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Role of Synthetic Organic Chemistry in Sustainable Agriculture

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Introduction

Undernourishment and malnutrition are major human health concerns in the developing world and these issues are becoming major threats with the increasing population.[1] According to the FOA, in 2050 the world's population is expected to be increased by 2 billion.Providing nutritious foods in adequate amount for the increasing world population is a challenging task.[2] Sustainable development in agriculture is critically important to improve theglobal food security and food nutrition. To achieve this goal world's agriculture has to increase the quantity and diversity of foods.

Synthetic organic chemistry has playing a major role in crop protection and food protection. The control of pathogens, insect pests and weeds has been the major contributor to the agricultural yield. New agro-chemicals has got escalating demand. Safe and efficient new organic molecules with new mode of actions will claim a place in agriculture for many years to come.On this note, synthetic organic chemistry so far has made a huge impact on discovering and manufacturing of new organic molecules for crop protectionas well as other critical issues in agriculture. The major aspects we cover from this article are the approaches of synthetic organic chemistry on some of the major concerns in sustainable agriculture such as climate change, minimizing post-harvest losses, reduction of fertilizer consumption and crop protection.

(i) Climate Change

Climatic changes due to fluctuations in temperatures and rainfall patterns are playing an essential role in global agricultural productivity.[3] Plants respondto theseclimatic changes by altering metabolism pathways.[4] It has been recognized that most of these metabolic pathways mediated by plant based small peptides.[5] The essential role of these small peptides (<100 amino acids) in plant growth and development can be used to mitigate the plant stress during climatic changes.Naturally these peptides are produced in plant cells. Some of these essential plant peptide sequences have already been recognized and summarize in Table 1.

Table 1

Peptide	Function
CLE 25[6]	Resistance to dehydrative stress
Calreticulin[7]	Drought and high salt tolerance, better root growth
Ph-AMP[8]	Broad spectrum antifungal activity
BPCH7[9]	Effective gene transfer in cells

These peptides can be synthesized using solid phase peptide synthesis (SPPS)10 and use as plant external plant stimuli to relive the plant stress during extreme conditions.

(ii) Water scarcity

Global agriculture accounts for about 70% of global water withdrawals, and also constantly competing with domestic, industrial and environmental uses even with limited availability.[11] Scarcity of water for agriculture is one of the future challenges to overcome to increase the crop production for the increasing population. Sustainable use and water management arecritically important to conserve water for agriculture and other uses. Innovations are required to manage sustainable irrigation practices for the crop production.

The three dimensional polymeric network materials which are capable of absorbing large amounts of water are termed as hydrogels.[12] These hydrogels can be able to retain water and nutrients as well as release them accordingly when the root zone of plants start to dry up. Harnessing the high swelling and slow water retention of hydrogels opens the novel avenues in agricultural applications.[13] Most of the developments in the area of hydrogel are based on natural polymers. However polypeptides,[14] polysaccharides[15] and synthetic polyvinyl and polyester can also be used as alternatives. These polymers can be synthesized and optimized using Synthetic organic techniques.[16]

(iii) Minimizing post-harvest losses

One-third of the global food production (worth about US $1 trillion), is lost during postharvest operations every year.[17] The reduction of postharvest losses can give higher returns compared to increasing crop production to meet escalating global food demand. Novel strategies to reduce postharvest losses can be achieved by using innovative multidisciplinary approaches involving synthetic organic chemistry.

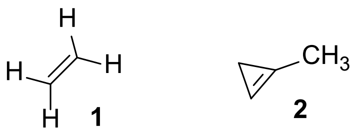
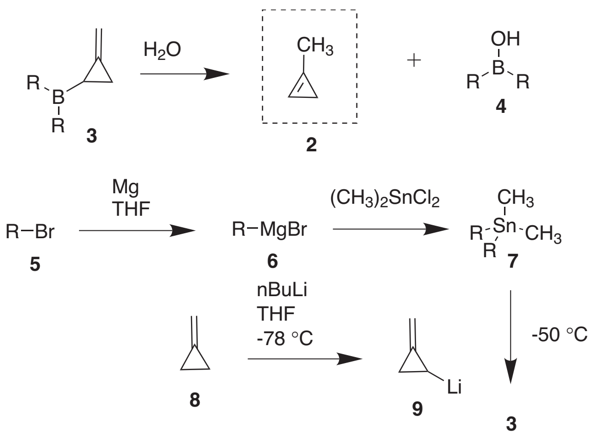


Figure 1: Structure of plant hormone ethylene,1 and ethylene inhibitor 1-methyl cyclopropene,2

Plant hormone ethylene can play a significant role in ripping fruits and yellowing leaves.[18] Uncontrolled ethylene exposure can induce significant changes in quality parameters of perishable plant products during the post-harvest storage. 1-methyl cyclopropene (1-MCP) is one of the competitive inhibitors in ethylene receptors of the plant and this compound can prevent ethylene binding even at minimum concentrations.[19]

Gases nature of 1-MCP at ambient temperature renders its usage in open field applications. Therefore stable complexes which can release 1-MCP gradually at ambient temperature could be much effective. These stable 1-MCP complexes can be synthesized using synthetic organic techniques. Scheme 1 depicted the synthesis of stable Boronated1-MCP complex[20] which releases the active component upon contact with water.



Scheme 1: Synthesis of 1-MCP boron complexes

(iv) Reduction of fertilizer consumption

Synthetic inorganic fertilizers are playing a key role in enhancing crop production.[21] However, overuse of these inorganic fertilizers in many parts of the world has contributed to soil, water and air pollution. The demand for inorganic fertilizers in the future is predicted to be increasedfurther with the world's population growth. New technologies employing to increase nutrient use efficiency (NUE)[22] and thereby reduction of fertilizer usage can be used as effective mitigation alternatives to control the environmental impacts of the inorganic fertilizers.

Chemically decomposing organic compounds such as isobutylidene-diurea (10)[23] andcrotonylidene-diurea (11)[24] can be used as controlled release N-fertilizers. These compounds can be prepared by using excess urea aldehyde condensation reaction.

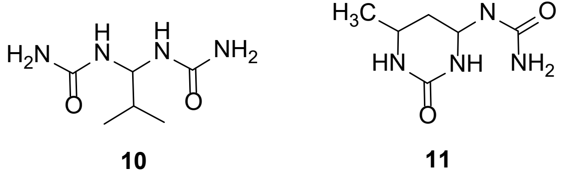


Figure 2: Chemically decomposing urea compounds

Inhibition of the conversion of ammonium-N to nitrate-N by soil bacteria can be a useful process to prevent leaching and denitrification.[25] Several small organic molecules can be used in this regard as inhibitors as shown in figure 3. Substituted schiff base type compounds have also been synthesized as potential inhibitors.[26]

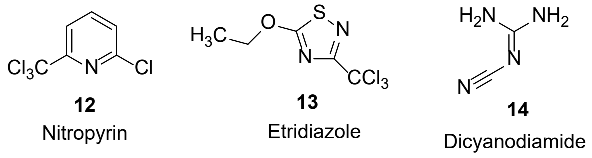


Figure 3: Key Inhibitors of nitrification reaction

(v) Modern Crop protection chemicals

Crop protection by using chemical strategies have been in practice for many decades. However the industry is constantlydemanding new moleculesdue to changing the agricultural environment and the cropresistance.[27] The three main groups of agrochemicals are herbicides, insecticides and fungicides.Among these,half of the crop protection chemicals are in fact herbicides. However, it has been noted that the resistance is appearing even for the most used herbicide Glyphosate.[28]

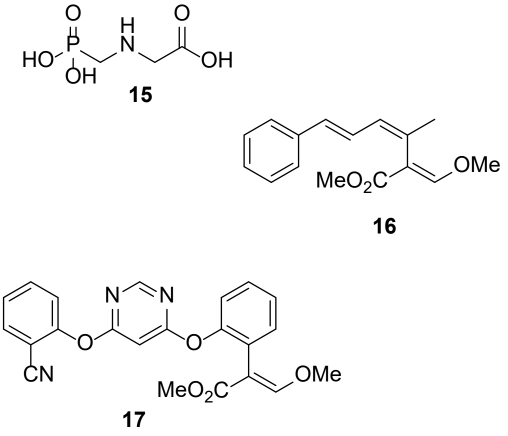


Figure 3: Structure of Glyphosate (15), natural product stobilurinA (16) and Azoxystrobin (17)

The resistance breaking nontoxic molecules with broad weed spectrum activity are constantly in need for the industry. Natural product stobilurin-A derived fungicide, azoxystrobin is a good example of broad spectrum fungicide which is effective against over 400 crop disease systems.[29] The invention of new agrochemicalsis exclusively relying on biological efficacy. However, there is a well establishing way of developing safe, effective and economical agrochemical leads. This involves screening of the biological target, use of bioactive natural products and their rationally designed analogs and mechanism based design.

Nature has been a frequent resource for many bioactive molecules. Even though most of the natural products are lacking the properties required for successful crop protection, they have provided better leads for crop protection chemicals. The structurally optimized target molecules then can be synthesized using synthetic organic chemistry.[30] Synthetic pyrethroid insecticides were perhaps the most enduring example in this regard which were derived from pyrethroids natural products (figure 4).[31]

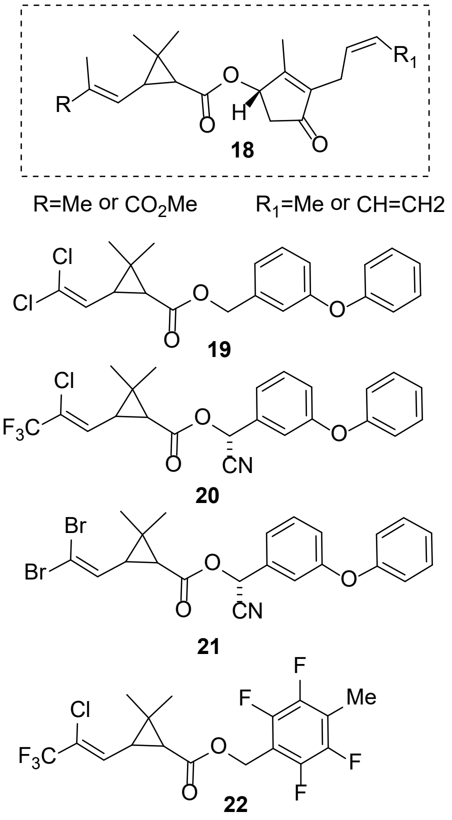


Figure 4: Natural and synthetic Pyrethroids

Summary

Constant supply of food forthe growing world is critically important. With its unique ability of bridging the structure and function, organic synthesis became an enabling science for many applied disciplines. In concert with other key science segments, organic synthesis is poised to address the key issues in global agriculture and food safety. Continues multidisciplinary research on agriculture organic interfacewillimmenselycontribute to economic developmentvia producing new compounds for safe, efficient agricultural practices. These new molecular architectures will facilitate the novel approaches to mitigate some of the key challenges in agriculture in order to increase the crop production especially in an agriculture dependent tropical country like ours.

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Guest Articles

Chemical Nature of Pesticides

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The phrase, "The Granary of the East" was used to describe the success of agriculture-based economy of our ancient nation. After European invasion, we lost our self-sustaining golden era, and gradually we started begging from developed countries and now we depend on their monetary loans and products. Pesticides are one of the major hazardous products, which we import without proper specifications, guidelines and monitoring. Today, it seems that these pesticides are making us sick or killing silently, particularly those who live in cultivating areas of Sri Lanka.

The substances or mixtures that use for controlling, preventing, destroying, repelling or attacking any biological organism are known as "**pesticides**". First historical evidence of pesticides came from Sumerian civilization, 2000 BCE. According to the archeologists, they have used sulfur to control mites and insects. Presently, about 2 million tons of pesticides are utilized globally, out of which 47.5% are herbicides, 29.5% are insecticides, 17.5% are fungicides and 5.5% are other pesticides.

Pesticides can be classified into two main groups based on;

- **Targeted use** - *e.g.* Algaecide (foralgae), Acaricide (for mites), Avicide (for birds), Bactericide (for bacteria), Fungicide (for fungi), Herbicide (for weeds), Insecticide (for insects), Biopesticide (derived from natural materials, *e.g.* baking Soda), *etc.*
- **Chemical nature** - This article intends to shine some light in this regard.

Pesticides based on chemical nature

Pesticides are classified depending on their chemical compositions, and are broadly classified as either organic or inorganic pesticides.

Inorganic pesticides are simple compounds