Middle East. The AI indicates a potential increase in the potential growth of *L. huidobrensis* in Southern South America, and Southern Africa; instead increasing temperature along the Equator will potentially **reduce** *L. huidobrensis* activity. Early predictions could help adaptation to climate change by developing and supporting farmers with adequate pest management strategies to reduce greater crop yield and quality losses. Adapting to avoid risk at the farm level implies an ecological and economic control of leafminer based on integrated pest management by promoting natural regulation and combining cultural practices with physical and chemical control.

Vegetable leafminer fly, *Liriomyza sativae* Blanchard

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The vegetable leafminer fly, *Liriomyza sativae* Blanchard, is a pest species from Central and North America, which had since the 1990s spread with infested plants to many parts of the world. In the tropics, subtropics and warmer parts of the temperate zone it has been established in the field, while in a colder climates of the northern hemisphere it has become a pest in greenhouses. Life cycle is completed between 15 ºC (40.2 days) and 30 ºC (12.4 days), with the optimum temperature for overall population growth between 25-30 ºC. *L. sativae* is a polyphagous pest of plants from nine plant families. Adults and larvae cause injuries to the plant foliage. *L. sativae* is reported as economically damaging on a wide variety of ornamental and vegetable crops (snow peas, sugar snap peas, French beans, tomatoes and potatoes). Yield losses range from 10 – 100%. The presence of unsightly larval mines and adult punctures in the leaf palisade of ornamental plants can further reduce crop value and rejection. The establishment risk index (ERI), the generation index (GI), and the activity index (AI) allow to predict and explain the future distribution and abundance potential of the pest under different climate change scenarios. An ERI of 0.8-1 reflects well the global distribution of *L. sativae* in the year 2000; further the high number of generations (GI>17) and the population growth (AI>20) of the species can be well predicted in tropical regions. Global predictions for 2050 indicate a potential reduction in the high-risk areas (ERI>0.8) in tropical zones and a slight range expansion to warmer subtropical areas but still with a low establishment potential of the pest (ERI of 0.6-0.8). Also, an increase of 2–4 generations can be potentially expected in most subtropical and tropical regions, as in North America (Mexico, southern USA), Central and South America, Africa, Asia (Middle East, south and Southeast Asia), southern Europe (Portugal, Spain) and Oceania. A high increase (AI>20) of the potential growth of *L. sativae* is predicted for tropical regions of central and South America, sub-Saharan Africa and Asia; instead increasing temperature along the Equator will potentially reduce *L. sativae* activity. Early predictions could help to adapt to climate change by developing and supporting farmers with adequate pest management strategies to reduce greater crop and quality losses. Adapting to avoid risk at the farm level implies an ecological and economic control of leafminer based on integrated pest management by promoting natural regulation and combining cultural practices with physical and chemical control.

Greenhouse Whitefly, *Trialeurodes vaporariorum* (Westwood)

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The greenhouse whitefly, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) is a widely distributed pest of ornamental and horticultural plants with over 250 genera of 85 plant families. Greenhouse whitefly is found widely around the world, including most of the temperate and subtropical regions of North America, South America, Europe, Central Asia and India, northern and eastern Africa, New Zealand and southern Australia. It does not thrive in most tropical locations, and occurs in colder regions only by virtue of its ability to survive winter in greenhouses. The origin of this species is not certain, but is thought to be Mexico or the southwestern United States. Whiteflies damage plants directly by sucking sap from leaves and indirectly by transmitting viruses and producing a sticky secretion known as honeydew, which prevents crops from functioning normally, as well as acting as a substrate for fungal growth (sooty moulds). Life cycle is completed between 15 ºC (46.71 days) and 28 ºC (21.87 days), with the optimum temperature for overall population growth ranged between 20 and 24 ºC. The establishment risk index (ERI), the generation index (GI), and the activity index (AI), allow to predict and explain the future distribution and abundance potential of the pest under different climate change scenarios. Regions with an ERI >0.6 reflects well the current global distribution of *T. vaporariorum* in the year 2000 in tropical and subtropical areas. Global predictions for 2050 indicate a potential reduction of high-risk areas (ERI>0.8) in tropical regions. A slight range expansion to subtropical and more temperate regions of Asia, North America, and Europe will get more suitable but still at a very low (ERI<0.45). A decrease in the number of generation (1-5) is expected in tropical regions, but an increase of 1-2 generations/year can be potentially expected in most subtropical and temperate regions. Similarly, whitefly activity will be severely affected by rising temperatures in tropical and subtropical regions, but an increase in the potential growth of *T. vaporariorum* is expected in temperate zones of North America and Europe. Early predictions could help to adapt to climate change by developing and supporting farmers with adequate pest management strategies to reduce greater crop and quality losses. Adapting to avoid risk at the farm level implies an ecological and economic control of leafminer based on integrated pest management by promoting natural regulation and combining cultural practices with physical and chemical control.

Sweet potato Whitefly, *Bemisia tabaci* (Gennadius) biotype B

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The sweetpotato whitefly *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae), native to eastern Asia, is a polyphagous pest with over 500 species of 63 families. The sweetpotato whitefly thrives worldwide in tropical, subtropical, and less predominately in temperate habitats. Cold temperatures kill both the adults and the larvae of the species. Feeding by immature *B. tabaci* has been associated with several physiological disorders of plants, such as tomato irregular ripening and squash silverleaf disorder. In addition, *B. tabaci* is a vector of many viruses, particularly of begomoviruses (*Geminiviridae*: *Begomovirus*): whitefly-transmitted viruses (WTVs) is among the most destructive plant viruses and early virus infection often results in total crop loss. Life cycle is completed between 15 ºC (156.54 days) and 32 ºC (35.73 days), with the optimum temperature for overall population growth between 20-25 ºC. The establishment risk index (ERI), the generation index (GI), and the activity index (AI), allowed predict and explain the future distribution and abundance potential of the pest under different climate change scenarios. An ERI of 0.8-1 under climate conditions of the year 2000 represent the regions where the likelihood of establishment is highest, being a serious pest problem in tropical and subtropical areas of Africa, Asia, Oceania, South and Central America. Global predictions for 2050 indicate a potential reduction of high-risk areas (ERI> 0.8) in tropical regions and an increase in subtropical regions. A slight range expansion to temperate zones as North America but with a low establishment potential of the pest (ERI <0.45) is observed. Generation index ranged from 8-14 and 6-8 generation/year in tropical and subtropical regions, respectively. The GI change indicates an increase of 1-3 generations by year in most tropical and subtropical regions: North and Eastern South America, southern Africa, The Caribbean, Asia (Indonesia, Malaysia, and Philippines) and Oceania (Papua New Guinea). In temperate regions like in North America and Europe only a low increase between 0-1 generation per year is expected. Global maps of the AI in year 2000 estimates a high activity of B. *tabaci* biotype B in tropical regions of South America, the Caribbean, Africa, Asia and Oceania. Predictions of changes for the 2050 scenario show a decrease in the potential growth of *B. tabaci* biotype B in most tropical and subtropical regions, and an expansion on temperate regions of North America and Europe is expected.

Maize pests

Spotted stemborer, *Chilo partellus* (Swinhoe)

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Maize (*Zea mays* L.) is a major staple food crop in Africa. However maize production is severely reduced by feeding Lepidopterous insect pests. In East and Southern Africa, *Chilo partellus* (Lepidoptera: Pyralidae) is one of the most damaging cereal stem borers mainly found in the warmer lowland areas. In this study, it was hypothesized that the future distribution and abundance of *C. partellus* will be affected greatly by global warming. The temperature-dependent population growth potential of *C. partellus* was studied on artificial diet under laboratory conditions at six constant temperatures (15, 18, 20, 25, 28, 30, 32 and 35˚C), relative humidity of 75 ± 5% and a photoperiod of L12: L12 h. Several non-linear models were fitted to life-table data to model development time, mortality and reproduction of the insect. We used process-based phenology models and risk mapping in a Geographic Information Systems to assess the impact of global warming on the future distribution of *C. partellus.* The process-based phenology model is made of a number of functions describing temperature-dependent processes, which includes development time, mortality and reproduction of the insect species. Cohort up-dating algorithm and rate summation approach were stochastically used for simulating age and stage structure populations and generate life-table parameters. For spatial analysis of the pest risk, three risk indices (Establishment Risk Index,, Generation Index and Activity index) were visualized in the GIS component of the advanced Insect Life Cycle modeling (ILCYM) software. To predict the future distribution of *C. partellus* we used the climate change scenario A1B obtained from WorldClim and CCAFS databases. The maps were compared with available data on the current distribution of *C. partellus* in Kenya. The results show that the development times of the different stages decreased with increasing temperatures ranging from 18˚C to 35˚C; at the extreme temperatures, 15 ˚C and 38˚C, no egg could hatch and no larvae completed development. The study concludes that *C. partellus* may potentially expand its range into higher altitude areas, highland tropics and moist transitional, with highest maize potential where the species has not been recorded yet. This has serious implication in terms of food security since these areas produce approximately 80% of the total maize in sub Saharan Africa

Maize stalk borer, *Busseola* fusca (Fuller)

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The maize stalk borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) is the most important indigenous pest of maize and other cereal crops throughout sub-Saharan Africa .It is more adapted to middle- and high- altitude zones (> 600 masl) in Eastern and Southern Africa where it is abundant in the highlands.In Central Africa, it occurs from sea level to over 2000 m. In West Africa, it is primarily a pest of sorghum in the dry Savannah zones. The temperature-dependent population growth potential of *B. fusca* was studied on artificial diet under laboratory conditions at six constant temperatures (12, 15, 18, 20, 25, 28, 30 and 35˚C,), relative humidity of 75 ± 5% and a photoperiod of L12: L12 h. Several non-linear models were fitted to the data to model development time, mortality and reproduction of the insect. We used process-based phenology models and risk mapping in a Geographic Information Systems to assess the impact of global warming on the future distribution of *B. fusca*. Life table parameters were calculated using Insect Life Cycle Modeling (ILCYM) software. At 12 and 35°C insects failed to develop. With the Insect Life Cycle Modeling (ILCYM) software, the obtained data on the temperature-dependent development of *B. fusca* was used to develop a process-based temperature phenology model. The model was used to estimate risk indices: the establishment risk index (ERI) that identifies areas in which the pest may survive and become permanently established, the generation index (GI), which estimates the mean number of generations the pest may produce within a given year and the activity index (AI), Further, a mapping and quantification of these indices changes between the climate scenarios of the years 2000 and 2050 was conducted using downscaled data of the scenario A1B from the worldClim database. The study concludes that *B.fusca* potential establishment and damage will progressively increase in highlands regions and may decrease in warmer cropping regions of the sub-Saharan Africa.

African pink borer, *Sesamia calamistis* (Hampson)

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The African pink stemborer *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) is widely distributed in Africa butonly economically important in West Africa .It does not often attain economically important status in Eastern and Southern Africa in spite of its wide occurrence on several crops. *S. calamistis* occurs at very low infestation levels and forms a small proportion of the total stem borer population outside West Africa. The contribution of *S. calamistis* to the total stem borer population varies over time and between regions but has been reported to be small in Southern Africa. The temperature-dependent population growth potential of *S. calamistis* was studied on artificial diet under laboratory condition at six constant temperatures (12, 15, 18, 20, 25, 28, 30 and 35˚C,), relative humidity of 75 ± 5% and a photoperiod of L12: L12 h. Several non-linear models were fitted to the data to model development time, mortality and reproduction of the insect. We used process-based phenology models and risk mapping in a Geographic Information Systems to assess the impact of global warming on the future distribution of *S. calamistis*. Life table parameters were calculated using Insect Life Cycle Modeling (ILCYM) software. At 12 and 35°C insects failed to develop. With the Insect Life Cycle Modeling (ILCYM) software, the obtained data on the temperature-dependent development of *S. calamistis* was used to develop a process-based temperature phenology model. After, the model was used to estimate risk indices: the establishment risk index (ERI) that identifies areas in which the pest may survive and become permanently established, the generation index (GI), which estimates the mean number of generations the pest may produce within a given year and the activity index (AI), Further, a mapping and quantification of these indices changes between the climate scenarios of the years 2000 and 2050 was conducted using downscaled data of the scenario A1B from the worldClim database. The study concludes that *S. calamistis* potential establishment, damage will progressively increase in highlands regions and may decrease in warmer cropping regions of the sub-Saharan Africa.

Cassava pests

Cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero

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The cassava mealygug, *Phenacoccus manihoti* Matile-Ferrero 1977 (Hemiptera: Pseudococcidae), like the cassava green mite, it became a serious pest for cassava soon after its accidental introduction into Africa from the Neotropics in early 1970s. It quickly spread across the cassava belt in Africa causing estimated initial losses in cassava production of up to 80%. This pest, which is largely found on cassava, was brought under biological control in much of sub-Saharan Africa with the introduction and distribution of the parasitoid *Anagyrus lopezi* (De Santis, 1964). The pest invaded Thailand in 2008 and subsequently at least four other countries in Southeast Asia. In Thailand, it was promptly brought under biological control by 2013 with the introduction of *A. lopezi* from Africa by IITA-Benin in 2009. Several publications provided comprehensive information on the response of *P. manihoti* to range of temperatures, but none of these data could be used for modeling this species phenology using the ILCYM software because the original raw data could not be obtained and ILCYM could not use published data based on means of variances. We therefore conducted experiments, similar in methodology to published experiments, under six constant temperatures (15, 20, 25, 30, 31, and 34°C), to obtain the necessary data to develop a phenology model for *P. manihoti* which were validated with data generated from similar experiments under fluctuating temperatures. We then used ILCYM to map *P. manihoti* distribution and abundance under current and future climate scenarios using 2000 and 2050 WorldClim database. The results of the phenology models compared well with published literature on *P. manihoti*, with highest simulated rates of increase between 25 and 30°C, but no development and reproduction beyond 34°C. Validation at fluctuating temperature provided good approximation for the output at the constant temperature similar to the average temperature during validation. Mapping current distribution approximated well present distribution and abundance patterns; while 2050 predictions show considerable reductions in range especially in Western Africa, Southern India, and northern areas of Southeast Asia, while a range expansion and increase abundance is predicted for southern Africa and Southeastern Asia with highest shifts in highland areas. The most effective adaptation against *P. manihoti* is monitoring and surveillance where it is not present, and the introduction and conservation of *A. lopezi* for effective biological control and risk avoidance at farm level.

Cassava green mite, *Mononychellus* tanajoa (Bondar)

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The cassava green mite, *Mononychellus tanajoa* (Bondar) (Acari: Tetranichidae), originating in Neotropics, became a serious pest of cassava soon after its accidental introduction into Africa in early 1970s. It quickly spread across the cassava belt in Africa causing average cassava yield losses of about 35%. To date *M. tanajoa* has not spread beyond Africa. The pest is highly specific to cassava and has the typical tetranychid mite life cycle. We developed process-based phenology model for *M. tanajoa,* using ILCYM software developed by CIP, generated from data collected under five constant temperatures (16, 21, 26, 31, and 36°C), with relative humidity of ~75% and L12:D12 photoperiod. This phenology model was validated with similar data generated under three sets of fluctuating temperatures (long dry seasons, long rainy season and short rainy season). In turn, we used ILCYM to map *M. tanajoa* distribution and abundance under current and future climate scenarios using 2000 and 2050 WorldClim database. Outputs from this study show that *M. tanajoa* did not develop at 16°C and temperatures ranging between 21 to 36°C were highly suitable for its development and reproduction. The output of current distributions compare well with published literature which shows that the tropics are highly favorable for this species and that it can potentially be found where cassava is grown. *M. tanajoa* is presently widely distributed throughout tropical and subtropical areas of Latin and Central America and in sub-Saharan Africa. It is still absent in tropical areas of Asia and the Pacific where conditions are highly suitable for its establishment. Warming climate is predicted to have small effects on the distribution of *M. tanajoa*, but abundance is likely to decline in large areas of Western Africa with higher abundance in the southern latitudes and highland areas. The most effective adaptation against this species is monitoring and surveillance where it is not present, and the introduction and conservation of predatory mites along with the use of hairy cassava varieties are best bet for risk avoidance at farm level.

Fruit pests

Tephritid fruit fly, *Bactrocera invadens* Drew, Tsura & White

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The Sri Lanka fruit fly, *Bactrocera invadens* Drew, Tsuruta & White (Diptera: Tephritidae), 2005 is a devastating highly polyphagous pest of fruits and vegetables (42 known hosts) in tropical Africa, where it was introduced in is presently found in at least 24 countries. In this study, we determined development, survival and reproduction of *B. invadens* on a carrot-based diet at six constant temperatures (15, 20, 25, 30, 33 and 35°C), with a relative humidity of ~75% and a L12:D12 photoperiod. We used these data in ILCYM to develop a temperature-based phenology model. We then used ILCYM for risk analysis of this pest under current and future climates using the three risk indices establishment, generation and activity. We modeled the phenology of this species quite successfully despite the long life cycle of this species at low temperature (~ 1 year). Our data is the only complete such data set over such range of temperatures. Mapping current distribution showed that this species can establish (as it has) widely in a range of tropical and subtropical conditions (but most successful at not more than 12 degrees north and south of the equator). There will be a reduction in both the distribution and abundance of this species in the tropics by the year 2050 but the indices of distribution and abundance remain high enough to indicate that this species will remain a serious threat to fruit production in tropical areas of the world. Risk reduction adaptations are quarantine and surveillance in areas predicted to be suitable for establishment of *B. invadens*, the implementation of already tested control options such as biological control with parasitoids (e.g., *F. arisanus*), use of mass trapping (male annihilation) and bait sprays with effective commercial baits (GF-120).

Annex 5: Country synopsis of important insect pests and aspects of climate change

Sudan

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Sudan is the 3rd largest country in Africa, with an area of 1,861,484 km^2. Irrigation water is available to support diversified agricultural activities such as production of cereal grains, oil crops and horticultural crops. Records of several indigenous agricultural insect pests started with the establishment of Agricultural Research Corporation (ARC) and Gezira irrigation scheme. Factors influencing insect population dynamics in the field and storage include the climate especially changes temperature and rainfall, and availability of host plants or food.

Sweetpotato whitefly: The whitefly *Bemisia tabaci* (Genn.) was detected in Gezira regionas a minor cotton pest before the era of pesticides application. The resurgence of *B. tabaci* as major pest of cottonin 1960s was attributed mainly to the wide application of broad spectrum insecticides which killed its natural enemies.. In the late 1970s, *B. tabaci* became a primary cotton pest reducing the quality of lint(stickiness). This therefore resulted in price reduction of cotton lint by 5 to 30 %. Vegetable crops are severely affected by *B. tabaci* through direct feeding and as a vector for plant viruses (Tomato yellow leaf curl virus, Watermelon chlorotic stunt virus and (Okra leaf curl virus). Recently, *B. tabaci* infestation is higher in comparison to the other virus vectors and farmers routinely apply two or more chemical insecticides in combination every three days during the cropping season.. Current research is focusing on evaluation of newly introduced insecticides, intercropping and development of virus resistance, particularly in tomato and cucurbits.

Fruit flies: Among the fruit flies of the family Tephritidae found in the Sudan, *Ceratitis capitata* and *Ceratitis cosyra* are considered as the most important pests to fruit trees such as mango, guava and citrus all over the country. Additionally, two new species *Bactrocera invadens* and the peach fruit fly, *B. zonata* (Saunders) have been reported in Blue Nile areas and Gezira state (Wad Medani and Elkamlin), respectively. Recently, *B. invadens* is spreading very fast and is now almost recorded from all parts of the country and largely displacing other dominant fruit fly species in all regions of mango production of the Sudan. Fruit fly activity, abundance and distribution vary throughout the year due to variation in climatic conditions and within the genus. In 2007, the fruit flies problems became severe and were listed among the major national pests of Sudan receiving considerable attention in control using male lures by the Plant Protection Directorate of the Ministry of Agriculture. The effective cultural control measures recommended in the country include cleaning of the orchards from infested dropped fruits, irrigation, ploughing and early harvesting.

Tomato leafminer: *Tuta absoluta* was first recorded in Khartoum State, Sudan, in 2010 and rapidly spread to all tomato growing areas in the country and is now considered as one of most devastating pests of tomato and other solanaceous crops (potato and eggplant). This newly introduced pest has found the shores of Sudan as a preferable refuge and rapidly bred. Crop yield losses up to 100% in the open fields and screenhouses tomato were observed. Many insecticide sprayfrequencies are required, sometimes every 3 days throughout the cropping season, and farmers often combining two or more products resulting in environmental hazard. Mass trapping using synthetic pheromones and chemical control were recommended for management of *T. absoluta* in Sudan. Two predators and three parasitoids were recorded in most surveyed areas in the country.

Serpentine Leafminers: The leaf miners *Liriomyza trifolii* (Burgess), and *L. sativae* (Blanchard) (Diptera: Agromyzidae) attack a variety of crops including tomato, potato, okra, eggplant and cucurbits and their wild relatives. These two *Liriomyza* species are major economic pests on both field and horticultural crops. Infestation levels of 48% and 86.5% were recorded on tomato and faba bean and caused yield losses of 44% and 45%, respectively.

Green date palm pit scale insect: The green date palm pit scale insect, *Asterolecanium phoenicis* (Rao.) (Homoptera: Coccidae) is considered as the main pest of date palm and listed among the major national pests of Sudan. It is believed to have been introduced in the country via the illegal introduction of offshoots from Saudi Arabia in 1974. The pest is found throughout the year and its population increases from October to January and decreases in August possibly due to uneven climatic conditions. Yield losses may range from 85 to 90% according to infestation rate, varieties and management.

African bollworm: The African bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), is one of the key pests causing severe yield losses in cereals, pulses, fiber crops, vegetables and fruit crops.. Variations in rainfall and temperature are the main factors influencing infestation rates and extent of damage from year to year and region to region. Recently, the African bollworm has become a serious pest attacking sorghum, cotton and tomato all over the country. Control measures include the use of conventional insecticides, bio-insecticides (Brigade and Agerin) and recently the use resistant transgenic cotton (*Bt* cotton).

Stem borers: Among cereal pests in Sudan, two stem borers, *Chilo partellus* and *Sesamia cretica* are the dominant species. These species cause more than 70% sorghum damage. *C. partellus* is common in the Gezira scheme of central Sudan while *S. cretica* is common in the Northern State. Early sowing date and growing tolerant varieties arethe best management practices for these stem borers. Temperature, rainfall and humidity are the factors responsible for the distributions of these two stem borers, with temperature being most important.

Spider mites: Red spider mite, *Tetranychus urticae* (Koch)(Acarina: Tetranychidae) emerged as a serious pest of vegetable crops including eggplant, tomato, cucumber, other fruits, field crops and recently severe damage was observed on potato.. On the other hand the dust spider mite, *Oligonychus afrasiaticus* (Meg.) (Acarida: Tetranychidae) attack date palm in north Sudan causing significant yield losses depending on the location and variety.

National capacities and adaptation plans: Research programs to study the bionomics, biology, the effect of biotic and abiotic factors and integrated pest management exist not only at ARC but also at other national agricultural research institutes and universities in the country.

Malawi

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Ministry of Agriculture and Food Security

Agriculture is key to food security, economic growth and wealth creation in Malawi. Crop pests create havoc in the agricultural sector as they contribute to losses at all stages that is, from seeding to harvest and storage. Most of these pests if not controlled, can cause total crop yield loss. Pest population dynamics and distribution has changed over time and space due to various factors including climatic variations. Some important crop pests that have been observed to increase in population, prevalence, recurrence and incidence during the past years probably due to changes in the climate are shown below:

Banana Aphid: The banana aphid, *Pentalonia nigronervosa*, is an economic important pest of banana. The pest is a vector of Banana Bunchy Top Virus (BBTV) in Malawi. The feeding damage caused by large colonies of aphids can cause blemishes on fruit and reduce their quality. BBTV was first observed in the central region of Malawi at Thiwi in Nkhokakota district in 1994. Thereafter, the disease spread to most regions except Karonga and Chitipa in the north bordering Tanzania. This caused a decline in banana production as the disease can cause a complete yield loss if the attack is early in the season and plants infested at later stage may produce abnormal or deformed fruits. There is a risk of losing the entire banana population just 20 years from the year the diseases was observed. Control strategies include destruction of the infected plants and use of disease-free plantlets. There is a challenge when some farmers refuse to destroy their plantation proper control measures of the vector need to be put in place including capacity building at institution level which is lacking at the moment.

Citrus Woolly Whitefly*:* The Citrus Woolly Whitefly (CWWF), *Aleurothrixus floccosus* Maskell, is a serious pest of citrus in Malawi. Primary host is citrus and others are guava, coffee, and mango but rarely having more than trace infestations. Since its accidental introduction in North Africa, Morocco in 1973, it has continued its course southwards in the continent. It was found in Egypt a few years later, and in 1992 it was in East Africa. In Malawi it was first observed in 1993, and its status in terms of distribution and severity was later confirmed in a survey conducted in 1995. This survey revealed the presence of CWWF in nearly all parts of the country where citrus is grown. It is now the most serious pest limiting citrus fruit production in the country. Citrus, which smallholder farmers mainly grow, is an income-generating commodity for the smallholder farmers. It is also a rich source of vitamin C that is readily available to the majority of the rural and urban population. The citrus woolly whitefly pause a threat to this important commodity. The damage caused by Woolly whitefly is through sucking plant juices from the leaves and by producing honeydew on the fruits and leaves. In the short term, it does not appear that the whitefly have a serious effect on tree health, as even heavily infested leaves appear to remain green and healthy. Overtime, the whitefly extensive feeding causes weaken trees and result in decreases in the quantity and size of the fruit which has significant impacts on the marketability and profitability of the fruits. Efforts have been tried through biological control but did not achieve any significant results.

Sweetpotato weevil: The Sweetpotato weevil, *Cylas puncticollis*, is the most serious pest of sweetpotato in Malawi. The larvae live in roots and vines. The adults are small black beetles. The damaging stage is the larvae and is also most noticeable. They attack the leaves, stems and roots of the sweetpotato, eating them and making holes. The larvae cause great damage as they bore into roots where the waste materials cause a bad taste and the holes open the way for secondary infestations of fungi and bacteria. High temperatures and cracking of the soil as the sweetpotato root enlarges favour sweetpotato weevil infestation. Control options include the encouraging of the farmers to seal the cracked soil, crop rotation, use of clean of vines, early planting and planting the vines deep in the soil.

Larger Grain Borer: The Larger Grain Borer, *Prostephanus truncatus* (Horn), is one of the primary postharvest pests of maize grain and dried cassava. It attacks both shelled and unshelled maize grain and it establishes well in the unshelled maize grain. The pest is widely distributed. It is now found in most of the African countries including Malawi. *P. truncatus* causes weight losses as high as 34% with the average weight losses of about 19% after period of six months. Control for *P. truncatus* has mostly hinged on the use of synthetic pesticides which proved to be effective. The use of biological methods such as *Teretrius nigrescens* is also important for the protection the environment but its nature worries the farmers for adoption. Since *P. truncatus* occurs in the forests, its presence in both farm stores and forest areas poses a challenge for pest management as farmers only treat their maize grain in storage with Actellic super or Novatellic. At present in Malawi, there is a small-scale release of the predator *T. nigrescens* done by the Department of Agricultural Research Services which is not adequate as biological control method requires large releases for the results to be tangible and no other management efforts of LGB control are currently done in forest areas in the country.

Cotton bollworm: The cotton bollworm, or the African bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a common pest of field crops. It has a large number of host plants (cotton, tomatoes, pigeon pea, cowpea, maize, sorghum, sunflower, chickpea, lupine, lucerne etc.). The cotton bollworm is a moth which feeds on flower nectar. The most destructive stage is the larval stage. *H. armigera* has the capacity to cause yield loss significantly if not controlled as the pests mainly attacks the fruiting bodies like cotton bolls, maize cobs and bean pods. The pests are usually controlled by the use of synthetic pesticides such as cypermethrin.

Fruit fly: *Bactrocera invadens* is a quarantine pest of Asian origin capable of infesting various commercial fruit crops. *B. invadens* was first detected on the African continent, in Kenya, in 2003. It is now listed in most countries in Western, Eastern and Central Africa as well as in some Southern African countries including Malawi. The pests cause the loss of millions of dollars in lost export revenue and threaten food security. In Malawi, *B. invadens* cause great damage in peaches, citrus, mangoes, apple, pear, coffee, guava and other cultivated and wild fruits. In mangoes both yield and quality as high as 100% have been recorded. Surveillance of this pest is currently being carried out to assess its population dynamics. This is a new pest in Malawi and sustainable control measures are not yet in place though the use of chemical pesticides is advised during the flowering stage.

Mozambique

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Ministry of Agriculture

Mozambique has a population of over 23.4 million people and more than 65% of the population lives in rural areas. The climate is warm and tropical with the average temperature of 28 °C. Day temperatures at the coast average between 24 and 27 °C but can rise up to 31 °C. Average annual rainfall of Mozambique along the coast line is 800 to 900 mm. Some areas of Mozambique receive an average of 2000 mm rainfall and 70-80% humidity. The rainy season runs from October to March in the South. It starts and also ends almost six weeks later in the north. The highest temperatures are experienced during the rainy season that is during the months of November to April. Dry Season is from April to November. Agriculture is the major economic activity which employs most of the rural population; the type of agriculture practiced is basically of subsistence, characterized by low levels of productivity compared with other Southern Africa Development Community (SADAC) countries due to some factors related to traditional agriculture practices and low utilization of agricultural inputs. The main cash crops are: Cashew nuts, coconuts, cotton, tobacco, banana, sesame, tea and soybeans and for subsistence maize, peanuts, beans, cowpea, sorghum, millet and others. Mozambique has optimum climatic conditions for occurrence of different types of pests and diseases during the period of crop development, the losses of incomes due to the attack of pests and diseases is estimated at 30% and 40% when control measures are not implemented in suitable periods of times. During the last five years agricultural production was seriously affected by the occurrence of pests and diseases which we suspect to be associated with climatic changes. Below, we highlighted the most important agricultural insect pests;

African armyworm: *Spodoptera exempta* occurs yearly all over the country between October and May.

Maize stalk borer: *Chillo partellus* and *Sesamia calamistis* previously occurred in hot areas of the country. Presently, surveys results showed spread of *C. partellus* to cooler areas probably due to climate change. *Busseola fusca* occurs in cool areas (Niassa and Manica provinces, north and center, respectively).

Red locust: *Nomadacris sempfasciata* occurs in tableland of Búzi-Gorongosa (Districts of Machanga, Búzi, Dondo, Beira, Nhamatanda and Gorongosa) and also in tableland of Dimba in Caia-province of Sofala.

Quelea bird: *Quelea quelea* occurs in Gaza and Maputo provinces, being devastator pest mainly in great thin cereals

Papaya mealybug: *Paracoccus marginatus* occurs in Pemba, Cabo-Delgado province in the north part of the country.

Fruit fly: *Bactrocera invadens*.

African armyworm: 8,000 ha from small scale farmers were infested by African armyworm *Spodoptera exempta*. As a control measure the Ministry of Agriculture allocated every year >$300,000 for purchase of chemical pesticides, sprayers and personal protection equipment. As a result, 580 small scale farmers and 88 community leaders were trained in monitoring and controlling of this pest in 75% of the total area. Pheromone trapshave been used for monitoring *S. exempta* populations.

National capacities in pest management, diagnostics and surveillance: The Ministry of Agriculture is doing its best in order to create a better institutional capacity. In this way, two new laboratories for fruit fly research were built in two provinces; Chimoio and Pemba; the Central laboratory of Entomology (NPPO) was recently rehabilitated and also the laboratories of the Faculty of Agronomy and Forestry Engineering of Eduardo Mondale University. In the National Plant Protection Organization, there is no special plan for only insect pests and its occurrence related to climatic changes. All pests and diseases are treated according to the national plan for pest insect management. A national working group for Pest Risks Analysis will be created, and systematic monitoring, control and mitigation of the main pests and diseases all over the country will be continuously carried out. Technicians will be trained in terms of plant protection at all levels (national, provincial and district), in the major border posts. Laboratories will be built and equipped for pests and diseases diagnoses. A survey and monitoring unit for pests and diseases focusing on export crops will be created. In general, the Ministry of Agriculture is concerned about the present situation and contacts with regional and international institutions have been made in order to get support to solve insect pests and diseases in the all country to contribute to increase agrarian productivity. Finally, from this workshop we hope to get support especially in terms of designing a national plan for insect pests related with climate changes.

Rwanda

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Potato, banana, cassava and sweetpotato are important crops in Rwanda. These crops contribute to national food security. Potato, banana and cassava are priority crops to which farmers have to put more efforts to have a good production. All four crops are facing the challenge of yield reduction due to pests and diseases. The pests are managed mainly by cultural practices and in some cases by chemical application depending on the pest.

Potato is an important cash crop in the northern and western zones of the country. The main insect pests of potato are leafminer flies, white grubs and aphids. These pests cause both direct and indirect crop damage, especially aphids which are vectors of potato viruses. For direct damage, leafminer flies create tunnels in the leaves; white grubs attack the potato tuber potato, garden pea, sweetpotato and cassava. Cultural practices are used in pest management and they include good tillage, picking and destroying pests, and good fertilization to manage white grubs and leafminer flies. Chemical insecticides are being used control leafminer flies and aphids.

Cassava is grown in mostly in eastern and south zones of Rwanda. The main pests attacking the crop are whiteflies, mealy bugs, grasshoppers and mites. The whiteflies are highly polyphagous and their direct damage on the plant is less, but they transmit cassava mosaic disease (CMD) which is a serious disease on cassava in Rwanda. The cassava mealy bug causes damage by sucking and growth reduction. The grasshoppers cause plant defoliation. The mites also suck the plant on under leaves of the plant and cause chlorotic spots. The use of clean materials is used to reduce the spread of mealybugs. To control grasshoppers, Durciban were used as an insecticide. For this pest, a collective control is more effective. Biological control were applied also to mealybug pests by *Epidinocarsis lopezi* (Hymenoptera: Encyrtidae), and a predatory mite *Typhodromalus aripo* helped on cassava mite control.

Banana is grown in the all country, especially in eastern and south provinces. The crop suffers mainly by weevils, mealy bugs, trips and aphids. Weevils' damage by creating tunnels in corms and at the end the plant shows symptoms such as wilting and drying of youngest leaves, and small bunches. Mealy bug insects are BSV (Banana Streak Virus) vectors. Trips are small insects which cause blemishes on the crop. Aphids transmit BBTV (Banana Bunchy Top Virus). For the pest management, the cultural methods are used: uprooting of infested plants to manage mealy bugs and trips, using of clean planting materials to prevent weevil and trip attacks. In general, the all banana pests can be managed by good husbandry.

Sweetpotato is widely grown. Very little information is available for this crop because it is not among priority crops promoted by the government. *Planococcus citri* (*Pseudococcus citri*), *Agronoscelis pubescens* (*Agronoscelus vesicolor*), *Gonocephalum simplex* and *Epilachna hirta* are the pests recognized to cause damage on the plant in Rwanda.

Other serious crop pests are Maize stalk borer, and aphids on cabbages.

National capacities in terms of institutions/laboratories dealing with insect pest management x climate change impacts, including diagnostics and surveillance: In Rwanda, there is a public institution in charge of crop inspection and quarantine, based in the Ministry of Agriculture and Livestock. The institution helps in plant pest and disease control issues before exporting and importing in the country. This is done by diagnosis in laboratories of Rubizi (in Kigali town), Rubona (in south zone) and in Musanze (Northern zone). All laboratories are under the responsibility of RAB. For surveillance, outbreaks in are reported to administration centers at the cell, sector, district, agriculture zone related to the province and then to the Ministry of Agriculture or RAB at National Level. Therefore, RAB has the four agricultural divisions' equivalent to the Provinces of the country. With the province there are districts which are divided in sectors, divided also in cells. At all levels there are staffs in charge of agriculture who report in plant pests and diseases.

National adaptation plans in plant protection and especially in insect pest management: In RAB and Ministry of Agriculture there are staffs in charge of crop pests and diseases organized in a special program of crop protection. In the four agricultural division zones, there are staffs also in charge of crop protection. The staffs work together with the district staffs in agriculture that monitor different cases of crop pests and diseases. In conclusion, whenever there is a case of crop pest, it is handled mainly by RAB in collaboration with local government staff (at district, sector and cell levels) in charge of agriculture.

Uganda

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Uganda is regarded as the food basket for East Africa with agriculture being the largest employer with 83% workforce in the agriculture sector which also contributes to 47% of total national exports and 24% of total GDP. The average rainfall ranges from 1,200 to 1,450 mm with two rainy seasons from March to May with peak in April and from August to November with a modest peak in October/November. Two dry seasons occur mainly in December to February and from June to September. Most of the regions have temperature ranges from 15 – 30 °C, and average altitude ranges from 1,000 – 1,800 m asl. The major crops are banana, robusta coffee, sugar cane, tea, oil palm, cassava, sweetpotato, potato, floriculture, horticulture (cabbage, okra, French beans, tomato), vanilla, fruits (mango, avocado) and natural forests. There have been cases of multiple diseases and pests on one crop at the same time and outbreaks of new diseases and pests are common which have been devastating agriculture. Major pests in major crops are:

Banana: Banana weevil (*Cosmopolites sordidus*), nematodes (*Radopholus similis*), mealybugs (*Planococcus citri*), banana aphid (*Pentalonia nigronervosa*)

Potato: Potato aphids, potato tuber moth (*Phthorimaea operculella),* potato leaf miner (*Liriomyza* spp.), cut worms.

Coffee: Coffee berry borer, Antestia bug, mealybugs, Coffee twig borer (*Xylosandrus compactus*), Coffee bean weevil (*Araecerus fasciculatus*).

Cassava: Green mite (*Mononychellus tanajoa*), mealybug (*Phenacoccus manihotii*), whitefly (*Bemisia tabaci*)

Maize: Stem borers, whiteflies, aphids, *Helicoverpa armigera,* maize and rice weevil (*Sitophilus* spp.), *Sitotroga cerealella, Rhyzopertha dominica*, larger grain borer (*Prostephanus truncatus*)

Tea: Yellow tea mite (*Hemitarsonemus latus*), red crevice mite (*Brevipalpus Geijskes*), and red spider mite (*oligonychus coffeae*), thrips (Black and yellow tea thrips), termites (*Microtermes natalesisis* and *Pseudoacanthotermes militaris*)

Sweet potato: Sweetpotato weevils, hornworm

Cabbage: Diamond back moth (*Plutella xylostella*)

Beans: Bean aphid (*Aphis fabae*), pod borer (*Maruca testulalis, Helicoverpa armigera),* flower thrips, sucking bugs, bean stem maggot (*Ophiomyia phaseoli*), Bean bruchids (weevils) (*Acanthoscelides obsoletus).*

Mango, apple: Fruit fly (*Bactrocera invadens*), Mango seed weevil

Plantation forests: Pine aphid

Sugar cane: Stem borer

Control strategies being employed: Cultural practices which include: use of un-infested planting material, removal of volunteer plants and crop debris (sanitation), timely planting and prompt harvesting to avoid a dry period, removal of alternate, wild hosts, planting away infested fields, hilling-up of soil around the base of plants and filling in of soil cracks, applying sufficient irrigation to prevent or reduce soil cracking. Chemical control: Pheromone traps are being promoted to reduce population of *Bactrocera invadens* in most of the country with high fruit producing regions. Biological control of the Larger Grain Borer with *Teretrius nigrescens*. Botanicals (tobacco, tephrosia, tagetes, neem) applied as powders (work as biocides, anti-oviposition deterrents, repellents); solarisation of stored grain in a solar heater in which all stages of insects die within under this treatment on a sunny day).

National Capacity to handle pest situation: NARO has 16 research institutes with six institutes having national mandates and 10 with regional /zonal mandates. Most of institutes have officers who are charged with surveillance and monitoring for occurrence of any pest. However the regional /zonal infrastructure is very weak in terms of laboratory capacity in diagnostics. In addition, the local government system has agricultural officers at all sub counties. These officers are also responsible monitoring for any pest occurrence.

National plans for insect pest management: Continued development of effective pest control strategies (NARO); policies that recommends and promotes IPM applications and control of any new introduction of new pest under different ministries; development and implementation of a monitoring system for pest management activities and impacts on non-target species.

RESEARCH PROGRAM ON Roots, Tubers and Bananas

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