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European chemical ecologists translate the language of life into sustainability

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1 The natural world speaks in chemistry

The natural world speaks in chemistry and chemical ecologists are the experts of this universal language. Indeed, the main channel for information transfer among cells, microbes, fungi, plants and animals, as well as across all biological kingdoms is through infochemicals: molecules or mixtures of molecules released by one cell or organism that influence the state and behavior of another cell or organism.

Natural compounds have been used in cosmetics and medicine for millennia. Yet, it was not until the late 19th century that the potential of these compounds in inter- and intra-specific communication began to be recognized. While chemical ecologists largely owe the development of their discipline to Thomas Eisner (Meinwald et al. 2011), pioneer studies include the identification of the first chemical signal used for intraspecific communication (Butenandt et al. 1959). The term pheromone was introduced by Karlson and Lüscher in the same year. Concurrently, Fraenkel (1959) authored an influential paper, "The Raison d'être of Secondary Plant Substances", suggesting that plant secondary metabolites serve as defensive mechanisms against herbivores rather than being metabolic byproducts. These seminal works collectively heralded the inception of contemporary chemical ecology.

Since then, chemical ecology has continued to bridge disciplines such as biology, chemistry, agriculture and environmental science. The universality of chemical communication across the tree of life and across biological levels of organization has resulted in a perplexing diversification of signals and signal receptors (i.e. chemodiversity) to allow for individual, sex-specific, species-specific and context-dependent signals. Chemical ecologists help resolve major societal and medical challenges, ranging from pest control to conservation and from preventing disease transmission to sustainable product development. Recent breakthroughs include leveraging natural signals to attract natural enemies of insect pests (Kansman et al. 2023), high-throughput assays of toxins and pollutants in relation to ecosystems and keystone species (Sylvester et al. 2023), identification of chemical cues for insect vectors of major diseases such as mosquitos and tsetse flies (Tchouassi et al. 2019), marine natural products and their roles (Carroll et al. 2024), and Green Chemistry frameworks for product development (Ganesh et al. 2021).

2 Chemoecology as a source of sustainable strategies

The development of sustainable pest control strategies has long been a major focus of chemical ecologists. Sex pheromones have been identified in numerous animal species and are now widely used for monitoring, trapping and mating disruption of pests (Witzgall et al. 2010). In addition, the successful push-pull management system makes use of chemical cues from intercropped plants to sustainably

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increase agricultural yields while reducing the use of synthetic compounds that may be harmful for animal and human health. Alongside terrestrial environments, including forest and agricultural biotopes, chemical ecologists also develop sustainable applications in aquatic ecosystems.

Unlike conventional insecticides, pheromones are generally species-specific. While these simple molecules are typically regarded as non-toxic, specialists will need to continually assess their safety as their usage expands and the doses introduced into the environment increase. Unfortunately, climate change-associated stressors can modify these chemically mediated interactions, causing info-disruption that scales up to the ecosystem level (Roggatz et al. 2022). The understanding of the underlying mechanisms is limited, in part because identifying the genes, molecules, and processes that mechanistically couple chemodiversity with sustainability requires challenging research programs that cross disciplinary and geographical boundaries.

3 A COST program to foster partnerships

The chemodiversity in nature is paralleled by the diversity in researchers and their fields. To unite the different branches across disciplines and geography, European chemical ecologists intend to build a pan-European, collaborative community like those in the Americas and in Asia. Under the leadership of Anne-Geneviève Bagnères, they have successfully applied to the European Cooperation in Science and Technology (COST) program, funded by the European Union. The program is called E-NICHE (**E**uropean **N**etwork **I**n **CH**emical **E**cology) and has started in October 2023. E-NICHE is currently linking over 200 participants, including nearly 60 young researchers and innovators, across 40 countries (https://e-niche.eu). It will be supported for four years.

Partnerships will be fostered among (a) scientists studying aquatic and terrestrial ecosystems; (b) natural product chemists, biochemists, molecular biologists and ecologists; (c) vertebrate and invertebrate biologists; (d) plant and animal biologists. Their interactions will generate original ideas and perspectives while simultaneously meeting societal needs, a challenge that involves the creation of new formulations, novel molecules, and innovative applications for natural compounds. While the network focuses primarily on European researchers, it aims to synergize its efforts with broader international networks, such as the International Society of Chemical Ecology (ISCE).

With the E-NICHE program, chemical ecologists mark a significant milestone in the journey of Europe towards sustainability. They envision a future where the language of life, translated through chemical mediation, becomes one of the cornerstones for building resilient ecosystems and fostering human well-being.

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