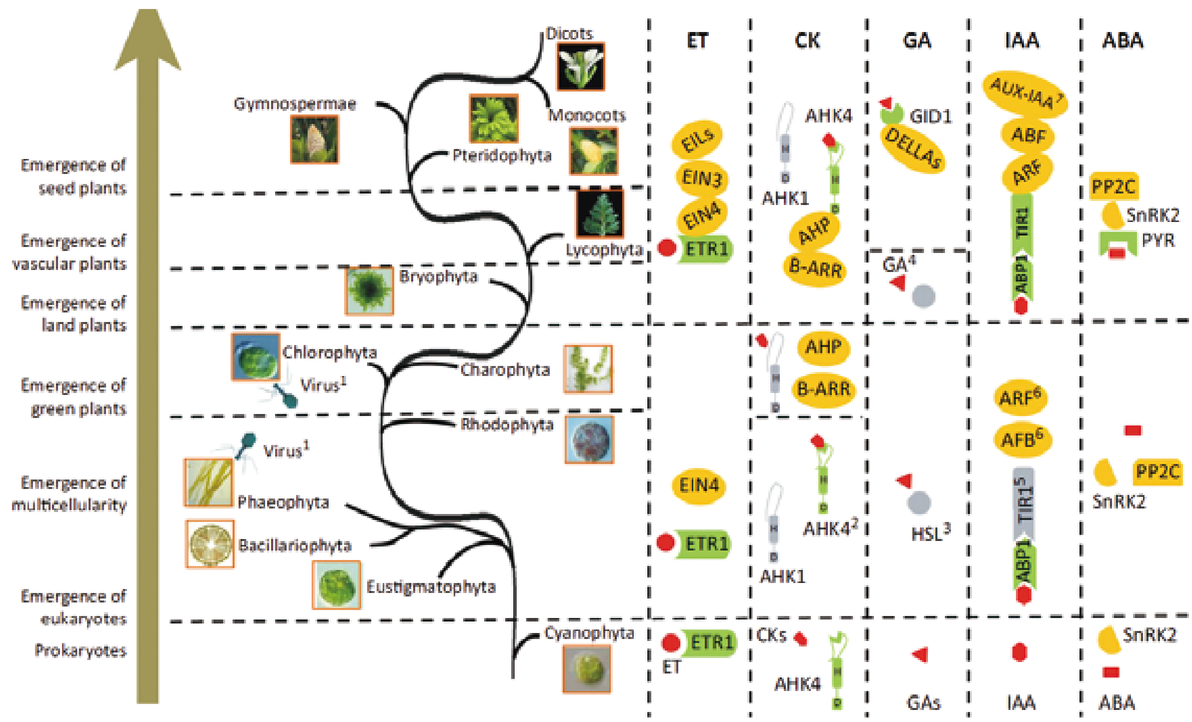
Exploiting the Power of Phytohormones in Microalgal Biotechnology

Phytohormones are a class of signaling molecules that are produced intrinsically in plants. In higher plants, phytohormones are usually synthesized in one location and then transported to another, exerting their physiological effects at extremely low concentrations. Although they are simple, small-molecule organic compounds, phytohormones regulate a wide variety of crucial and economically relevant processes in flowering plants, such as seed development, dormancy, germination, vegetative growth and stress responses in flowing plants. Despite these pivotal regulatory



Proposed model for the evolution of phytohormone pathways: ethylene (ET), cytokinin (CK), gibberellin (GA), indole-3-acetic acid (IAA), and abscisic acid (ABA). Biosynthesis of these plant hormones may be largely inherited from cyanobacteria via endosymbiosis, whereas the signaling components may have acquired their current functions through stepwise evolution. Phytohormones, receptor precursors, receptors, and transcriptional factors are shown as red, grey, green, and yellow symbols, respectively. The superscript numbers denote: 1, lateral gene transfer of phytohormone-related elements may occur between viruses and microalgae (i.e., *Chlorella variabilis* NC64A and *Ectocarpus siliculosus*); 2, homologs of AHK4 are only found in cyanobacteria *Synechocystis* sp. PCC 6803 and the brown alga *Ectocarpus siliculosus*; 3, the ancient hormone-sensitive lipase (HSL) is the precursor of plant GID1, and the first functioning GID1 may have evolved in ancient lycophytes; 4, although GAs have not been found in moss, the moss (i.e., *P. patens*) produces and utilizes GA-type diterpenes as an endogenous regulator in development; 5, homologs of auxin receptor ABP1 are found in green algae *Chlorella variabilis* NC64A and *Chlorella pyrenoidosa*, whereas a homolog of auxin receptor TIR1 is found only in brown alga *Ectocarpus siliculosus* but lacks the auxin-binding motifs; 6, homologs of the auxin signaling components ARFs have been found in the green algae *Chlamydomonas reinhardtii*, *Coccomyxa subellipsoidea*, and *Volvox carteri*, and in the brown alga *Ectocarpus siliculosus*, while AFBs have been found in the green algae *Chlorella pyrenoidosa*, *Coccomyxa subellipsoidea*, and in the diatom *Thalassiosira pseudonana*; 7, Brophyta harbor an intermediate form of AUX-IAA that is unlikely to be an active factor in the early auxin response. Note that Bryophyta, Lycophyta and gymnosperms as represented here comprise several lineages and might not be monophyletic. The signaling components in microalgae indicated here have not been experimentally studied, thus whether they are *bona fide* signaling components remains to be validated. Moreover, the presence of homologs of the signaling pathways does not necessarily indicate the occurrence of classical phytohormone responses.

roles in growth and development of higher plants, the origin and evolution of phytohormones have been controversial, and their presence and physiological roles in evolutionarily ancient, unicellular plants such as microalgae remain elusive.

Dr. LU Yandu and Dr. XU Jian from the CAS Qingdao Institute of Bioenergy and Bioprocess Technology conducted comparative genomics and metabolic reconstruction of sequenced microalgae, and unveiled the distribution and evolution of the biosynthetic and signaling pathways of phytohormones in microalgae and other plants, including auxin, abscisic acid (ABA), cytokinin (CK), ethylene (ET), and gibberellins (GAs). By reviewing the recent discoveries on this research frontier in a comprehensive manner, they put forward a number of conclusions. First, present-day microalgae possess functional phytohormone metabolic pathways. Moreover, evidence is accumulating that suggest the origination of modern higher plant phytohormone biosynthesis pathways from ancient microalgae, even though some of the microalgal phytohormone signaling pathways remain unknown. In fact, despite the high degree of similarity in phytohormones metabolism pathways between many microalgae and higher plants, presently unknown signaling mechanisms are likely present in microalgae to transmit the phytohormone signals. Finally, manipulation of phytohormones in microalgae may represent untapped yet enormous opportunities for biofuel feedstock development.

Their review article stirred broad interest among the plant, algae and biofuel research communities world-wide, and was selected as the cover story in the May 2015 issue of *Trends in Plant Science*. This work was supported by the National Natural Science Foundation of China and the State Key Development Program of Basic Research of China.