Flowering Time Control in Plants

-How plants know the time to flower?

Masaki NIWA
Grad. Sch. Biostudies, Kyoto Univ.
Why can plants bloom every year in the same season?

→ They should know the best season to flower.

Winter

Spring

Winter Antelope Valley, California

Spring Antelope Valley, California
How can plants know the season?
-What is the environmental cues?

Rainfall

Temperature

Sunshine hours

Photoperiod

(Rainfall precipitation)

(Temperature)

(Hours of sunshine)

(Daylight length)
Molecular mechanisms in which plants know ...

- Photoperiod
- Temperature

Winter
Spring

Antelope Valley, California
*Arabidopsis thaliana* life cycle (biennial accession) = 2 year life cycle

- **Fall**: Long days, Before cold
- **Winter**: Short days, During cold
- **Spring**: Long days, After cold
- **Summer**:
Photoperiodism
-the physiological reaction of organisms to the length of day or night.

- Change in color
  - Winter
  - Summer

- Migration

- Hibernation

- Flowering
Photoperiodism in plants

**Short-day (SD) plants**
flower when the day length is shorter than a critical length.

**Long-day (LD) plants**
flower when the day length is longer than a critical length.
Do plants monitor the length of day or night?

= Plants are light-sensitive in night?

Plants monitor the length of night.

Night break (Flash of light)

Short-day (SD) plants

Long-day (LD) plants
How do plants know the night length?

- External coincidence model

Pittendrigh and Minis (1964)

Internal oscillator

Subjective day

Subjective night

Long days

External cue
How do plants know the night length?

- External coincidence model  
  Pittendrigh and Minis (1964)

![Diagram showing the concept of subjective day and night with external cues and internal oscillators.]

Subjective day

Subjective night

External cue

Short days

Internal oscillator
How do plants know the night length?

- External coincidence model  

Pittendrigh and Minis (1964)

Internal oscillator

Subjective day

Subjective night

Short days + night break

External cue

night break

night break
How do plants know the night length?

- External coincidence model

Pittendrigh and Minis (1964)

Internal oscillator = CO mRNA/protein

Subjective day

Subjective night
**What is **CONSTANS (CO)**?**

- CO promotes flowering under long days.
- CO encodes a B-Box Zinc-Finger family protein.
- CO activates FT (=florigen gene) transcription.
CO expression shows a constant diurnal oscillation

**CO mRNA**

Molecular basis for the external coincidence model

\[ \text{Internal oscillator} = \text{CO mRNA} \ (= \text{CO protein expression}) \]

Subjective night

Subjective day

How is the internal oscillator generated?

*CO* mRNA

How do plants integrate internal and external signals?

CO protein

CO protein is highly unstable in dark

GFP-CO (constitutively expressed)  autofluorescence

Valverde et al., Science (2004), modified
CO protein is highly unstable in dark due to proteasome degradation.

Laubinger et al., Development (2006)
Jang et al., EMBO J. (2008)

Lian et al., Genes Dev. (2011)
Liu et al., Genes Dev. (2011)

induction of downstream genes

Zuo et al., Curr. Biol. (2011)
Lian et al., Genes Dev. (2011)
Molecular basis for the external coincidence model

**Internal oscillator** = **CO protein expression**

**External cue** = **CO protein stabilization**

- **Long days** + **night break**
- **Short days**
Molecular basis for the external coincidence model

Internal oscillator = CO protein expression

External cue = CO protein stabilization

CO protein degradation

Short days
Summary - photoperiod

Circadian clock

CO mRNA

CO protein

FT, SOC1, …
(flowering activators)

Internal oscillator

External cue

CRY
blue light receptor

in light

Ubiquitin ligase

COP1-SPA

in dark

coincidence!
How can plants know the season?

Photoperiod

Temperature

Photoperiod +

fall?  spring?

Kyoto
Vernalization

Arabidopsis (biennial accession) = 2 year life cycle

SD 22°C → LD 22°C → SD 4°C → LD 22°C → LD 4°C → LD 22°C
Vernalization

Arabidopsis (annual accession) = 1 year life cycle

= \Delta FLC

SD 22°C → LD 22°C
What is FLC?

FLC: FLOWERING LOCUS C
MADS-box transcription factor
Dominant repressor of flowering

Vernalization

Photoperiod

CO protein

FT, SOC1, …
(flowering activators)
Plants remember the temperature of previous 6 weeks?

*Arabidopsis halleri* subsp. *gemmifera* (perennial species)

-FLC expression level is most correlated when considering cold experience of past 42 days (= 6 weeks).

Aikawa et al., *PNAS* (2010)
Cold memory is loaded on the chromatin.

Before cold

*FLC* is actively transcribed

(\(H3K4me3\)
(\(H3K36me3\)
acetylation
\(H2Bub1\)
active marks)

After cold

*FLC* is completely repressed

\((H3K27me3)\)
repressive marks

LHP1
How is FLC chromatin structure changed?

Before cold

FLC

PRC2 complex

Nucleation region
How is *FLC* chromatin structure changed?

**During cold**

*VIN3* is up-regulated during cold.


**PHD-PRC2 complex**

*PHD-PRC2 complex* induces H3K27me3 in nucleation region.

How is FLC chromatin structure changed?

After cold (warm temperature)

Repressive marks spread throughout the gene body in a mitotically stable state.

De Lucia et al., PNAS (2008)
Summary - vernalization

Cold → VIN3, ncRNA → FLC expression → FT, SOC1, … (flowering activators)
Summary

-How can plants know the season?

Fall
CO +
FLC +

Summer

Winter
CO -
FLC

Spring
CO +
FLC -