Light regulated development in plants

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Talk Outline

• Light control of Plant Development

• Photoreceptors

• Signaling Mechanisms
For plants: Light = Food

Animals can walk to better foraging

Plants must grow to better foraging

As a consequence, plant development is extensively regulated by the environment
Plants monitor many aspects of their light environment in real time

- Intensity
- Color (also known as “quality”)
- Direction
- Duration

Seed plants require light for the synthesis of chlorophyll... and for photosynthesis.
Light regulates many aspects of development

Action Spectroscopy: effectiveness of different wavelengths of light to support a biological response

Okazaki Large Spectrograph
Light regulates many aspects of development

• Seed Germination
  – Light induces germination
    • Red (R) promotes germination
    • Far-red (FR) inhibits germination
    • Depends on seed size

Adapted from Borthwick et al, 1952
Light regulates many aspects of development

• **Seed Germination**

• **Seedling Emergence**
  – Light is a cue for seedling emergence
  – In the dark seedlings show *etiolated* growth:
    • apical “hook”
    • unexpanded cotyledons
    • elongated hypocotyl
  – Light causes **de-etiolation**:
    • hypocotyl elongation is inhibited
    • the hook straightens
    • cotyledons expand and green

Taiz & Zeiger, Plant Physiology, Fourth Edition, Fig. 17.1 (2006)
Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)

Courtesy of Roger Hangarter: http://plantsinmotion.bio.indiana.edu

Courtesy of Takatoshi Kagawa
http://www.agbi.tsukuba.ac.jp/~k-lab/tropism/stem.html
Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement within cells

Sakai et al PNAS 2001
Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement
- Amount of growth
  - stem and petiole elongation
- Resource allocation
  - amount of carbon to leaves, roots, shoot, seed, fruit.
  - therefore affects extent of organ development
  - defense vs. growth paradigm

Shade Avoidance
Light quality signals neighbor proximity (Shade avoidance)
Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement
- Amount of growth
- Resource allocation
- Flowering time
  - Many plants use light to determine daylength and thereby seasonality
    - Long day plants are induced to flower when days are longer than a critical threshold
    - Short day plants are induced to flower when days are shorter than a critical threshold
Take Home Message

Plant development is strongly affected by the light environment.
Genetic Screens for Light Signaling Mutants

- *hy (elongated hypocotyl)* mutants have tall hypocotyls in the light.

- *cop (constitutively photomorphogenic)* and *det (de-etiolated)* mutants are de-etiolated even in the dark.
Hy (elongated hypocotyl) loci are mostly photoreceptor mutants

- HY1 & HY2 encode enzymes of phytochrome chromophore
- HY3 encodes phytochrome B
- HY4 encodes cryptochrome
- HY5 encodes MYB transcription factor (promotes light-reg’d genes)
- HY8 encodes phytochrome A

Cop and det mutants are repressors of photomorphogenesis.

- COP1 & DET1 regulate protein degradation in darkness
- Other COP/FUS loci are components of the proteosome
- DET2 involved in brassinosteroid metabolism (and growth regulation)
- DET3 involved in vacuolar H+-ATPase (and growth regulation)
Photomorphogenesis: Integration of light signal perception by multiple photoreceptors

- **PHYA/B/C**
- **CRY1/2/3**
- **PHOT1/2**
- **ZTL/FKF1**
- **UVR8**

**Plant development**
- seed germination
- de-etiolation
- floral induction
- senescence

**Plant growth**
- shade avoidance
- phototropism
- organelle movement
Flavin-based photosensors are widespread in plants and mediate blue light responses (PHOT/CRY/ZTL/FKF)

Phototropism in seedlings (first described by Darwin)

<- blue light

<- blue light
(no phototropin)

blue light

Col (WT)  cry2  cry1

Cryptochromes & Seedling Growth
Phototropism, chloroplast movement & stomata opening are all mediated by phototropins, Phot1 and Phot2.

PHOT1 mediates the low fluence response.

PHOT2 mediates the high fluence response.

Briggs & Christie 2002 TIPS 7, 204-210
Bilin-based phytochromes detect shade by measuring the red/far-red ratio (PHY).

From Casal, ARPB 2013
Take Home Message

Plant development is strongly affected by the light environment.

In addition to the photosynthetic apparatus, plants possess a wide variety of flavin- and bilin-based photoreceptors that sense light color, intensity, direction and duration of exposure to regulate both growth and development.
Phytochrome Modes of Action

LF

Pr $\rightarrow$ Pfr $\rightarrow$ R/FR reversible

PhyB

VLF

Pr $\rightarrow$ Pfr $\rightarrow$ R inductive

PhyC

HIR

Pr $\rightarrow$ Pfr $\rightarrow$ continuous light required

PhyA
Although important, phytochromes are non-essential …

... but, plant growth and development is severely impaired.

Arabidopsis thaliana

Hu et al., 2013 PNAS
Arrested plant development in darkness is overcome by phytochrome activation.

Constitutive phytochrome alleles permit plant development in the absence of light.

Su & Lagarias 2007 Plant Cell
Phytochromes regulate >10% of the plant transcriptome...

... in a manner independent of photosynthesis.

Hu, Su & Lagarias, 2009 Mol. Plant
In the nucleus, aPIFs promote derepression of aPIFs, leading to the nuclear translocation of rPIFs, which interact with LHCP and SSU. This results in the production of Pfr, which undergoes turnover and outputs 1 and 2.

In the cytosol, Pfr absorbs light (hv) and converts to Pr, which degrades and reforms Pfr. Pr can also be converted to (apo)PHYA-E, which produces mRNA for the production of ALA, HEME, BV IXα, and PΦB.

The process involves H+, Ca2+, and X- ions.
Some Take Home Messages

Plant development is strongly affected by the light environment.

In addition to the photosynthetic apparatus, plants possess a wide variety of flavin- and bilin-based photoreceptors that sense light color, intensity, direction and duration of exposure to regulate both growth and development.

Such regulators are non-essential for survival in controlled light environments, but are essential for successful competition with other plants for survival in a fluctuating diurnal light environment.
Crosstalk between photoreceptors

Crosstalk between photoreceptors

Brian Thomas 2006 JXB
Some Take Home Messages

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These photoreceptors have overlapping and distinct signaling pathways which regulate development in a wide variety of light environments.