Of course. Here is the processed document, formatted according to your detailed instructions.

DOCUMENT SUMMARY

This 2000 review by McCarty and Chory explores the evolution of signal transduction pathways in vascular plants, highlighting a mix of conserved and novel mechanisms compared to animals. The paper discusses key plant signaling pathways, such as those for **auxin**, **phytochrome** (light), and **ethylene**, revealing how plants have adapted ancient molecular tools (like ubiquitin ligases and prokaryotic-derived receptors) and innovated new ones (like novel transcription factor families) to manage their unique biological constraints, such as photoautotrophic growth and the presence of a cell wall.

FILENAME

`mccarty_2000_research_report_plant_signaling_pathways`

METADATA

Category: RESEARCH **Type:** report **Relevance:** Reference **Update Frequency:** Static **Tags:** #plant-biology #signal-transduction #evolution #receptors #transcription-factors #auxin #phytochrome #ethylene **Related Docs:**

- `davis_2000_research_report_signal_transduction_jnk_mapk`
- `cheung_2000_research_report_histone_modification_epigenetics`
  Supersedes: N/A

FORMATTED CONTENT

Conservation and Innovation in Plant Signaling Pathways

Introduction

As nature's second grand experiment in complex development, vascular plants have strategic importance to our understanding of the mechanisms and evolution of signal transduction pathways. At least a billion years have passed since plants, animals, and fungi diverged. Recent advances allow comparative analysis of the signal transduction pathways in plants and animals, offering new insight into the nature and complexity of signaling pathways that were present in a common ancestor. In this review, we pay particular attention to origins of novelty in the evolution of signaling pathways in plants.

Three important signal transduction pathways illustrate an intermingling of conserved and novel mechanisms:

1. **Auxin Signaling:** Mediated by a highly conserved **ubiquitin ligase complex (SCF)**.
2. **Phytochrome Signaling:** The photoreceptor for red light is a **serine/threonine kinase**.
3. **Ethylene Signaling:** Involves a **raf-like protein kinase** and novel transcription factors.

Plant evolution has taken a very different course under a very different set of constraints than animal evolution. Among the more obvious features are photoautotrophic growth, absence of mobility, and the presence of a semirigid cell wall.

Key Themes in Plant Signaling

Signals from the Environment

For a sessile photosynthetic organism, sensing the external environment is possibly as important as signaling among cells within the organism. Consequently, developmental pathways in plants are more strongly coupled to light and other external environmental cues (e.g., temperature and water) than is typical in animals. Plants have the richest array of light-sensing mechanisms of any group of organisms, including **phytochromes** (red light) and **cryptochromes** (blue light).

Signaling in a Biophysical Context

The cell wall is a key target of signal transduction pathways that regulate growth and is also a physical barrier to diffusion. The network of **plasmadesmatal connections** unites the cytosolic compartments of all cells in the plant into a single symplasm, allowing for long-distance transport of mRNA and proteins. Plants also lack **integrins**, but a novel class of **wall-associated kinases (WAKs)** are candidates for coupling the cytoskeleton to the extracellular matrix.

Signaling in Development

> The generalization that developmental pathways are less conserved than responses common to unicellular organisms is consistent with the hypothesis that multicellular development evolved independently in plants and animal lineages.

Signaling pathways that are central to animal development (**Ras, Wnt, Hedgehog**) are not detected in plants. Instead, plants repeatedly use a core set of classic hormone pathways—**auxin, cytokinin, abscisic acid, gibberellin, and ethylene**—in many different developmental contexts. This suggests that development evolved through duplication and innovation on basic pathways that were recruited early in the evolution of the respective lineages.

Another strong theme in plant signaling networks is a prevalence of **negatively regulated pathways**. For example, in the ethylene pathway, the receptors actively inhibit the ethylene response in the absence of the hormone. Ethylene binding inactivates this inhibition.

Sources of Innovation and Novelty

Innovation in the Input Layer: Ligands and Receptors

- **Conserved Biosynthesis, Novel Signaling:** Plants and animals share conserved biosynthetic pathways for steroid and retinoid-like hormones (**brassinosteroids** and **abscisic acid**). However, the signal transduction mechanisms are completely different. Plants perceive steroids at the plasma membrane through a **leucine-rich-repeat (LRR) receptor kinase**, whereas animals use intracellular nuclear receptors.
- **The Prokaryotic Heritage:** Two important receptor families, **phytochromes** and **ethylene receptors**, are derived from bacterial two-component histidine kinase systems, likely inherited from the cyanobacterial progenitor of the chloroplast. In plants, these have been modified to integrate with eukaryotic signaling, for example, by evolving from histidine kinases to serine/threonine kinases.
- **Diversification of Receptor Kinases:** The **receptor serine/threonine kinases** comprise the largest and most diverse class of receptor proteins in plants, with over 300 related genes in *Arabidopsis*. In contrast, receptor tyrosine kinases, prevalent in animals, have not been detected in plants. The largest family is the **leucine-rich-repeat (LRR)** class, which typically mediates protein-protein interactions and likely recognizes peptide hormones.

Innovation in the Output Layer: Novel Transcription Factors

Genetic analysis of diverse plant signaling pathways has revealed several novel families of DNA binding proteins that are unique to plants.

- The **B3 domain** proteins are implicated in abscisic acid (ABA) and auxin response pathways.
- The **EIN3 family** of transcription factors is involved in ethylene signaling.
- The **AP2 domain** proteins are implicated in a variety of processes including ABA, cold, and ethylene responses, as well as floral organ identity.

> The plant-specific proteins were discovered almost exclusively in developmental pathways that are unique to plant biology. A similar generalization applies on the animal side suggesting that recruitment of new transcription factors has played a significant role in the evolution of novelty in these lineages.

Other families of conserved eukaryotic transcription factors, like the **MADS box** and **MYB** gene families, have been disproportionately amplified in plants compared to other eukaryotes.

Conclusions and Prospects

Plant signal transduction pathways display an intriguing montage of both novelty and conservation. The source materials derive from expected sources, like the progenitor of the chloroplast genome, but also include a surprising number of novel genes of unknown origin.

A key question is why the *Arabidopsis* genome has nearly twice the gene number of *Drosophila*, an organism that is arguably more complex.

- One possibility is that plant genomes have a higher level of **functional redundancy** overall due to the fact that polyploidy (whole genome duplication) is better tolerated in plants.
- Alternatively, functional complexity may be partitioned differently, with plants using a larger number of less complex genes to achieve what animals do with a smaller number of more complex genes.

Clearly, these are very early days in the era of comparative functional genomics, and we can look forward to many new insights into the evolution of novelty in eukaryotic signal transduction pathways.