NATIONAL SCIENCE AND TECHNOLOGY FORUM

PROCEEDINGS OF DISCUSSION FORUM
PLANT HEALTH IN SOUTH AFRICA: THREATS TO BIOSECURITY, BIODIVERSITY AND FOOD SECURITY

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Virtual Online Discussion Forum

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DAY ONE: PLANT PATHOLOGY, PESTS AND EPIDEMICS

OPENING AND WELCOME

Ms Jansie Niehaus, Executive Director of the National Science and Technology Forum (NSTF) welcomed everyone to the Discussion Forum and thanked the presenters for participating in the event. The forum would be recorded, and the presentations would be posted on the NSTF website with the permission of the presenters.

The United Nations declared 2020 as the International Year of Plant Health (IYPH). The Year was extended until 1 July 2021 due to the postponement of some key initiatives caused by the COVID-19 pandemic.

SESSION 1: CHAIR: MS JANSIE NIEHAUS, EXECUTIVE DIRECTOR, NSTF

A global perspective on tree health: Celebrating the United Nations 2020 International Year of Plant Health (Prof Mike Wingfield, 2020 Recipient of NSTF-South32 Award, Advisor to the University of Pretoria Executive)

In considering tree health, it should be remembered that tree health issues pertain equally to all plants. One key difference between agricultural crops and trees is that trees grow for long periods and have to contend with invasions, but their ability to cope is small. Tree health plays an important part in food security, particularly because of the impact of trees on the quality of water and air. Climate change is impacting heavily on tree health in many parts of the world, but this vast subject is not included in this presentation, which focuses entirely on tree health as impacted by insect pests and microbial pathogens.

The general perception of forests is often confined to the dense forests of the Northern Hemisphere or the arboreal parts of tropical areas, but the incidence of forests is more complex than that and also includes woody ecosystems such as the South African Fynbos and the savannah woodlands of East Africa. It is also important to note that every organism that interacts with trees is dependent on the health of the tree.

Trees occur in all aspects of our lives and are planted for many different reasons. Examples include the jacarandas in Pretoria planted for both their beauty and for shade in urban streets, and the commercial forests that provide both timber and cellulose products and also create many work opportunities. These trees usually originated in forests elsewhere in the world. Fruit trees that form an important part of our agricultural production are also mostly native to other parts of the world. The avocado, for example, was imported from South America, where there are now very few natural forests of this tree left in its original habitat, which is a serious issue in respect of bio- and genetic diversity.

Pathogens and pests have a huge negative impact on trees. There are many instances of this impact, but some examples include Dutch elm disease in the Northern Hemisphere. The disease became apparent at the beginning of the last century and is caused by a microbial fungal pathogen carried by insects, which has devastated landscapes both in Europe and America. The pine plantations in Chile have been devastated by a beetle, and root disease has killed avocado trees globally. In the urban environment, there are also many examples including the devastation caused by the shot hole borer in South Africa. These examples illustrate the extent of pathogens and pests and their impact on tree health.

Many studies have confirmed that pathogens are mostly introduced by the movement of people and goods around the world. A huge amount of goods and materials are moved by air or shipping, and with them we also move pests and pathogens. In addition, studies show that 70% of pathogens that were introduced into Europe were through the live plant trade, including cut flowers, bulbs and nursery plants, but this is difficult to restrict due to its economic importance.

In the forest environment, a study of eucalyptus plantations around the world shows that between 1870 and 1970, one new pest species was identified on average every 6.3 years; this situation changed from 1970 onwards, with a new pest species occurring on average every 1.4 years. This is a dramatic change and all indications are that this is due to the movement of material related to the eucalyptus industry such as plant material and seeds. There is unfortunately every indication that this will not reach a plateau, but that the numbers will continue to rise. Seed is often overlooked as a carrier of pathogens and even though every effort is made to clean seed, pathogens and pests are often still present.

Fortunately, the application of increasingly powerful technology has already provided solutions, and will continue to do so. Some examples include the development of pathogen-resistant eucalyptus plants in South East Asia through the selection of gene types showing resistance qualities; the control of the wood wasp living with wood-rotting fungus that made pine forests sustainable; the safe and effective use of chemical control; and quarantine, which is extremely important but quite complex to manage.

The development of recombinant DNA technology has brought with it amazing tools, from the discovery of structural DNA, to DNA sequencing and the post-genome era. The team at the University of Pretoria (UP) worked on sequencing the first fungus from Africa. Not only was it important to know the DNA of the fungus, but the process was used as a teaching tool, which offered young people an opportunity to work in the field of sequencing technologies. The DNA era has enabled a higher level of understanding, and meta-genomic tools are very powerful in identifying microbial pathogens.

The COVID-19 pandemic of the past year has been very worrying and somewhat unexpected, but as microbiologists studying plant diseases, it is amazing how the tools for tree diseases are similar to the technologies used to fight the Coronavirus. Unfortunately, trees do not have vaccines to protect them, which makes tree health more difficult to manage. Technologies have rapidly been developed to address the problems of the Coronavirus virus. In South Africa, within weeks of the identification of the virus, the genome had been sequenced, which made it possible to map the spread of the pandemic. An understanding of variability was also developed, since the speed at which variants emerged was very important in how vaccines would perform. All these technologies are useful when dealing with trees. Quarantine is also very important, as well as the management of information and the sifting of data. There is a need for collaboration and global strategies in the field of tree health.

Bill Gates, in discussing the response to the Ebola virus, said that at least 10,000 people would not have died if technology that was already in existence had been applied. This also brings to mind the Red Queen hypothesis, derived from a statement in *Through the Looking Glass* by Lewis Carroll, where the Red Queen makes Alice aware of the danger of running on the same spot. We should not stay in the same place – we need to keep moving in our response to tree pests and pathogens.

The role of Natural Science Collections and Biobanks in plant health (Prof Michelle Hamer, Director: Natural Science Collections Facility, South African National Biodiversity Institute)

The focus of the presentation is on two initiatives, the Natural Science Collections and the Biodiversity Biobanks, their aims and how these contribute to plant health, and the challenges of maintaining these collections.

The Natural Science Collections is a Department of Science and Innovation (DSI) project initiated early in 2017 as part of the South African Research Infrastructure Roadmap initiative. The collections comprise a network of 16 institutions, including museums, science councils (the South African National Biodiversity Institute, Agricultural Research Council and South African Institute for Aquatic Biology), and three university herbaria. The coordinating hub is at the South African National Biodiversity Institute (SANBI). The focus is on preserved, non-living collections of plants, animals, fossils and fungi.

The Biodiversity Biobanks are also a DSI Infrastructure Roadmap initiative, which has been slow to start but is now getting going. The scope of the Biobanks is frozen plant and animal tissue and DNA extracts, gene banks and microbial cultures, including agricultural Biobanks. The core focus is the long-term preservation of selected samples on behalf of the nation and allowing access to samples for research and development purposes both nationally and internationally.

Specific involvement of institutions in the two initiatives includes:

- The South African Institute for Aquatic Biology (SAIAB) and SANParks (South African National Parks) are involved with animal species, and previously also the National Zoological Gardens.
- SANBI has signed a partnership agreement with the Millennium Seed Bank, a plant DNA bank.

- The Department of Agriculture, Land Reform and Rural Development (DALRRD) is involved with the Plant Germplasm collection, comprising mostly commercial crops, but also some medicinal and crop wild relatives.
- The University of the Free State (UFS) contributes through the yeast collection.
- The University of the Western Cape (UWC) has a collection of microbial cultures.
- The Agricultural Research Council (ARC) works on crop and plant viruses, Rhizobium and other soil bacteria cultures, fungi cultures and extracted DNA, germplasm and tissue culture, various fruit and vegetable crops, and some ornamental and medicinal plants.

The two initiatives, the Natural Science Collections and the Biobanks, are separate but have some common aims. Both aim to secure collections, including rescuing orphaned collections, upgrading datasets and data management. They also aim to increase the use of the collections for research, development and decision-making and to increase awareness of the collections and their value. In order to achieve these aims, it is essential to professionalise collection and data management through staffing and capacity development. Transformation from operating in isolation to being part of a network is required, and the collections should be accessible to be used by external researchers. It is also important to navigate the complex legislation and permit requirements.

With respect to the Natural Science Collections, it is more difficult to show how these collections contribute directly to plant health. They are important as a record of what species we have and where they are recorded, and how this has changed over time. The collections span almost 200 years and provide historical data that allow changes in distribution over time to be mapped. This can be applied to both invasive species expanding their range or threatened species that have a shrinking range, as well as the detection of the origins of diseases and pests. The collections are used as a reference for the identification of biological materials, soil organisms, pests, pollinators, and indigenous and alien plant species, all of which are relevant to plant health.

The data from these collections, especially data on locality, are critical in conservation assessment projects. The Red List of South African Plants published in 2009 and updated on a regular basis, as well as data on pollinators, rely on information from these collections, which is also important for environmental assessment and spatial-planning projects. Without healthy ecosystems, we will not have healthy crops or indigenous species.

The data from the collections have been used for projects on crop wild relatives. Crop wild relatives are species with genetic traits that could improve crop viability; 1574 species have been identified in South Africa, including relatives of rice, rye, barley, cucumber, potatoes, tomatoes and many others. Plant specimen data, including the areas where they occur, are important for conservation, and once these species have been mapped, the material is collected for inclusion in gene banks.

Biodiversity Biobanks have a more direct relationship to plant health. Plant germ plasm, seedbanks, tissue cultures, and plant and crop diversity aspects contribute to research in a range of fields, such as physiology, seed biology and genetics. They also contribute to the conservation of threatened species and the rehabilitation of ecosystems. In the domain of agriculture, they contribute to plant breeding, the supply of stock for subsistence and commercial farming (crops, fodder), and are critical for the development of new varieties, or replacement when farmers lose existing stock to disease.

The microbial cultures, bacteria, viruses and fungi diversity, including plant pathogens and plant growth-promoting forms, are essential for research on taxonomy, diversity, plant pathology and biotechnology. These are also important in the commercial development of products such as inoculants for soils to promote plant and crop growth and resilience. The microbial cultures serve as a reference for the identification of plant pathogens and diagnostics.

The biorepositories contribute directly to human health. Through the preservation of these repositories, agricultural productivity is increased, leading to better food security and ultimately health and well-being. This concept is sometimes difficult to communicate, and it can be useful to look at the process the other way round. Without well-maintained biorepositories, there would be a lack of verifiable data, inaccurate identification and wrong diagnoses. Moreover, there would be no reserve stock in the case of devastation, which would impact negatively on food security, the economy and the environment. Microbes change quickly, and without the collections it would be impossible to go back to see what had happened before.

Despite the value of the collections, however, they remain under risk. Workers are committed to the collections but remain undervalued. The DSI funding does not cover day-to-day operations, and because the significance of the biorepositories is not always evident, they are at high risk of budget cuts or even closure at times of financial stress, not only in SA but globally. In addition, the ongoing neglect of maintenance of buildings could have serious effects on collections, with disastrous results.

Challenges with regard to people issues include communication, fragmentation and isolation of individuals, collections and institutions, weak alignment with national priorities and resistance to opening up access to collections and data because of a sense of ownership by individuals and institutions. New ways of operating for increased efficiency and professionalism are urgently needed.

Challenges with regard to permit issues include the holding and sharing of plant samples of importance to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Threatened or Protected Species (ToPS) Convention, registration of a scientific institution, standing permits and collecting permits. Further challenges in this domain include the supply of samples and the access and benefit-sharing legislation, as well as the implications of the international discussion on Digital Sequence Information on Genetic Resources (DSI), under the auspices of a work stream of the Convention on Biological Diversity (CBD) and its Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (Nagoya Protocol).

In addition, there are challenges of aligning national legislation with EU interpretations of the Nagoya Protocol. Many South African species, strains and varieties are already scattered across the world in repositories or cultivation. Currently, the Millennium Seed Bank at Kew Gardens holds a large collection of seeds from South African plants, and the only indigenous plant DNA bank is a duplicate of the one at Kew (funded by the Darwin Initiative).

Some balance and a clear, rational plan are needed. The collections have so much potential to make a meaningful contribution to plant health, but there is much work to be done.

The impact of a tiny beetle and its deadly fungus on South Africa's forests (Prof Wilhelm de Beer, Forestry and Agriculture Biotechnology Institute, University of Pretoria)

The focus of the presentation is on a little beetle that is receiving a lot of attention in South Africa, and on how to prepare for similar invasions. References to forests include natural forests, commercial forests, old trees such as those planted by Simon van der Stel in the Cape, and also urban forests such as the City of Johannesburg.

The plane trees in the Pietermaritzburg Botanical Gardens formed part of a project funded by SANBI that looked at all the botanical gardens in South Africa, using them as indicators of new arrivals of pests in the country. During the study, marks resembling shot gun holes were identified on the plane trees. Tiny holes were seen first; on removal of the bark, a streak caused by a fungus became visible; and then the small beetles of about 3mm in size were found.

The beetles were studied under a microscope and their DNA was sequenced to facilitate identification. The sequence from the Pietermaritzburg beetles proved to be identical to those found in California and Israel. There are four different species of shot hole beetle and it is difficult to identify the species. The species found in South Africa is the polyphagous shot hole borer (PHSB). It is important to be able to differentiate between the beetles and to look out for new gene types.

The beetles usually breed in dead or dying trees, where they establish galleries for that purpose. The beetles take fungi to the galleries to provide them with food, and three different fungi have been identified. The DNA of the fungi from Pietermaritzburg was sequenced and was 100% identical to galleries from a stem that was cut in Johannesburg. The fungus blocks the sap flow of the tree, and the tree ultimately dies.

The borer was described a long time ago in South East Asia, and was then found in California in 2003 and in Israel in 2008, where they were identified on avocado trees. The borer was sequenced in Durban in 2012 but the sequencing went unnoticed until 2017 when work was started on the borer. The borer beetle has thus definitely been in South Africa since at least 2012.

It is difficult to compile a list of host trees, since the shot borer attacks many different trees. An important distinction is made between different types of infestations. Reproductive host trees are those that the beetle infests and where it successfully establishes a breeding gallery in which the fungus grows, eggs are laid, and larvae develop into mature adults, thus completing its life cycle. The majority of reproductive hosts eventually succumb to the disease symptoms caused by the fungus. Non-reproductive host trees are attacked by the beetle, but the beetles do not establish breeding galleries. The fungus may or may not cause disease, and the trees are generally not expected to die. There are also trees that repel the beetle. Many host species have been identified in California. In South Africa, 150 host species have been identified, and the list is constantly being updated. Identification is made difficult by the fact that even if a beetle is found on a particular tree, it does not mean that it will infect all the trees of that species, and also does not mean that all the trees will die.

It is reasonably certain that the PSHB entered South Africa in wood or some sort of wood product from South East Asia. Wood that is moved around locally as firewood or transplanted plants can also contribute to the borer beetle becoming invasive. Sugar cane ought to be a barrier to the beetle, but it is now a carrier. The beetle can move with wood chips, but this is less of a problem; however, nursery stock is of concern.

Beetles are present across three sectors: agricultural and commercial forests, natural forests and urban forests. Some examples include trees in Johannesburg that were perfectly healthy four years ago and are now dying, oak trees in George that have been infected, and beetles moving from Somerset West to Stellenbosch where they are attacking oak trees in particular. In the City of Tshwane, the borer is becoming a major issue, including infestations in trees in the Union Building gardens.

In the agricultural sector, the beetle has been found in avocado and macadamia trees, but is not causing much damage at the moment in farm crops. In the commercial forestry sector, the eucalyptus is not affected. In the domain of native forests, the borer is moving from Tsitsikamma up to Durban and Richards Bay, and a number of tree species are being attacked. The beetle is being found in numerous locations around South Africa, and although not recorded in Limpopo it is probably just a matter of no reports yet.

There are many possibilities with respect to treatment. No form of chemical treatment will be effective, and treatment is thus a matter of management. Infected trees should be cut down and the beetles killed. Especially in urban areas, diversity of planting would be helpful, which would also make urban forests more resilient to climate change. It is recommended that trees not be transplanted or moved.

Much research is being conducted across the country, but especially at Stellenbosch University (SU), UP and Rhodes University. It is a large team effort. There are problems of governance in the control of the beetles, since they occur in many different areas, which fall under the mandate and authority many different departments and municipalities. A governance document for dealing with the governance problems related to managing the shot hole borer has now been prepared and accepted by government; the document also deals with facilitation for reaching government departments and cities.

In reviewing the impact of the beetle, not all trees will die, but urban areas will be the worst affected Plane trees, oak trees and maple trees will be the most vulnerable. An assessment conducted by SU and UP on the influence of the beetle over the next ten years shows that there is a need to diversify. Native trees might be lost and ecosystems might change. Surveys are also being funded by DSI on biological control.

Information regarding the research and contact addresses is available on the Forestry and Agricultural Biotechnology Institute (FABI) website. An email address for shot hole borer enquiries is also available on the website.

Question and answer session

Question – Mr Ben Durham: The talk provokes in us the need to protect and stop what is happening. However, perhaps the response should rather be to recognise that the rate of change in the environment is inevitable and to focus rather on protection or on skills development such as genetic modification or

synthetic biology, and also to look less at indigenous species and rather at species that are more resilient. Is conservation a viable long-term strategy?
Response – Prof Wingfield: This is a very complex question. There are many different angles and opinions, but for me the area of most concern is our native ecosystems, because when a pest finds a susceptible host there is little that can be done and in those cases the devastation will continue. It is also important to look at biobanks and at preserving seed sources. We need to do all that we are doing, as we rely on plants for our livelihoods and food. With the Coronavirus, many focused on the negative aspect of the first variant being identified in South Africa, whereas I applauded the sophisticated technology available in this country that was used to identify the variant. We need to maintain what we have and to develop technology that we can depend on in the future.

Question – Mr Ben Durham: Are we seeing more complex export and import permits, effectively encouraging illegal activities?
Response – Prof Hamer: There will always be people breaking the law, sometimes intentionally but often unintentionally, because they do not know the law and because it is so complex. It is difficult for biologists to do their work; just in performing their tasks they are often breaking the law. One hopes there is something that will happen to try and address this situation.

Question – Ms Buyisiwe Ngubane: What is the difference between reproductive and non-reproductive trees with respect to the shot hole borer. What are the respective roles of reproductive and non-productive trees? Do reproductive trees spread the disease?
Response – Prof de Beer: The beetle attacks different trees and establishes a breeding gallery with the fungus, which eventually kills the reproductive tree. For whatever reason, non-reproductive trees can be infected but do not die, even if the fungus is present. In terms of management, reproductive host trees need to be removed when there is an infestation.

Question – Dr Ida Wilson: Do you see plants recovering where shot hole borer has been detected, as in the willow trees in California?
Response – Prof de Beer: Unfortunately, our surveys have been interrupted by the COVID-19 pandemic, especially in the Tsitsikamma and Durban areas, but we have seen improvements. The pecan trees in Jan Kempdorp have improved after inoculation. California is a bit different, but they have seen new shoots from recovering trees. However, my feeling is that a branch of the same tree, once it is thick enough, will be re-infected by the beetle. We have not looked at this in our research to date and it is an important area to be investigated.

Question – Mr Ben Durham: In response to the concerns expressed by Prof Hamer, from the government perspective, policies are developed with specific intent in mind. Government needs to be alerted if things are not functioning as they are intended and whether the policy needs to be changed. We have a number of complex access and benefit-sharing regulations that have good intent, but if they are difficult for academics to comply with, people will remain ignorant of the law. We need to make an assessment of whether there is a need to change. Is there any comment on the regulatory environment in South Africa?
Response – Prof Wingfield: We all strongly endorse the intention of the Nagoya Protocol; however, academics were not included in the discussions of the protocol. This presents problems in relation to collecting plats for research and the national good. South Africa has excellent laws, but implementation is often not effective.
Prof Hamer: Legislation needs to be reviewed. It is not a matter of forcing academics to be compliant, but there are problems with the implementation of the legislation. There have been instances of consignments of plants being blocked and of scientists not being able to publish in Europe because of lack of compliance. There needs to be a realistic re-look at the laws.
Mr Jan Hendrik Venter: International treaties and protocols are signed by politicians with very little scientific input. This is a global issue. Maybe we could start to look at how to address this. Another issue is that many things are over-legislated, contributing to non-compliance. Trade laws may also be too restrictive, leading to smuggling. There is a need to adapt the legislation. The stance of the Nagoya Protocol on bioprospecting is very noble, but the current laws are a severe hindrance to researchers.

SESSION 2: CHAIR - DR ANSA VAN VUUREN, SENIOR RESEARCH MANAGER: AGRICULTURAL RESEARCH COUNCIL

Whither (or wither) plant pathology in the next 50 years? (Prof Wijnand Swart, President, South African Society for Plant Pathology)

In looking at plant pathology and how it will develop in the next 50 years, it is necessary to contextualise this and look at the plant pathology timeline. We need to know the history and development of the discipline of plant pathology in order to understand its future direction.

As early as 286 BC, Theophrastus, the father of botany, studied the diseases of trees and cereals. He was followed in 1665 by Robert Hooke, who showed that plant pathogens caused disease. In 1675, Antonie van Leeuwenhoek invented the compound microscope and became one of the first explorers of the microscopic world, and one of the first people to observe cells. The momentous potato blight in Ireland between 1845 and 1852 resulted in the death of more than one million people and the emigration of more than two million people to the USA. In 1853, Anton de Bary, the father of modern mycology, established that fungi are the cause and not the result of plant disease. In more modern times, in 1903 the first Department of Plant Pathology was established at the University of California under Prof Ralph Smith, and in 1907 the first academic department of plant pathology was started at Cornell University. In 1921, Paul van der Bijl was appointed as the first Professor of Plant Pathology and Mycology in South Africa at Stellenbosch University, and the South African Society for Plant Pathology (SASPP) was founded in 1962.

Fifty years ago in 1971, Prof William C. Snyder from the University of California published an article in the *Annual Review of Phytopathology*, claiming "Today the Sciences, including Plant Pathology, and even the Universities are in trouble… Terms such as 'agriculture' and 'plant pathology' are a bit 'out,' while 'ecology' and 'environment' are 'in'." Yet actually the concerns of ecology and the environment are built into plant pathology. More than most other disciplines, plant pathology is concerned with the inter-relationships of the pathogen and host, ecologically and in relation to the total environment. No other discipline is more concerned with ecology and the environment. If the public really knew about plant pathology, it would be considered 'in'.

In looking at old and new concepts in plant pathology, we see that the disease triangle (host, pathogen and environment) was followed by the disease tetrahedron which included the dimension of time, and ultimately the disease pyramid which added the human element. More recently Prof Bernard Slippers, in an article in the *South African Journal of Science*, introduced a fifth dimension, namely society and the microbiome. Slippers maintains that the fifth dimension will have a profound impact on disease development and outcomes, at scales from the local to the global. The aim of plant pathologists, in collaboration with other fields and sectors of society, should be a continuously adaptive and resilient system that can buffer against shocks such as pandemics.

The future challenges for plant pathology include the increasing demand for food to support the booming global population, in association with the reduction in production potential in agriculture due to competition for land in fertile areas and the exhaustion of marginal arable lands. In addition, there is an increased risk of disease epidemics from agricultural intensification and the use of monocultures, the depletion of natural resources and the influence of climate change.

At an international congress held in Glasgow in 2003, I.R. Crute (Principal Scientific Officer at the UK National Vegetable Research Station) shared a view of what would be required for a sustainable future for plant pathology: it would need to be based on the use of one or more renewable resources and would not break down due to evolutionary change. The strategy would have a broad spectrum of applicability and would be affordable in the context of the local economy and crop value.

In 2011, in an article in the *Journal of Agricultural Science*, J.A. Lucas outlined the three key issues facing plant pathologists in the 21st century: firstly, to strengthen food security while safeguarding the health of associated ecosystems and reducing dependency on natural resources; secondly, to devise pest and disease control systems that are sustainable; and thirdly to develop appropriate crop protection technologies and mechanisms for their use. Lucas also identified future technologies that would have an impact on plant pathology: disease detection and diagnosis, plant defence and immunity, accessing and exploiting genetic diversity, pathogen targets for intervention, and ecological approaches to disease control.

Molecular diagnostics are receiving increasing attention in the field of disease detection and diagnosis. DNA-based technologies have greatly increased the speed, sensitivity and accuracy of pest and pathogen detection and diagnosis. The development of biosensors that are able to identify pathogen inoculum in real time, coupled to information networks, will provide real-time monitoring and surveillance of crops or stored produce, giving early warning of emerging problems and new invasive species.

In the past decade, reports of the use of nanotechnology in phytopathology have grown exponentially, and nanomaterials have been integrated into disease-management strategies and diagnostics and used as molecular tools. Nanotechnology can increase productivity using nanopesticides and nanofertilisers; improve the quality of the soil using nanozeolites and hydrogels; stimulate plant growth using nanomaterials, and provide smart monitoring via nanosensors and wireless communication devices, including artificial intelligence. Sensor systems can be successfully used in precision agriculture and plant phenotyping. Hyperspectral technology-based plant disease detection, as a typical type of non-invasive technology, is drawing increasing attention from precision agriculture.

In the domain of plant defence and immunity, induced plant resistance is being improved by priming of plant defences to help deal with a diversity of biotic and abiotic stress. Salicylic acid, jasmonic acid and ethylene signalling pathways are potentially antagonistic, but the emerging view is that synergy can be achieved between these parts of the plant defence network to achieve broad-spectrum resistance to pests and pathogens.

Plant defence activators and the future prospects of delivering chemicals modulating plant resistance by means of biological agents, such as engineered microbial colonists, might lend themselves to low-cost seed or propagation material treatments, removing the need for expensive spray regimes. The success of such approaches will depend on improved knowledge of microbial ecology and population dynamics in microbiomes, and the role of specific signal molecules.

Another interesting idea put forward by Jana Sperschneider in 2019 was related to applications of machine learning (ML), using statistical methods to identify patterns in data, commonly divided into unsupervised and supervised approaches. Light reflectance from a healthy rice plant leaf, for example, will differ from that of a stressed leaf and can be measured using sensors. By sequencing pathogen or plant genomes, it is possible to identify genes that are involved in host–pathogen interactions. ML can enable the detection of cytoplasmic effector pathogen proteins that enter the cytoplasm of host plant cells.

Sequencing the genomes of major crop species and their wild relatives will expand the known gene pool and diversity of genetic resources available for plant breeders to access. Genetic modification approaches will facilitate pyramiding resistance genes in crops with different specificities and modes of action, thereby reducing the risk of directional selection for virulence by pathogens.

In the field of pathogen targets for intervention, a new era beckons in which the prospect of ‘crop pharmacology’ based on signal molecules and their receptors will become a reality. This will be based on the development of new chemistries designed to manipulate specific molecular targets, either in regulating host resistance or disabling the disease-causing processes of pathogens, and will be driven by an exponential increase in genomic, transcriptomic, proteomic and metabolomic information populating databases, and improving the tools to manage, mine and interpret this information.

Understanding the ecology of pathogens will improve the ability to exploit their natural enemies or antagonists. Volatile organic compounds, either from natural plant sources or engineered in transgenic crops, will be used to modify pathogen behaviour.

With regard to ecological approaches to disease control, the introduction of invasive pathogen species and the effects of climate change will have a particular impact on emerging plant diseases and managing epidemics. The effects of climate change on enhancing and mitigating the interchange of influencers is very complex and requires much research at all levels. It is therefore critical to take a holistic approach to understanding how and why pathogenesis occurs in order to effectively manage for diseases, given the synergies of changing environmental conditions.

Crandall *et al*. (2020) developed a multiomics approach, which allows for a detailed picture of plant-microbial interactions and can ultimately allow the building of predictive models of how microbes and plants will respond to stress under environmental change. Omics approaches, from the genotype to the phenotype, will inform plant disease ecology in a holistic manner and can shed light on microbial communities above and below ground.

There is a need to move towards a systems-thinking approach. Phytobiomes consist of plants, their environment, and their associated communities of organisms. A systems-level understanding of phytobiomes will enable the sustainable and profitable production of sufficient crops to meet global demand, while minimising negative impacts on the environment.

Some elements of systems thinking would entail that future epidemiology must bridge scales from the genetic to the global level. The catalyst for this interdisciplinary approach would be the application of mathematical modelling to successfully capture the complexities of host–pathogen–environment interactions. This approach presents some major opportunities, including an unprecedented capacity to gather and analyse big data. Anti-microbial resistance has the potential to cause epidemics not experienced since the pre-antibiotic era, and epidemiological models therefore need to be merged with an economic and behavioural framework.

In educating future plant pathologists, the ‘One Health’ concept should be applied, which demands the collaboration of multiple disciplines across people, animals, plants and the environment. The integration of a wide range of disciplines, including systems engineering, biogeochemistry, genomics, biochemistry, physiology and ecology, will all be required components of this complex cocktail. The complexities need to be understood in working across and between disciplines. It is interesting to note that the International Congress of Plant Pathology (ICPP) 2023 has adopted ‘One Health for all crops and trees’ as the theme for the conference.

Whither or wither plant pathology? It will evolve as an interdisciplinary science; food security will be a dominant theme, and climate change will be extremely important. Collaborations with biomedical and aeronautical engineers, nanotechnologists and computer scientists will help develop micro-sensory technology for the detection of new pathogens for use in biosecurity, diagnostics and epidemiological modelling.

Perhaps in the not-too-distant future, there will be a plant disease Tricorder©, like the one used by Dr McCoy in Star Trek: an instrument that contains a DNA chip from virtually every known plant pathogen, making it possible to identify the disease within seconds, and to access all available information about its control, by simply snipping off a piece of the infected plant material and slipping it into the Tricorder©. This is perhaps far-fetched, but no doubt possible.

Threat of migratory and invasive insect pests to food security in South Africa (Dr Roger Price, Manager: Insect Ecology Division, Agricultural Research Council)

Locusts have been legislated as notifiable pests in South Africa since about 1911. Four species of locusts occur in South Africa: the brown locust, the red locust, the African migratory locust and the southern African desert locust, which is a subspecies of the more infamous North African desert locust. Other migratory pests are the African armyworm, the fall armyworm, the tomato leafminer and the oriental fruit fly. Apart from these pests, there are a plethora of other migratory and invasive pests such as the quelea bird and many invasive alien plants.

The impact of invasions on farmers is considerable. Crop yield losses mean direct economic losses to farmers and reduce competitiveness. The additional costs of control reduce farmers’ profits. Commercial farmers on large farms with high-value crops have high costs of crop protection, but also have access to modern pesticides, application techniques and genetically modified (GM) crops. These farmers also have access to technical advice. By comparison, smallholder farmers are very vulnerable to complete crop loss. The invasions mean low yields and high relative input costs related to fuel, seed and fertiliser. Moreover, smallholder farmers have poor access to technical advice and low resilience to agricultural risks such as pests, droughts and economic shocks. To millions of smallholder farmers across Africa, invasions may be the last straw.

The brown locust is the most economically important locust, as it has high fecundity and outbreak frequency. In the last 100 years, there have been outbreaks requiring control nine out of ten years, which poses a huge threat to food security. The outbreak area is the semi-arid Karoo, but swarms escaping from the Karoo can invade the entire southern African region. Before the availability of insecticides, swarms of locusts used to rampage across southern Africa right up to the Zambezi River, and most African governments deemed locusts to be the main agricultural pest to contend with. Hopper bands are usually fairly small, but the bands increase in size in the more remote areas. During the day, they walk in bands for several kilometres a day and then they form swarms. Farmers spray the locusts in the early morning to try to control the damage to crops. There are very few years in which there are no locust outbreaks.

The African migratory locust has recently been causing problems in Zambia, Zimbabwe and Angola. Local outbreaks of this locust generally occur in grasslands and cereal cropland areas and can cause heavy damage to maize, sorghum and wheat crops. Red locusts do not breed in this country; they may invade South Africa but do not cause much damage here. There have been outbreaks of the African desert locust in the Kalahari north of Upington, but the swarms are small and do not constitute a major risk. As a country, South Africa needs to manage the issue of locusts urgently.

Another insect pest is the African army worm, or commando worm as it is known locally, which causes large outbreaks about once a decade and small outbreaks every three or four years. The worms crawl on the ground and then march across crops causing immense damage. It is too expensive to control the worms over the large areas where they occur.

The fall armyworm originated in South America and then moved to West Africa. It is now spread throughout Africa and reached southern Africa in 2017, where it is now well established in warm areas. It is a recent pest, but a very serious one for maize. The worms dangle on silk threads to move between maize plants and then damage the growth point of the maize very quickly. The ARC is funded by the Department of Agriculture to investigate fall armyworm overwintering hotspots in South Africa. This worm is no longer an invasive species, and has become endemic in the country. In summer, the worms occur in the maize-producing parts of the country. In winter, they are killed by frost and they take refuge in areas of smallholder farming where maize is grown all year round.

The ARC was funded to conduct a survey of the socio-economic impact of the fall armyworm on smallholder farms in Limpopo. Approximately 3500 farms covering 40,000 hectares of land have been affected, and 77% of these farmers planted maize on small areas of land. These small areas of maize are planted year round for the cob vendor market, and most plant open-pollinated maize. Crop losses are between 25% and 100%, and many farmers had to replant more than once in a season, which depleted financial resources. These smallholder farmers rely on the provincial government to provide inputs, ploughing and pesticides. The fall armyworm has been financially crippling, directly impacting homestead food security. Few farmers have the skills or resources to plant alternative crops and have had to sell their livestock and household goods to survive. Many have sought employment on other farms or have looked for work in the city. The pressure of the fall armyworm will force many farmers to give up farming entirely.

Another recent invasive pest is the oriental fruit fly which was imported from Asia into Kenya in 2003. There are now at least four pest fruit fly species of Asian origin in African. The movement of the fruit fly can be traced via the major transport routes and arrived in South Africa in 2010.The fly is highly polyphagous and a major pest of mango, avocado and stone fruit. Commercial farmers spray to control this pest, but smallholders have become a reservoir for pest populations. The yield loss of mango in Africa is 40–90%, which is of serious concern for smallholder farms, but commercial farmers need be aware of the risks. Some groups are monitoring the distribution and density of the fly through baited fruit traps.

Tuta absoluta, or the tomato leafminer, is a major pest affecting tomatoes in tunnels and fields and causing devastation to smallholder farms. Large farmers are spraying against the leafminer, but there is a risk of a build-up of insecticide resistance. Smallholder farms are experiencing a complete loss of crops, and the production of tomatoes by smallholder farms is threatened to the extent that it might disappear. The management of *Tuta absoluta* is not good, without any scouting or warning system, and the indiscriminate use of chemicals with little knowledge of when to spray and when not to spray. There is a need for technology transfer and training and the implementation of strategies. Natural enemies have been identified, and there needs to be more emphasis placed on introducing these.

Pests will continue to threaten food security in South Africa. Fall armyworm, *Tuta absoluta* and oriental fruit fly are of particular concern for smallholder farmers and threaten homestead food security and income. All farmers are facing escalating input costs and environmental damage from the increasing application of pesticides, and the threat of build-up of insecticide resistance means that farmers will have to switch production or go out of business.

Locust monitoring and control in southern Africa is weak. Locusts are getting out of hand and becoming more expensive to monitor, locate and manage. The next plague is coming, so effective management is essential.

With regard to management strategies for invasive pests, phase one would be to ‘know your enemy’. This would include a trap network for early warning, training, monitoring, identification, reporting and data management and predictive models for early warning.

Phase two would be proactive management over the short and medium terms. This should include information regarding safe and effective insecticides and application methods. Training the trainers in pest scouting and pest management is also important, and training courses and information should be available to all farmers. Socio-economic assessment of the impact of invasive species on smallholder livelihoods and the targeting of pest populations at the most vulnerable stages could provide valuable information for control.

Phase three would be the development of management strategies for the medium to long term, which would include the availability of pest management information, effective outbreak monitoring, early-warning services available for specific pests, biological control, and the evaluation of cultural control strategies. The adoption of best-practice strategies for the management of invasive pests, environmental risk analysis of insecticide control measures, and insecticide resistance management strategies would also be important.

Question and answer session

Question – Mr Rheinhardt Sieberhagen: The National Metrology Institute has recently started the calibration of hyperspectral drones used in agriculture. Is there any knowledge of projects using this technology?
Response – Dr Berger: Hyperspectral imaging is part of the programme at FABI and we are interested in talking to people regarding calibration. A hyperspectral camera has just been acquired and this will be discussed on Day Two of the Discussion Forum.

Question – Dr Derek Watt: To what extent have biosecurity and pest control methods been put in place in collaboration with surrounding countries in the Southern African Development Community (SADC)?
Response – Dr van Vuuren: An initiative by the Food and Agriculture Organization (FAO) was rolled down from regional to national level. The initiative used a comprehensive approach of providing training on pests and diseases including armyworm, fruit flies and others. The roll-out included field schools teaching identification and control methods. It is difficult to do research in the context of such an initiative due to the restrictions, but it did have many positive results, including the local use of ash applied to maize plants to control the armyworm without pesticides.
Mr Jan Hendrik Venter: The FAO now recognises transboundary pests; this will be dealt with on Day Two of the Discussion Forum. There are problems in dealing with these issues, as we talk about transboundary pests, regional pests and cross-border pests, for example, and there are different international signatories to agreements. The World Trade Organisation (WTO) agreement on sanitary and phytosanitary procedures, for example, is not focused on pests but on trade. A global group was established recently to scan and identify pests at a global and regional level. A great deal of work will be involved in developing a system that can serve as an early warning to countries. It will not be foolproof when there are things like the shot hole borers that just appear in a few countries and will therefore not be globally included. There are a number of initiatives under way, but funding is an issue. South Africa can perhaps cope, but many other countries in the region do not have the capacity to conduct surveys.

Question – Prof Rachel Wynberg: You describe a worrying situation. How much of this is due to the production methods that we are using, which are reliant on monocultures and the use of chemicals, thus reducing the ability of any natural system to maintain an agricultural balance. Surely we need a new approach to agriculture?
Response – Dr Price: It is becoming increasingly evident that current practices are not economically or environmentally sustainable. We need to get into some sort of harmony to be viable going forward. If we continue to spray, there will be insecticide resistance. *Tuta absoluta* is being heavily sprayed with a variety of insecticides and pesticides and will be a candidate for resistance. If that happens, it will become impossible to grow tomatoes in South Africa. Pests are gaining control, and smallholders will be heavily damaged or even decimated unless we are careful.
Response – Dr van Vuuren: We will have to balance the short-term against the long-term effects on the environment. Time will tell if we will succeed. The signs are worrying, but many companies do have programmes in place where they, for instance, look at pollinators.

Question – Mr Ben Durham: It is not clear where the primary responsibility for management strategies lies. Obviously, the responsibilities involve both the private and public sectors combined, but what does the government's interest in small-scale farmers suggest? Is there any discussion with government and crop developers with respect to the way forward?
Response – Dr van Vuuren: Some big companies do have small-scale farmer programmes. The government perspective would entail issues of sustainability and a long-term view, which can be very different. There is support, but whether it is sufficient and whether it filters down to all levels is a problem. The rolling out of programmes to grassroots level is essential.
Mr Jan Hendrik Venter: Rolling out government initiatives is complicated because of the difficulty of linking different entities within government, as their mandates do not necessarily stretch far enough. The ARC has completed five projects on the armyworm, for example, and the results are ready to be analysed and a way forward determined. Projects will need to be implemented by the Department of Agriculture, Land Reform and Rural Development (DALRRD). Other departments and levels of government would need to be involved, but working across departments is very difficult.

Question: What support do smallholder farmers have from DALRRD and provincial authorities for fighting pests?
Response – Dr van Vuuren: The ARC has a fully equipped mobile plant clinic for use by anyone; there is just an issue of funding to implement it. This would be good for outreach programmes, which could provide a lot of information for further study.
Question – Dr Tlou Masehela: Is there any resistance to using pesticides on the one hand, or are ethical issues raised against genome technology on the other hand? Can all these things be made to complement each other, and where do we find the middle ground?
Response – Dr Price: We talk about integrated strategies, but in fact very little is being done and there is very little evidence of integrating pesticides and the environment. Habitat and conservation techniques give way to the pressure to make money and produce food.

WRAP-UP: DAY ONE

Ms Jansie Niehaus thanked all the speakers and participants in the forum. With the approval of the speakers, the presentations would be loaded on the NSTF website, as would the proceedings and a media release.

DAY TWO: PLANT HEALTH AND BIOSECURITY; PLANT HEALTH AND INNOVATION

OPENING AND WELCOME

Ms Jansie Niehaus, Executive Director of the NSTF, welcomed everyone to Day Two of the Discussion Forum, and particularly mentioned guests from the Chinese, Argentinian and Germany embassies, two delegates from Australia (one of whom was representing the Queensland University of Technology), attendees from Namibia and several government departments.

SESSION 1: CHAIR – PROF DAVE BERGER, FORESTRY AND AGRICULTURAL BIOTECHNOLOGY INSTITUTE, UNIVERSITY OF PRETORIA

Keynote address: Are there enough honey bees for sustainable food production? (Prof Robin Crewe, Senior Research Fellow: Centre for the Advancement of Scholarship, University of Pretoria)

Many people do not appreciate that for sustainable food production, we need the pollination services that honey bees offer.

There has been a lot of speculation of what the world would look like without bees, referring specifically to honey bees and not the 20,000 other species of bees, and often projecting a doomsday scenario for the absence of bees. In the light of the doomsday scenario, it is interesting to look at what has happened in the USA from 1969 to 2020 with respect to managed honey bee colonies, not the colonies that exist in the wild. On 1 April 2020, census day for bees, there were approximately 3 million managed colonies in the USA. To put this in context, the almond crop in California needs 2.5 million colonies in a season in order to pollinate a single crop. Beekeepers in the USA thus have to produce a large number of colonies in a short space of time in order to provide that pollination service. The key to the problem is producing enough bees at the right time.

The circumstances surrounding FAO data on the decline of managed bee colonies need to be taken into account. The number of managed colonies have more than doubled on a global scale since the baseline of 1961, showing that colonies are being maintained. In 1990, there was a dramatic decline in managed colonies in Europe, which coincided with the fall of the Berlin Wall. Many East German beekeepers had been paid subsidies to keep bees, and when the subsidies ceased with the fall of the wall, the colonies declined. It is important to note that not only are colonies of bees needed for pollination, but also the beekeepers who manage them.

In relation to the doomsday scenario, it is possible to speculate what the world looked like before bees. There were no flowering plants until the early Cretaceous era (145–113 million years ago) when flowering plants and associated bees emerged. The collaboration between evolving flowering plants and early bee species started in the relatively dry regions of Western Gondwana some 120 million years ago. The details of this interaction are largely unknown, because the Apid bees arose from an ancestral vegan wasp that switched to feeding on nectar from flowering plants and gave rise to four groups of bees: the orchid bees of South America, the honey bees, the bumblebees and the stingless bees. The fossil record shows about 40 species of Apid bees, with the largest proportion being honey bees. There are about 761 Apid bee species in existence today. Most Apid bee species have increased in number, except for honey bees which have declined. Honey bees, which are ubiquitous around the world, account for only 12 species out of the 761 total Apid bee species.

The early fossil records, from approximately 60 million years ago, are of stingless worker bees, so social bees have existed since then. During the Oligocene climate era, 34–23 million years ago, the number of bees expanded, one of the reasons for which was the very large temperate zone, especially across the northern part of the globe.

There were two types of bees that existed at that time: one was open-nesting species with a single comb and both dwarf and giant bee varieties, and the other was cavity-nesting species of intermediate size with multiple combs. Honey bees had a certain polar distribution around the North Pole, and these fossil bees were mostly a giant open-nesting species. When the climate changed, there were two mass extinctions of honey bees, with honey bees becoming completely extinct in America and open-nesting bees becoming extinct in Europe. Bees then moved to South Asia. Bees have occupied different parts of the globe at different times and are very sensitive to climate change.

Several species of bee occur in South East Asia or China, and some in India and the Arabian Peninsula. There is a group of open-nesting species that are either dwarf or giant, but these bees do not support a large beekeeping industry because the colonies are too small. The Asian honey bee is used successfully in agriculture. Some of these species occur in Malaysia, Sulawesi and Sabah, but their restricted distribution means they have no significance from an agricultural point of view. The western honey bee was originally found in Europe, Africa and the Middle East and is the bee on which most agricultural activities are based at present.

The western honey bee now has a global distribution thanks to human intervention. The African honey bee was introduced into Brazil in 1957 and has now spread across South America and Central America and into the USA. There has been a massive expansion of both the distribution of the species and its numbers. In comparison, the distribution of the Asian honey bee is confined to India, Japan, China, the Malaysian Peninsula, Cambodia and Myanmar.

We are now largely dependent on a single species of bee for most agricultural pollination, which is a significant risk in respect of biodiversity. We are dependent on the moving of honey bees into crops and out again before the application of insecticides, and also dependent on a sustainable source of honey bee colonies.

The source of these colonies are either from wild populations in Africa, Europe and the Middle East, or feral populations in the Americas and Australia. The influence of beekeepers is also important, and there are two types of these. One is the beekeepers that are colony multipliers, generally found in Europe, North America, China, Australia and New Zealand. The second are the colony harvesters of Africa, and Central and South America. Sustainability is thus dependent on the management of these two kinds of beekeeping strategies. It is interesting to note that China and the East are now largely using the western honey bee for both pollination and honey production, and that China has now become a major producer of honey based on this species.

Responsible colony harvesting of honey bee colonies for industrial farming and rural development is dependent on determining the size of the wild population and the variation of the population size in relation to climate. With that data, it is possible to determine safe levels of harvesting in various different biomes. Continuous monitoring of the state of the wild population is necessary to adjust harvesting levels and avoid over-harvesting.

It is necessary to know the population density. In social insects, this is determined by the number of colonies, which reflects the number of reproductively active queens. Finding and counting colonies is very difficult because they are cryptic, so alternative estimation methods are required. Currently two methods are used. One is the use of virgin queens that will go on a mating flight to a drone area and mate with 20–30 drones. Some sperm is stored for the production of offspring; if the offspring are analysed, it is possible to determine the number of colonies that were in the area when the queen was mated, providing a rough estimate of colony densities. The second is drone trapping using Williams drone traps in congregation areas. It is possible to determine which queen produced them, which can also help to determine colony densities. In a single small study, we obtained a single once-off picture, but we have no idea of seasonal changes or sizes in different biomes of southern Africa. There is a huge dearth of knowledge.

We currently know too little about colony density over large geographic areas to ensure an adequate supply of honey bees. We know nothing about the seasonal fluctuation in colony numbers. We need to determine if there are enough colonies to provide for the scaling up of agricultural production. This will be determined by two things: the number of colonies available, and the number of beekeepers who can supply pollination services. We need to effectively manage honey bee populations for sustainable agricultural production.

It is difficult to predict if we have enough colonies to supply pollination needs. The FAO data do not address this question. Pollination services are not measured by national governments, which tend to measure products rather than services. The number of colonies used in providing pollination services is not recorded. The data show only the number of colonies held by beekeepers in apiaries, and we do not know how many of these are used for pollination services. There is no current method for determining what the pollination service deficit will be in the future.

Pollination services are a unique national requirement that must be provided locally and cannot be solved by importation. South Africa's bee population and beekeepers need to provide these services, and we need to have much more information in order to provide services for pollination into the future.

Question and answer session

Question – Prof Mike Wingfield: Could the pathogens that are natural to one species be dangerous to another species?
Response – Prof Crewe: This is a serious problem, and one reason not to import bumble bees for pollination in tunnel agriculture as there is often a spill over of pathogens from one species to another. There is strong evidence of this from Europe, where bumble bees infected honey bees and vice versa. The importation of colonies of bumble bees carries a huge risk, as it is almost impossible to guarantee that they will be pathogen free. The transfer of pathogens is serious and should be avoided.

Question – Prof Brenda Wingfield: Kiwi fruit growers in South Africa are importing pollen to pollinate crops.
Response – Prof Crewe: Importing pollen to ensure results is a kind of controlled breeding. It is possible to put pollen traps in front of colonies, and as the bees leave they will pick it up and pollinate the flowers. This is a possible way to control breeding or to ensure that effective pollination is taking place.
Question – Prof Berger: To mitigate the risk of having a single species providing pollination, is there any potential to exploit the Asian species as an alternative, or are there any other wild species that have potential?
Response – Prof Crewe: There are one or two other species of bees used for pollination, particularly in Canada, but this involves the very careful rearing of a particular species to make them available in sufficiently large numbers. The advantage of honey bees is that there are 20,000–40,000 individuals in one colony, and many colonies can be used for one crop, which makes their use the easiest. Non-social bees are difficult to manage and produce in large-enough numbers to make pollination effective. The Asian colonies are relatively small, but the transfer of pathogens is very dangerous and can wipe out colonies.

Biosecurity and early warning systems (Mr Jan Hendrik Venter, Department of Agriculture, Land Reform and Rural Development)

Biosecurity and early warning systems are topics that are not always well defined. We need to understand where we are on a global level, but also what we can do in South Africa. We need to look at whether we are winning or losing the game.

The United Nations has set 17 goals for sustainable development which are to be reached by 2030. Is biosecurity influencing these goals? Biosecurity deals with protecting the planet, which is thus related to clean water and sanitation. Protecting life on land will lead to better jobs, economic growth and innovation. Innovation will in turn lead to the development of new biotechnologies which might help to reduce poverty. Poverty alleviation could assist in providing quality education, and possibly more responsible consumption of food and less hunger, which could reduce crime and provide for a good justice system. This is an indication that all the goals are interrelated, and fundamentally related to biosecurity.

There are many definitions of biosecurity. The Cambridge dictionary definition clearly looks at animals and people, while the Oxford dictionary definition focuses on humans. The FAO looks at agriculture, which includes both animals and humans, and provides a good basis for focus. Biosecurity is not well defined in any legislation, but the FAO speaks of a strategic and integrated approach, and the analysis and management of risks, and policy and regulatory frameworks.

An early warning system for plants would assist in defining which pests are coming, how we can detect them early enough, and how we then manage them. Elements of an early warning system could include horizon scanning, modelling, surveys, prioritisation, mapping tools, data management tools, preparedness plans, surveillance networks and diagnostic capacity. Most pests cannot be eradicated if we wait too long, and it is thus important to have the appropriate legislation and funding in place to do what needs to be done.

There is constant movement of goods and produce around the world, and South Africa has a well-established agricultural export and import industry. Pests are transported with these goods and are threatening food security. We already protect food from a number of identified pests, which is expensive and could possibly be avoided or reduced. The most commonly intercepted pests on imports are fruit flies on fruit, larger and lesser grain borers in grain storage, and white flies, mealybugs and other small pathogens on ornamental plants. There are many bugs and pathogens, and it is difficult to test for all of them.

Some international organisations are assisting in the control of pests. The WTO promotes trade but has recognised the problem of spreading pests. They have developed an agreement on sanitary and phytosanitary procedures that will make the trade in plant and animal products safer. The agreement contains 14 articles for the assessment of risk and the appropriate control measures. The agreement also offers some technical assistance, so there is some global focus on addressing the problem.

The WTO collaborates with bodies to develop standards. The United Nations Human Rights Council, which provides food to countries at war, has appropriate standards. The FAO, which is fighting famine across the world, assists in fighting pests. The International Plant Protection Convention (IPPC), signed in 1951 and overseen by the FAO, develops standards for food security and environmental protection. The 1997 New Revised Text of the IPPC outlines basic principles to manage risk and for operational control, surveillance and emergency measures.

There is a need for legislation, without which it is impossible to conduct a proper risk analysis or to enforce export and import compliance. This is also important with regard to the importation of host material. Without legislation and control, pests have the potential to become established. South Africa has a large agricultural industry and there is legislation in place for both import and national control of this industry. The management of this control is based on collaboration between industry, government and scientists through steering committees, which have been successful in managing past infestations and creating preparedness those that might occur in the future.

Examples of serious quarantined pests already in South Africa are the oriental fruit fly, the fall armyworm and the banana bunchy top virus. The citrus greening pest has not yet arrived in South Africa, but could devastate all the citrus trees if it were to reach this country. It already has a vector in Africa and is expected to arrive within the next few years.

It is difficult to know which pests we will encounter. Perhaps early warning systems will enable better management, but there is a need for government to provide funding and facilities. We need to manage pests and pathogens collectively, as these are impossible for a single country to manage individually. We need diagnostic networks, the collaboration of scientists, funded projects and pest reporting.

Question and answer session

Question: Is there any evidence of host switching by indigenous pests, from indigenous plant species to crops; for example, the shot hole borer occurring in sugar cane?
Response – Mr Jan Hendrik Venter: There is definitely evidence of this. Some pests do this very quickly, especially where monocultures are used. Insects and pathogens are very adaptable.

Question: Why are we dependent on the data from the Centre for Agriculture and Bioscience International (CABI)?
Response – Mr Jan Hendrik Venter: CABI collects data on various pests from different sources. There are mistakes in the data, so it is necessary to check the source data, but it is very easily accessed. The data are country based, so a single sighting will be listed for the whole country. It is difficult to get point data, since many countries do not want to divulge such data, but point data are required to study issues such as the influence of climate, and the locality of pests and pathogens in relation to ports and cities. An example of country data being misleading is that tropical fruit flies were recently detected in Vienna, which is by no means tropical. The pest was imported and it thrived during the summer, and then in winter the population died off.

Question – Dr Berger: What is the role of citizen science in dealing with biosecurity threats?
Response – Mr Jan Hendrik Venter: Citizen science is becoming more important worldwide as governments have to rely on local communities to assist in the detection of pests. This is lacking in South Africa, where reliable communication channels for such data are not available. There is a company in the country that has developed a freeware siting application, and they share the results with government. This is an important development that should be more widely rolled out, and we also need to build capacity to receive and respond to information. Australia has developed a public–private partnership model, and also has a fund managed by industry rather than government.
Response – Prof Crewe: There has been an upsurge in amateur beekeeping in Europe and the USA, which is important for establishing a lobby to assist in protecting these species. In Africa, bees are more defensive and more of a challenge, and most cities have laws to prevent keeping bees. Another aspect of citizen science is bee hotels. Essentially, a bee hotel is a block of wood with holes of difference sizes drilled into it that allows for the nesting of non-social bees, which form the majority of the species that we have. This provides significant information about biodiversity and changes in abundance over different seasons. South Africa has approximately 2000 species of bees, and bee hotels could provide useful information.

Question – Prof Mike Wingfield: In the naming of organisms in policy, what is the difficulty of using gene types?
Response – Mr Jan Hendrik Venter: This matter is a regulatory 'nightmare' as it is critical to first identify the right pathogen or insect and host before legislation can be developed. This does create problems with databases such as CABI, but the situation is changing; where previously no specifics were given, there is now much more detail. Another problem is that international databases take information from one another, so scientific publications are a very important tool to veto broad-based databases.

Question – Prof Berger: What is the problem of adulteration in honey production in South Africa?
Response – Prof Crewe: In honey, adulteration is related to the fact that very often various kinds of sugar syrup are added to honey to increase the bulk, and then a product named honey is sold with only about 10% honey content. There are countries that produce bulk honey and export this. The importing country may then sell the produce as having originated in a country where honey has a higher value. Some new molecular techniques can help to detect fraudulent activities, and we are getting better at identifying the sources of honey. It is an 'arms race' between the fraudulent producers and the investigators.

SESSION 2: CHAIR – PROF WIJNAND SWART, PRESIDENT, SOUTH AFRICAN SOCIETY FOR PLANT PATHOLOGY

Artificial intelligence and the future of crop health monitoring (Prof Dave Berger, Forestry and Agricultural Biotechnology Institute, University of Pretoria)

A case study is being undertaken using artificial intelligence (AI) in the automatic identification of maize disease; in reality, there is always a mixture of diseases and we want to be able to differentiate between them. If South Africa had a system like this, it could it be developed into a crop-health monitoring system countrywide.

Maize disease identification is necessary, as these diseases can be very detrimental to susceptible maize and can cause up to 72% loss of yield for smallholder farmers, so identification of the specific disease is essential. The four most common foliar diseases in maize are included in the study, namely grey leaf spot disease, northern leaf blight, Phaeosphaeria leaf spot, and common rust. These diseases are relatively simple to identify, but it becomes complicated when there is a mixture of diseases on a single plant, which is why it was decided to develop a method of identification using AI tools.

The Oxford dictionary defines AI as the development and use of computer systems for tasks normally requiring human intelligence. In the field, there are two main areas of AI: machine learning and deep learning. Machine learning is a method that enables an algorithm to learn from existing data and use that knowledge to make predictions for unknown future events. For deep learning, computer scientists mimic how the brain works, and neural networks look at hundreds of features in order to identify the features of specific targets. Deep learning techniques are being used to identify maize diseases.

In order to use the deep learning technique for disease identification, it is first necessary to collect a set of data, which in this case was a collection from previous field trips, and then construct a database for use in the learning technique. Following this, the neural networks are trained to identify the diseased compared with the healthy. The current case study uses convolutional neural networks for deep learning; for this method, it is necessary to have two sets of data: a training set and a test set. There are many different approaches that can be used. From the case study, it will be necessary to first evaluate the prediction accuracy of the tools, which will be followed by the development of an application (app) for deployment to farmers, industry and citizen scientists.

Students were used to collect pictures of crops, which were incorporated into a database and annotated for use in learning by the neural networks. In simple terms, the user uploads a photo and the computer extracts features and characteristics for a specific disease, which is then identified by using a convolutional neural network. Identification of the disease involves reducing the number of characteristics, followed by computer learning and then the identification of characteristics and comparison with healthy material, which leads to classification.

The database at the University of Pretoria (UP) holds more than 2000 records. The most accurate results obtained so far approached 75% accuracy in identifying grey leaf spot disease. The process is still a work in progress, and currently a new set of samples is being produced in which every lesion is marked on the leaf. This will help to identify the disease, and the number of infected leaves will also be counted. This will be very useful for breeders and will eventually be expanded to include all four of the most common foliar diseases in maize.

The UP vision of getting a countrywide system in place includes the establishment at Innovation Africa, a UP initiative, of an Innovation Information Hub as part of a wider African Hub to serve as a repository for crop disease diagnostic records, the development of the surveillance app and data visualisation, supported by AI. The Information Hub already holds some 15,000 records of forestry pests and diseases, and crop diseases, and the grain industry will be a new addition. Cropwatch Africa is working with FABI to develop a biosecurity surveillance app that will allow citizen scientists, farmers, tree growers and breeders to submit information. Tools for data visualisation will be built into the database. AI has much potential, and the Innovation Africa team has a group of scientists working with them on tools such as computer learning, which will assist with data management, data visualisation and prediction. This is an exciting development for the future.

In using the case study to develop an application, we have found that AI is a powerful tool. If it is possible to use neural networks to identify one disease, this approach could be expanded to all diseases. UP is keen to develop a group to work on this. We also need to train and produce graduates to work in multidisciplinary teams to develop practical solutions that can be rolled out across the country and the continent. We hope to move to continent-wide prediction and surveillance assisted by AI and an app that everyone could benefit from.

Question and answer session

Question: When will this app become available?
Response – Prof Berger: We wanted it to be ready last week, but we will only release it when we are sure it works effectively at a high level of precision. We will probably start by making it available for people to submit images, which will help to build the database and enlarge the network. The second phase would be the identification of diseases. We have many ideas of how to involve young people in capturing photos and uploading these on the database.

Question: Which data were used for the convolutional neural network?
Response – Prof Berger: The data used was the current database of over 2000 images with mixtures of diseases, as these diseases commonly occur together. We use 80% of the samples collected for the training dataset and 20% for the test dataset. Currently we have achieved 75% accuracy for the identification of grey leaf spot disease from the more complicated mixed data set. This work is only in the development stage, so it is not yet possible to answer questions on how it will work. There has been a steep learning curve in considering what is needed to solve the problems.

Disease resistance in small grain cereals: The South African approach (Prof Willem Boshoff, Natural and Agricultural Sciences, University of the Free State)

Rust research on pathogens that affect small grain cereals is essential, as pathogens have posed a threat to these cereals in South Africa for a long time.

Winter cereals are usually planted early in autumn and harvested in early summer. South Africa has a long history of crop improvement on this group of cereals. Wheat was first planted in South Africa in 1652, and wheat breeding was initiated in 1902. Barley breeding started in 1978, and oat improvements are mainly through introductions from overseas. In the improvement sector, the ARC Small Grain Unit was founded in 1976, Sensako (Syngenta Seeds) was established in 1958, Pannar Seed wheat breeding was established in 1987 by Corteva Agriscience, and AB InBev has been involved in the local improvement of barley since 1978. Rust resistance is a long-standing priority of local breeders.

The symptoms of stem rust in wheat appear as pustules on stems, which can burst and spread spores to other stems. Stem rust is potentially the most damaging rust for wheat, but leaf rust and stripe rust are also damaging. These pathogens are controlled through breeding and chemicals. Barley is susceptible to leaf rust and stem rust, and oats to stem and crown rust. The pathogens also attack wild oats.

In breeding for rust resistance, it is important to understand the pathogens. It is equally important to conduct surveillance studies and take samples for the identification of isolates to determine the effect on current cultivars, which provides important information to breeders. It is also important to find new samples for use in resistance breeding. There is long-standing collaboration between plant pathologists and breeders for the management of control measures. In South Africa, we have built up considerable expertise over the years and have access to laboratories and funding.

Challenges in rust control include the fact that the pathogens evolve and mutate, which means that it is a continuous long-term management process. Other significant factors are the ease of dispersal of the pathogens over long distances and the fact that they can affect several cultivars at the same time.

With regard to the variability in cereal rusts in South Africa, new races have been observed in stem rust, leaf rust and stripe rust in wheat; leaf rust in barley; and crown rust in oats, and there have been incursions of the three forms of rust that attack wheat. Many variants can develop from a single rust.

The importance of disease resistance is the addition of value to seed. Resistance can also form part of an integrated control strategy and lowers the risk of epidemic outbreaks. Resistance also contributes to a smaller pathogen population and lowers the risk of mutation. Preventing the repetitive application of chemicals is very important. This is also an issue of affordability, as some pathogens are difficult to control chemically.

There are several types of rust resistance, and combining the different sources of resistance is complex for breeders. From a breeder's perspective, yield and quality are key components, but there are always several breeding goals to be met. Furthermore, the market is small, with low income potential compared with the high cost of breeding. Breeders often lack resources. From a producer's point of view, yield is probably the most important issue. Knowledge of disease susceptibility and reliable cultivar response data are extremely important. The choice of cultivars is important, as it is impossible to have cultivars that are resistant to all forms of rust.

There has been a marked increase in the yields of wheat in South Africa in the last few years resulting from higher disease resistance. Barley shows a similar improvement in yield. Rust resistance screening includes an annual review of all cultivars for resistance and reaction to pathogens. Every two years, all the data regarding cultivars and pathogens are shared with producers and breeders.

Cultivars can show different levels of resistance, and wheat shows a high level of cultivars with resistance to pathogens. The levels of resistance and moderate levels of susceptibility have shown improvements since 1996. In barley, the response to resistance to leaf rust is also showing a big improvement in the last few years. Several races have been identified, including seven for crown rust. Breeders make use of available data to develop more resilient strains.

Future cultivars are expected to contain more complex sources of resistance. Resources and expertise to identify and manage rust pathogens can only be secured through sustained funding. It is essential to monitor rust pathogens and maintain living collections of cultures. Rust research must support industry needs, and breeders must be advised on resistance sources and should offer support in rust screening. Producers must be kept informed of the response of cultivars and control strategies.

A great deal of progress has been made, and we look forward to cultivars with higher resistance. Sustained funding is necessary, as are monitoring and surveillance. There are good systems and a strong national footprint in this domain.

Use of crop climate models to develop advisories (Prof Sue Walker, Principal Researcher, Agrometeorology, Agricultural Research Council)

Climate models are used to simulate all factors affecting the Earth’s climate. These are a complex mathematical representation of major climate system components such as atmosphere, land surface, ocean and sea ice, and their interactions. In these models, the Earth is divided into a three-dimensional grid of cells, and the results of matter and energy processes modelled in each cell are passed to neighbouring cells. The models are about energy balance around the Earth driven by solar radiation and other energy transfers. Global models are scaled down to regional level and ultimately local level. At that level, the coverage is approximately 15 km^2.

In South Africa, warming is taking place because of climate change. From the current models, increases in temperature of 2–3°C will be evident by 2050, and of 3–5°C by 2100. This is what we will have to deal with in the future, and it will affect crop production and disease. To assist with crop disease predictions, it is important to develop advisories. In looking at the effects of temperature on crops, an additional 3°C could cause a 20% reduction in crop yield in tropical areas.

A crop climate model comprises mathematical equations that represent reactions occurring within plants, and interactions between crops and the environment. Agricultural systems are characterised by many organisational levels, from individual components in a single plant, to constituent plants and farms, or a whole agricultural region or nation. The main aim of crop models is to estimate harvestable or economic yield using the Harvest Index.

There are various different types of models, including both static and dynamic models. Empirical models are regression equations and are not easily transferable. Mechanistic models describe behaviour and systems and mimic relevant physical, chemical and biological processes. Deterministic and stochastic models provide definite predictions for quantities and simulation, and optimising models imitate system and management options.

Crop simulation models are specific for specific crops and usually have a daily time step, with soil and crop characteristics as standard input. Daily climate data are included, as well as agronomic management practices such as fertilisation. Models are used where there is a need for calibration and validation for cultivars and the environment, and to predict growth, development, yield and water use.

Crop models can be used as a research tool, as a crop system management tool and also for policy analysis and the development of advisories. As an example, data from Zimbabwe showing the maize yield levels with various levels of added nitrogen can be used to determine the optimum level of nitrogen application and would feed into the development of an advisory balancing agronomic practices. Advisories can also be developed to evaluate risk – for example, occurrences such as El Niño – which would directly affect planting times. Crop models can also be used for policy analysis; for example, in the use of different irrigation systems under conditions of low, medium and high rainfall. This could also provide an input to advisories. With respect to climate change, it is possible to conduct a gap analysis looking, for example, at changes in yield in different cultivars. Long-term crop runs could be used for the selection of crops.

The modelling of diseases and pests represents a gap in crop modelling; this type of modelling is not sufficiently comprehensive and powerful, and does not simulate pest and disease outbreaks. There is a need for integration of pest models into crop models, as variability across this field is lacking, with the exception of precision agriculture applications. There is a need for monitoring instruments for pests, diseases and infections. Crop models could include information on disease control, and there is also a place for the involvement of chemicals and temperature data.

Disease modelling could include agronomic practices such as mulching and crop rotation, chemical control such as spraying and fumigation, and biocontrol agents. Resistant genes could also be included, as could geocontrol which includes factors such as temperature, rainfall and radiation. Climate trends are one of the building blocks that have been used for a number of different diseases, and biomass would vary according to disease infection.

Examples of weather affecting diseases include the increased spread of stem and leaf rust in temperatures above 20°C, whereas temperatures of approximately 15°C favour stripe or yellow rust. Soybean rust development is favoured by temperatures ranging from 12–29°C, a continuous period of wetness on leaves, or relative humidity above 75% for more than 12 hours. The optimum germination for maize smut is 13–20°C, soil temperatures above 25°C, and relative humidity of 60–90% with 1 mm of rain.

An example of an early warning model is the Grape Compass, which is an online decision-support system for viticulturists and grape growers. This model makes reliable forecasts of fungal disease risks in vineyards, including the instance of powdery mildew, downy mildew and Botrytis. Another early warning model, AgriCloud developed by the ARC, uses weather data with agricultural information tailored to specific needs, and can advise on weather conditions that are conducive to spraying. The advice covers three days at a time and is available in 11 languages.

The formulation of advisories requires inputs such as basic experimental results; relationships between crop growth, disease infestation and weather parameters; weather forecasts and satellite monitoring of fields. The outputs would include routine advisories, location-specific information, and messages relevant to farm operations, and would rely on a delivery system and a client database.

There is a need to work across disciplines. We already have weather forecasts down to small areas; we have crop models for a variety of crops, and some independent disease models, but these are not well integrated into the crop models. There are advisories and there is monitoring, but we need to be able work in transdisciplinary teams for the development of the best advisories.

Managing the risks to biodiversity using insects: biocontrol in South Africa (Dr Candice Lyons, Department of Biological Sciences, University of Cape Town)

Biocontrol is the process of managing invasive species, insects, animals or plants using natural enemies. The focus of this presentation is on plants. In most instances, the enemies come from the same population area as the weeds. If the invasive species is from Australia, for example, then the biocontrol agents would most probably also come from Australia. Biological control does not aim at eradicating weed species, but rather at managing the size of the population of the weed. Biocontrol is considered a self-perpetuating and long-term solution to management, and is relatively inexpensive when compared to traditional means of management such as manual clearing or spraying of insecticides.

In managing invasive plants, the biocontrol agents used most frequently are insects, mites and pathogens. Biocontrol agents target specific plant organs, such as the vegetative parts of the plant (its leaves, stems or roots) or the reproductive parts (flowers, fruits or seeds).

There are two main biocontrol strategies that can be implemented to manage invasive species. If the aim is to get rid of the invasive plant species, scientists select the available types of biocontrol agents that cause the most damage. In such projects, scientists may use agents that affect the vegetative parts of the plant as well as agents that reduce seed production. However, if the target plant is useful in certain situations but becomes a pest when uncontrolled, the strategy of containment may instead be applied, making use of agents that attack the reproductive parts of the plants, which are not killed, but future spread will be curtailed.

In South Africa, there is a procedure which is widely used by a variety of stakeholders, particularly researchers in the field of biocontrol. This procedure assigns levels for the management of the weed species: complete control, substantial control or negligible control. This is often a very subjective assessment, and levels of control might change as informed by research. There are many publications regarding the levels of control in South Africa.

Some case studies that have used the level of control principle include the complete control of the Castanea tree in the Western and Eastern Cape through the use of three weevil species. The first known instance of substantial control in South Africa was aimed at the Protea species, but unfortunately the control agents completely exterminated the prickly pear population, and in the Kruger Park the agent had a detrimental effect on the biodiversity of the area. A moth and the cochineal beetle were then used to clear the site of the original agent. Biocontrol is not always effective, and there are several factors that can influence its success.

Substantial control of several Acacia species has required an integrated management strategy. In some Acacia species, wasps have been used that affect the reproductive part of the plant, and in other instances three weevils have been used together to effect control. There is only one agent for the complete control of water weed, and for this to be effective hundreds of thousands of insects need to be released at one time. Some insects are grown in laboratories, some are caught in the wild and others have to be imported. In the application of substantial control of Hakea in the Fynbos biome, five insects plus an indigenous fungus were released. It is important to understand that different species become established in different areas, so there are no standard solutions.

In the field of biocontrol, there are instances of high impact and some where this procedure has not been as successful. The success or failure is influenced by a variety of factors such as host mismatches, or species from different localities that need to be caught and tested for effectiveness. Despite all the constraints, biocontrol provides an economical and environmentally acceptable means of control.

What has been presented here is by no means a complete picture of biocontrol, and there is a great deal of research in this field globally. South Africa is one of the top five countries in the world implementing biocontrol.

Question and answer session

Question: Are you using hyperspectral imaging for auto identification, and what research is being done on spectral indices for different crops or tree species?
Response – Prof Berger: I was talking about just using RGB (red, green and blue) wavelengths. Hyperspectral imaging obviously has other possibilities, as it includes a wider range of colours and looks at different characteristics of the image. There is a lot of work being done with hyperspectral cameras, and we are excited to start exploring this field.

Comment: Identifying grey leaf spot disease at 75% accuracy cannot really be accurately assessed by farmers who are not scientists.
Response – Prof Berger: We know that 100% is not attainable, but we would like to get results somewhat higher than 75% in order to have something that is reliable.

Question: Has there been a case where insects used in biocontrol have jumped to other plants and detrimentally impacted on an ecosystem?
Response – Dr Lyons: Fortunately, there have been no instances of this in South Africa. Agents go through very stringent testing before use. It is very rare to have negative non-target effects.

Question – Mr Johann Venter: Does the long lifespan of trees in relation to the short lifespan of insects have an effect, and could the insects change feeding and reproduction habits to another host?
Response – Dr Lyons: This would not happen. There is no reason for the insects to change their host, because the trees will be there for longer than the plants, and pathogens are very host specific.

Question – Ms Debbie Schultz: How much of the resistance breeding falls under the heading of genetically modified, and how are the negative perceptions dealt with?
Response – Prof Boshoff: In wheat, there has been no adoption of genetically modified resources, although a lot of research has been done. Another factor is that this field is still regulated in South Africa.

Question – Prof Wijnand Swart: There was a programme looking at remote sensing for monitoring disease in South Africa. Is anyone working in this area?

Response – Prof Willem Boshoff: It is quite possible to do this, but it needs to be included in field research, as physical samples are essential for verification.

Question: Mr Denis Hunt: The control of the water hyacinth on the Hartebeestpoort Dam does not seem to be very successful. Do we know why not?
Response: Dr Lyons: This is an example of some biocontrol projects being successful and some not. I believe from the team working in this domain that it is a complex problem, but basically the high level of nutrients in the dam means that the water hyacinth plants develop too quickly for the insects to gain control over the population.

Question – Dr Sue Walker: Is there a biocontrol programme under way to control the pinkie weeds in Gauteng?
Response – Dr Lyons: I unfortunately do not know what pinkie weed is, but if it is the pompom weed, there is a biocontrol programme on the go.

Question – Prof Mike Wingfield: Thank you for a good summary of biocontrol in South Africa. When introducing a new biocontrol pest, how much attention is given to introducing a sufficiently broad population genetically to avoid genetic bottlenecks in the future?
Response – Dr Candice Lyons: This would depend on the particular situation, how quickly species can turn over, and the reproductive capacity of the insects. In working in the field, I always try to introduce insects from several populations to avoid genetic bottlenecks. It all depends on the time available, the system one is working on, and how many generations a species might have in a year.

Question – Dr David Livingstone: Does hyperspectral imaging take into account the different stages of foliar diseases?
Response – Prof Berger: It is often hard to detect the earlier stages of disease, but this might be possible with hyperspectral imaging. We will have to start with trials with artificial inoculations.

Question – Prof Dave Berger: Can members of the public release biocontrol agents; is there legislation; and who do they contact to get hold of agents?
Response – Dr Lyons: The public can use agents, but should advise authorities and researchers working in the field when they do. There are agents that are distributed to farmers for Hakea, for example, so it is possible for the public to become involved, but it does need to be controlled and managed. The Department of Environmental Affairs has biosecurity officers in each province; even though they are difficult to get hold of, that should be the point of contact. The researchers working with a particular weed would be the most reliable contacts for information.

Question – Mr Jan Hendrik Venter: Is anything being done to identify viral symptoms that contribute to maize beetle necrosis?
Response – Prof Dave Berger: Maize beetle necrosis is a big threat in East Africa and is a combination of two viruses, each with its own symptoms. Scientists are working on the virus. Clearly the next phase of development will have images of other potential viruses. There is a great deal of next-generation sequencing being conducted, and this is a very powerful tool.

Question – Mr Denis Hunt: One wonders if there might be a solution to the shot hole borer through biocontrol.

CLOSURE

Ms Jansie Niehaus thanked everyone for their contributions and participation. The presentations and videos would be on the NSTF website, with the permission of the presenters, and the proceedings would also be on the website in two to three weeks' time. A media release would be prepared that would highlight the issues that had emerged, and that too would be available in a couple of weeks.

APPENDIX 1: LIST OF ACRONYMS

ARC	Agricultural Research Council
CABI	Centre for Agriculture and Bioscience International
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
COVID-19	Coronavirus disease 2019
DALRRD	Department of Agriculture, Land Reform and Rural Development
DNA	Deoxyribonucleic acid
DSI	Department of Science and Innovation
EU	European Union
FABI	Forestry and Agricultural Biotechnology Institute
FAO	Food and Agriculture Organization
GM	Genetically modified
ICPP	International Congress of Plant Pathology
IPPC	International Plant Protection Convention
ML	Machine learning
NSTF	National Science and Technology Forum
PHSB	Polyphagous shot hole borer
SANBI	South African National Biodiversity Institute
SU	Stellenbosch University
UP	University of Pretoria
USA	United States of America
WTO	World Trade Organisation

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University of Pretoria	Ms Jane Ramaswe
University of Pretoria	Ms Denine Rudolph
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University of Pretoria	Prof Jacquie van der Waals
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University of Pretoria	Mr Lungelo Ntamane
University of Pretoria	Dr Raphael Ployet
University of Pretoria	Prof Brenda Wingfield
University of Pretoria	Ms Samkelisiwe Thango
University of Pretoria	Ms Susanna Anbu
University of Pretoria	Ms Iné Botha
University of South Africa	Ms Christinah Chokwe
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University of the Free State	Dr Thulisile Mphambukeli
University of the Free State	Prof Martie Smit
University of the Free State	Dr Elmarie van der Watt
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