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Sustainable Management of Diseases in Horticulture: Conventional and New Options

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Abstract
To reduce the impact of chemical pesticides on the environment, there are relevant efforts to enhance the possibility of controlling plant diseases using environmentally friendly biocontrol agents or natural products that show pathogen control capacity. Preventive measures related to the choice of cultivars, soil fertility, integrated pest management (IPM), and organic farming strategies are still the basis for obtaining satisfactory crop yields and reducing classical pesticide utilisation through the application of commercially available and eco-friendly control agents. Effective pathogen detection at borders to avoid quarantine pathogens is mandatory to reduce the risk of future epidemics. New technical support for the development of sustainable pathogen control is currently being provided by forecasting models, precision farming, nanotechnology, and endotherapy. New biocontrol agents and natural products, disease management through plant nutrition, systemic resistance inducers, and gene-silencing technology will provide solutions for obtaining satisfactory disease control in horticulture. The "multi-stakeholder partnership" strategy can promote the implementation of sustainable crop protection.

Introduction
The concepts that illustrate sustainable agriculture have been posed and defined decades ago and can be summarised by the principles and approaches described by F.A.O. Considering that the complete achievement of all such goals still requires a relevant effort, the success of sustainable agriculture mainly depends on the acceptance of these principles by the farmers, which should actively identify strategies for maintaining, enhancing, and developing their on-site resources (i.e., soil, water, air, biodiversity, and landscape) for future generations. However, the need for a continuously widespread application of sustainability criteria in agriculture with less impact on the environment is also necessary in a world where food demand is increasing. The success of obtaining satisfactory pathogen management according to sustainable agriculture principles requires parallel actions to prevent the spread of phytopathogens. From this perspective, effective quarantine measures are necessary to avoid the introduction of destructive plant pathogens into new areas of cultivation. Currently, this aspect is particularly relevant because of the extensive global circulation of plant materials and climate change. Modern diagnostic tools should be implemented at the points of plant material circulation (i.e., airports and ports) and the local entry points (i.e., regional phytosanitary services). Local quarantine agencies can be assisted by climate-matching tools and geographical information systems that can predict the possibility of pathogen spread in a new area. There is a focus on the main strategies based on the utilisation of well-known and new biocontrol agents and products or compounds with a low impact on the environment that

are already developed or undergoing achievements regarding the control of some diseases of woody and herbaceous crops. New technologies to augment the efficacy of disease control in sustainable agriculture (Fig.1).

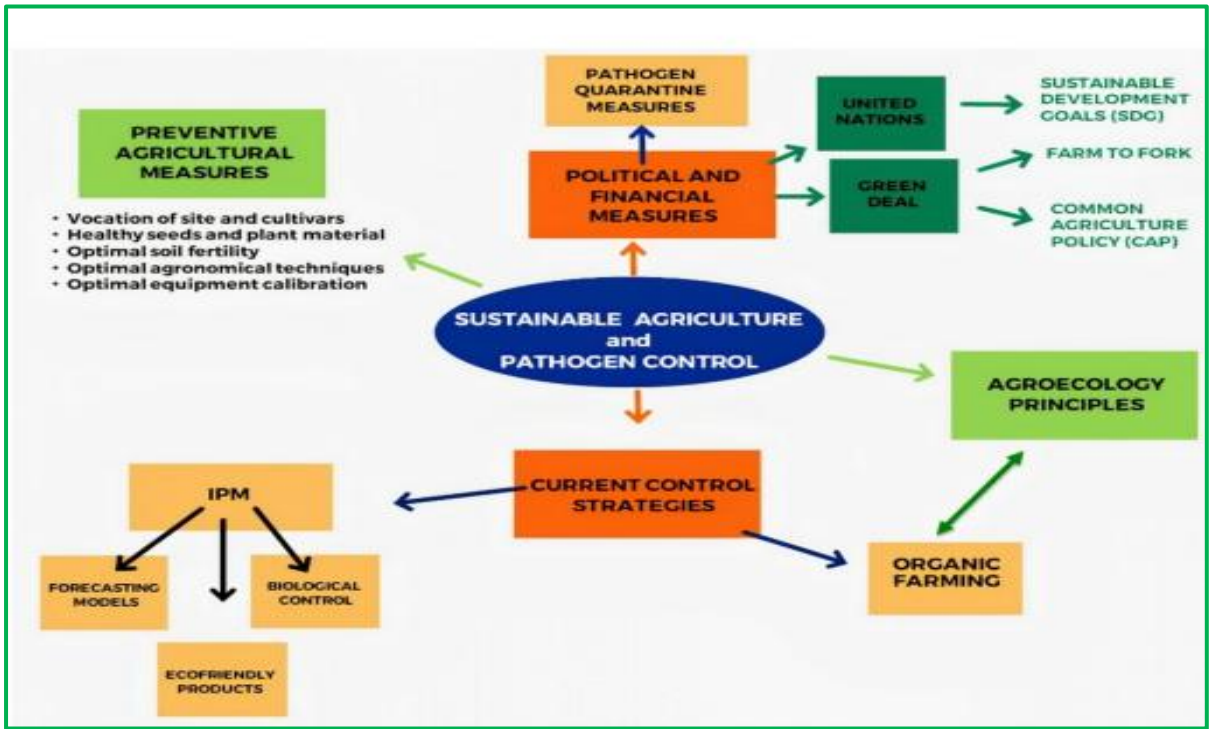

Figure 1. Synoptic panel that shows the current strategies and policies related to the achievement of sustainable disease control in horticulture.

The Basis for a Sustainable Disease Control: The Preventive Measures

- Suitability and Selection of the Site and Cultivars: In addition to the economic aspects and infrastructural facilities, the climatic factors characterising an area must be considered for the choice of the crop to be cultivated. At present, this issue is relevant because of climatic changes that affect most areas of the world. Climate change can result in the adoption of different pathogen control strategies and agronomical techniques, owing to the possible adaptation of new pathogens to the new climatic scenario.
- Healthy Seeds and Plant Material: The healthy phyto-sanitary status of seeds, tubers, plantlets, potted plants, and propagative material is a fundamental prerequisite for initiating cultural cycles. At present, this aspect is particularly important considering the extensive global circulation of these commodities.
- Optimal Soil Fertility and Agronomical Techniques: One of the pillars of the European Common Agricultural Policy (CAP) is the maintenance and enhancement of soil fertility; correct soil management is one of the fundamental prerequisites for sustainability in agriculture.
- Sustainable Agriculture and Pathogen Control: The Basis for an Effective Sustainable Pathogen Control Knowledge of the genomic structure, virulence factors, and epidemiology of pathogens is the basis for developing fine-tuned strategies for the effective control of biotic diseases in crops. Selected biocontrol agents or compounds with potential curative effects should be tested against different strains of pathogens that represent the entire population structure.
- Current Control Strategies: Integrated pest management (IPM) is the current strategy that allows for the effective control of many plant pathogens in many cases. According to the European Union Framework Directive on the sustainable use of pesticides, IPM "means careful consideration of all available plant protection methods and subsequent integration

of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment.

- Disease-Forecasting Models: Disease forecasting is based on mechanical models designed with the input of climatic data and the pathogen cycle of disease to alert the grower on whether, when, and how to apply an agrochemical or a biocontrol agent to protect crops (Fig.2). Such models are dynamic because they analyse the changes in the components of an epidemic over time according to external variables (i.e., climatic data, pathogen multiplication, and plant growth stage in relation to disease development).

Figure 2. Scheme of a modern decision support system based on a forecasting model for plant disease management. Information about crop-specific characteristics (A1), environmental conditions (A2), crop and plant status (A3), and agricultural operations (A4) flows from the crop to a remote server (B1), and it is stored in database (B2). This information is then used as an input for running mathematical models and decision algorithms (B3), which generate decision supports and alerts to the grower for deciding when and how apply a protective agent (C1).

- **Biological Control:** Biological control agents for plant diseases are defined as naturally occurring microorganisms capable of suppressing the growth and proliferation of a target pathogen by different mechanisms of action. (i.e., competition for space and nutrients, antibiosis, predation, induced host resistance, and lytic enzymes).
- **Natural Products and Compounds:** A natural product with a potential use for controlling plant diseases can be defined as a physiologically active chemical that is synthesised by plants, microorganisms, or animals. These products can act as antimicrobials or inducers of systemic resistance, are usually easily biodegradable, and do not persist in the environment. Some of them can act as templates for chemical pesticides (i.e., synthetic analogues), such as the fungicide strobilurin, which was named with reference to *Strobilurus tenacellus*, a wood-rotting mushroom. Chitosan and its derivatives, alkaloids, flavonoids, terpenes, proteins, and phenolic compounds. Developing Control Strategies A synoptic panel concerning developing control strategies is shown in Figure 3.

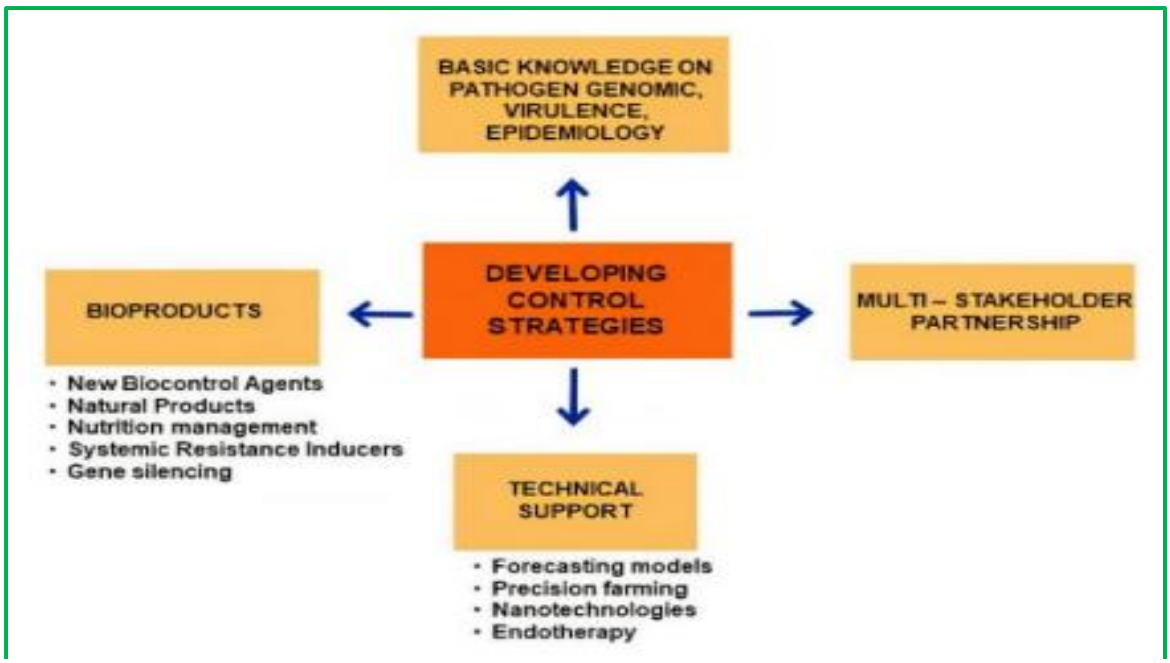

Figure 3. Synoptic panel that illustrates the developing disease control strategies for sustainable agriculture.

Conclusions

The successful control of plant diseases in horticulture has long been a pillar of both food production and the conservation of agroecosystems. At present, these two goals are becoming increasingly urgent due to the rapid increase in human population and the threats posed by climate change.

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