OptimIA

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# Temperature

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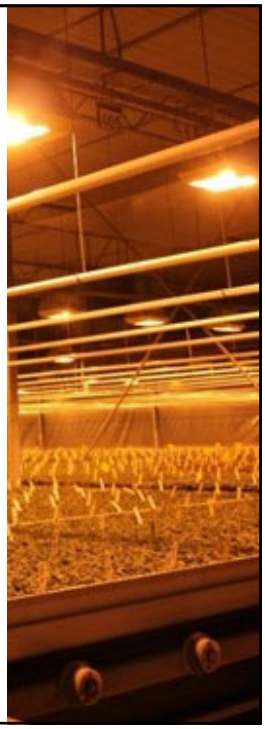

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## What Environmental Parameters can be Controlled and Monitored?

**Aerial zone (leaves)**
- Light (PPFD, DLI)
- Light quality (wavelength)
- Day length
- Air and plant temperature
- $CO_2$ concentration
- Relative humidity (vapor pressure deficit)
- Air velocity

**Root zone**
- Water
- pH
- Nutrients
- $O_2$
- Temperature

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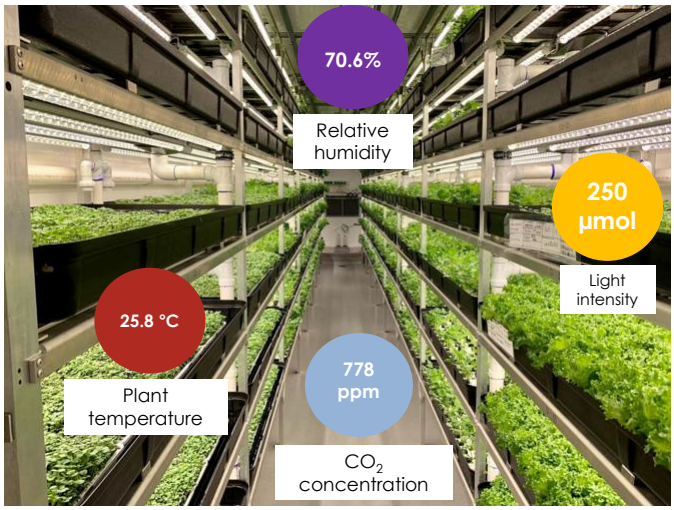
## Environmental Factors to Consider

- **Temperature**
- Light
- Humidity
- $CO_2$ concentration
- Air current speed

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## Temperature Effects on Plants

- Physiological processes are affected by plant temperature, which is determined by transfer of heat between **plant tissues** and the surrounding **environment**
- Controls rate of cell division, and thus root and shoot development
- Indirectly influences growth characteristics (branching, biomass accumulation, flower number, etc., which are primarily a function of accumulated light over time)

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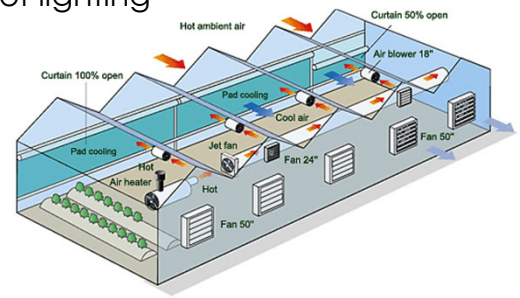
# Temperature Effects on Plants

- Monitoring and managing air temperature is essential
  - Relatively constant for vertical production indoors (leading to increased control of physiological activity)
    - Can be expensive and challenging to maintain cooler temperatures due to the influence of lighting
  - Less control in greenhouse

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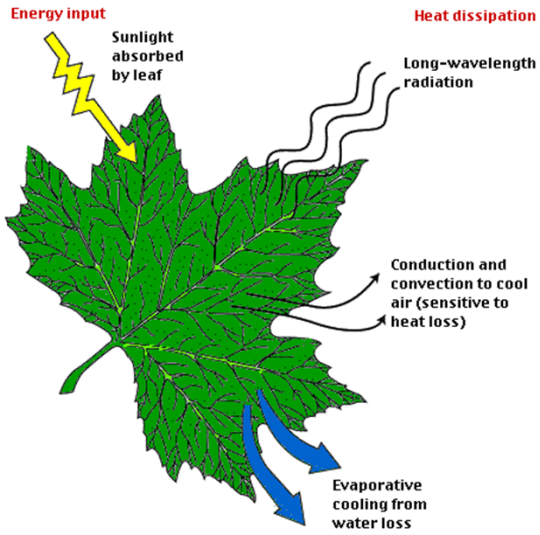
# Temperature Effects on Plants

## Energy balance

- Energy received by plants includes:
  - Absorbed radiant energy from lamps
  - Absorbed infrared radiation from surroundings
- Energy leaving plants includes:
  - Energy lost through emitting infrared radiation (long-wave radiation)
  - Convection and conduction
  - Heat loss through evaporation

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## Temperature Effects on Plants

- Plants regulate their temperature through:
  - Radiation
  - Transpiration
  - Convection
  - Leaf orientation, shape and hairs
  - Heat shock proteins

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## Temperature Effects on Plants

### Radiation

- Leaves have low absorption in the near infrared range (700 – 1,500 nm), most reflected or transmitted
- Leaves have high absorption in the far infrared range (1,500 – 30,000 nm), contributes significantly to thermal energy load
- Primary sources of radiant energy in CEA:
  - Lamps
  - ~~Reflectors~~
  - ~~Sunlight~~

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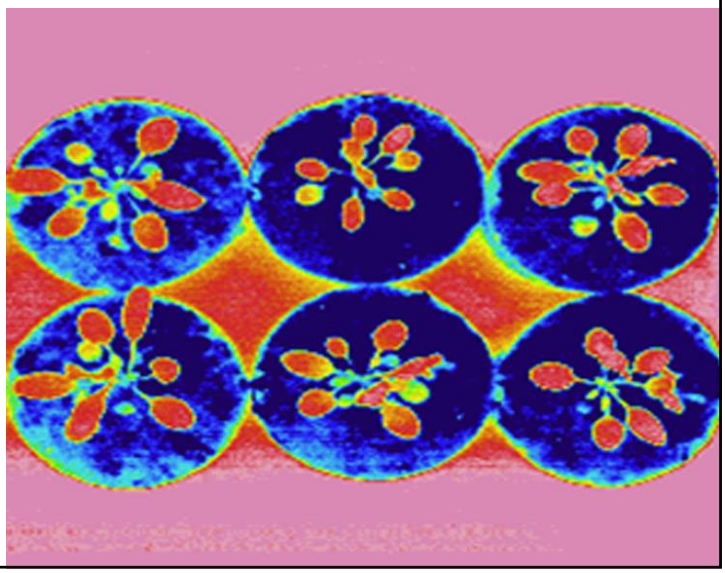
## Infrared Radiation

Plant temperature higher (red areas) than the substrate temperature (blue areas)



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## Temperature Effects on Plants

### Radiation

- HPS lamps have a surface temperature of over 212 °F (100 °C) and emit large quantities of far-infrared radiation
  - Results in increased leaf temperature regardless of air temperature
  - As comparison, LEDs have surface temperature of ~86 °F (~30 °C)

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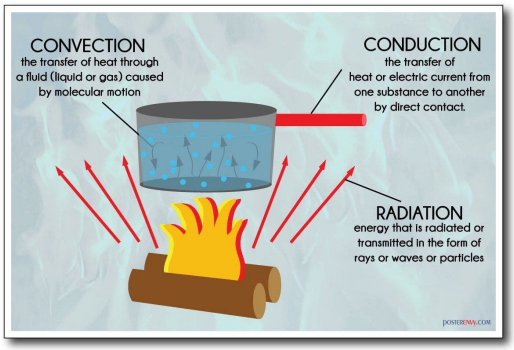
# Temperature Effects on Plants

## Heat conduction and convection

Heat is transferred via **conduction** from leaf cells to air molecules in contact with the leaf

- Limited without convective movement due to low thermal conductivity of air
- Can also occur between plant parts and substrate (water in hydroponic systems)

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# Temperature Effects on Plants

Heat is transferred via **convection** when air moves across the plant. Two types of convection:

- Free (natural) – heat transferred from leaves causes air to warm, expand, and decrease in density.
  - Buoyant warm air moves upward away from plant
- Forced – caused by wind or fans.
  - Speeds of more than 0.5 $m \cdot s^{-1}$ are required for gas exchange, so 0.5 – 1.0 $m \cdot s^{-1}$ is common target


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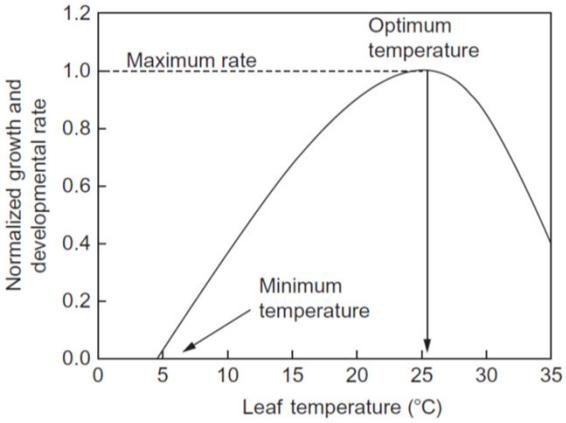
## Temperature

- Daytime temperature
  - photosynthesis
  - transpiration rate
- Nighttime temperature
  - dark respiration
- Average daily temperature (ADT)
  - rate of development

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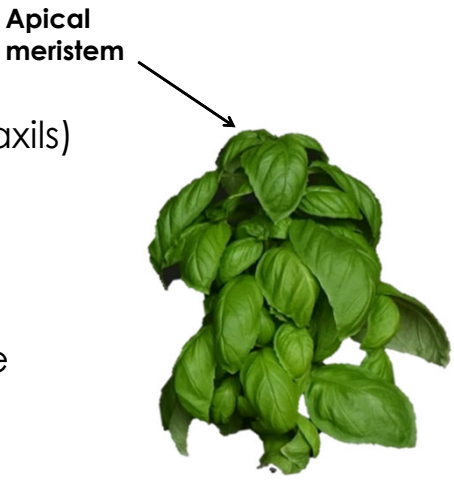
## Plant Development

- Development refers to changes in the meristematic tissues (shoot tips and leaf axils) where leaves and flowers initiate and develop.
- The rate of development is primarily determined by the average temperature over time.
  - Can be used to increase or decrease how a plant develops towards marketability

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## Average Daily Temperature

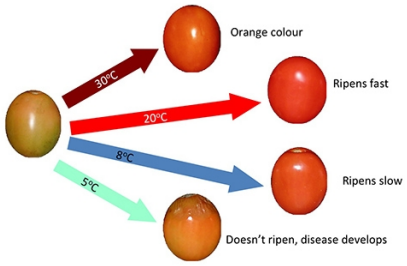
Influences

Crop timing

- Time to flower
- Time to unfold a leaf

Flower and fruit size

- Leaf size
- Root growth
- Ripening

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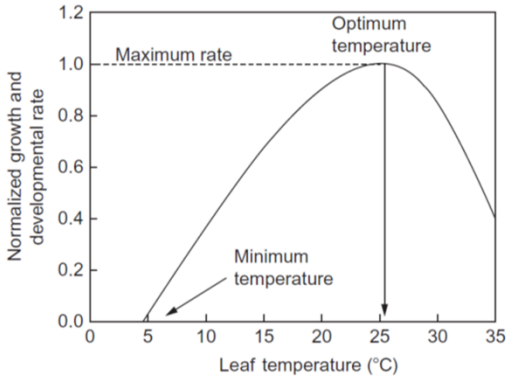
## Average daily temperature

- Base (or Minimum) Temperature ($T_b$)
  - The temperature above which development proceeds
- Optimal Temperature ($T_{opt}$)
  - The temperature at which plant development is maximal
- Maximum Temperature ($T_{max}$)
  - The temperature above which development ceases

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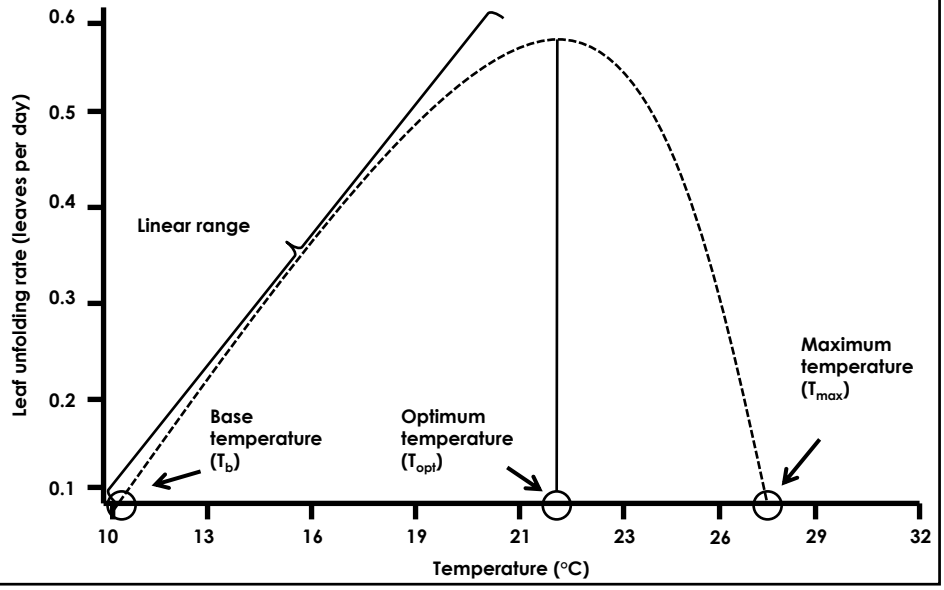
# Plant Development

As long as temperatures are within the linear range, biomass and developmental stage can be well correlated with the average daily temperature

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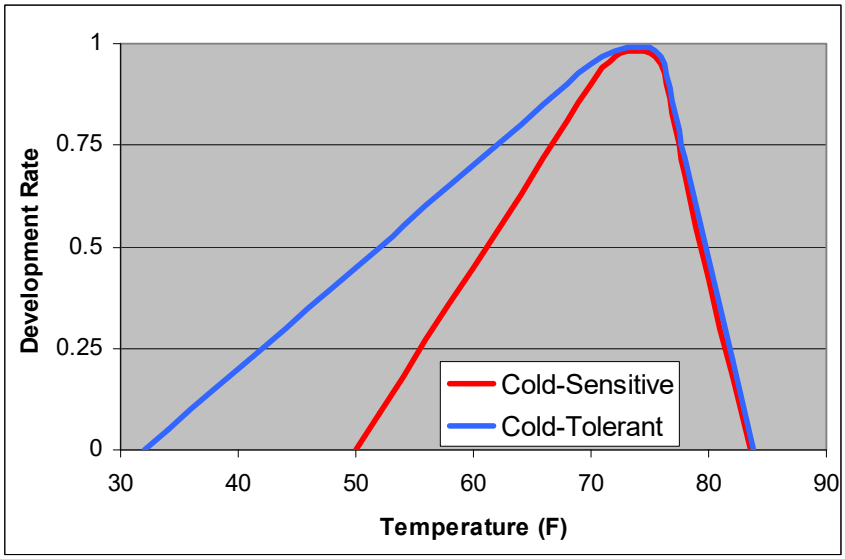
# Plant Development

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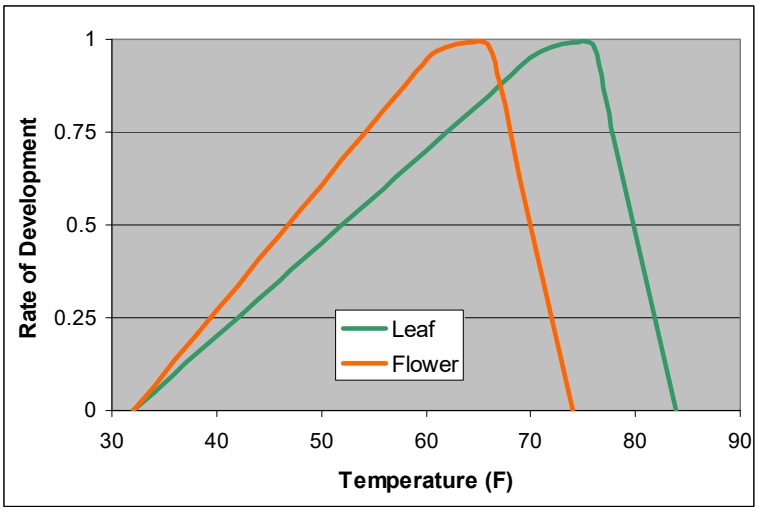
# Plant Development

The optimal temperatures for flower and leaf development can be different for the same plant

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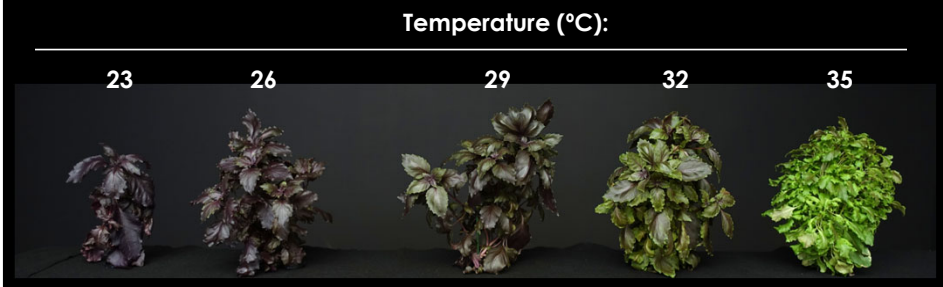
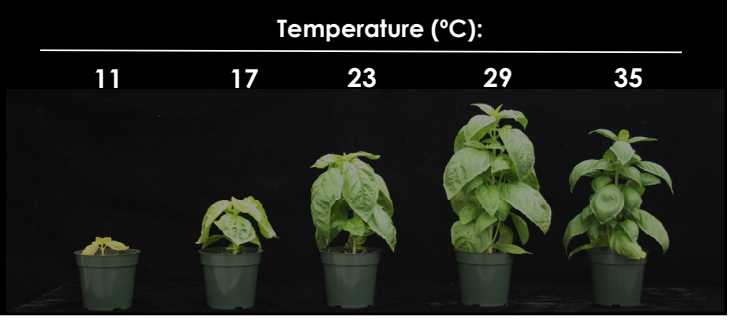



Basil 'Red Rubin'

Basil 'Nufar'

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# Strawberry 'Albion'

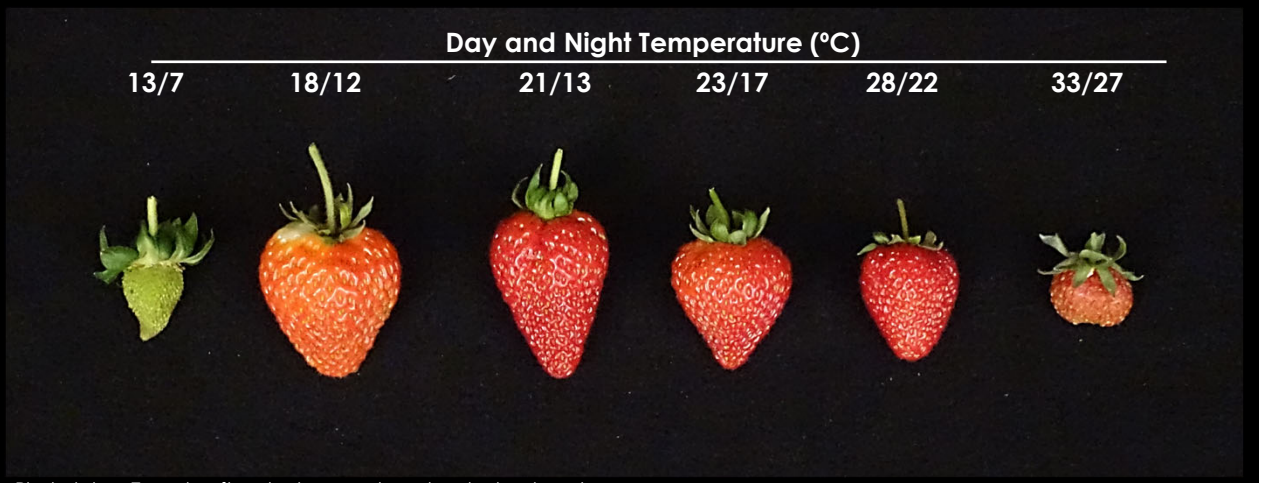


Photo taken 7 weeks after plants were placed under treatments

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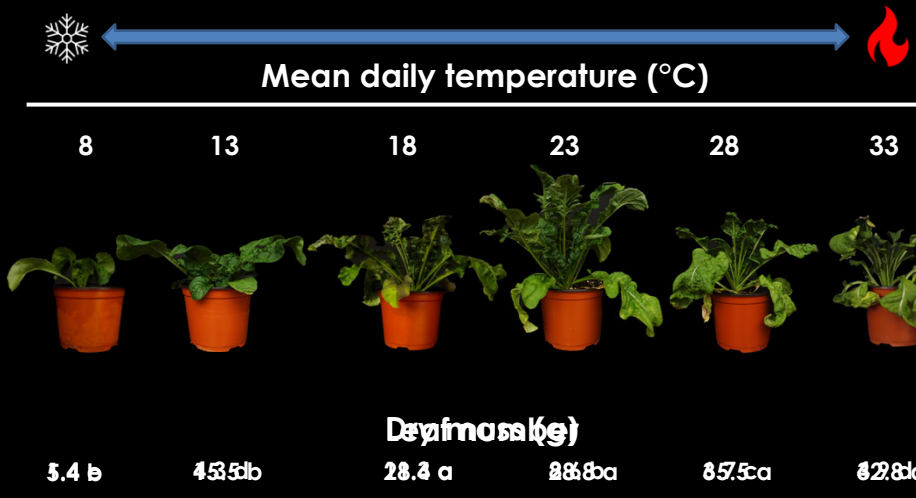
# Arugula 'Astro'




35 d; target VPD of 1.0

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## Kale 'Red Russian'

Mean daily temperature (°C)


35 d; target VPD of 1.0

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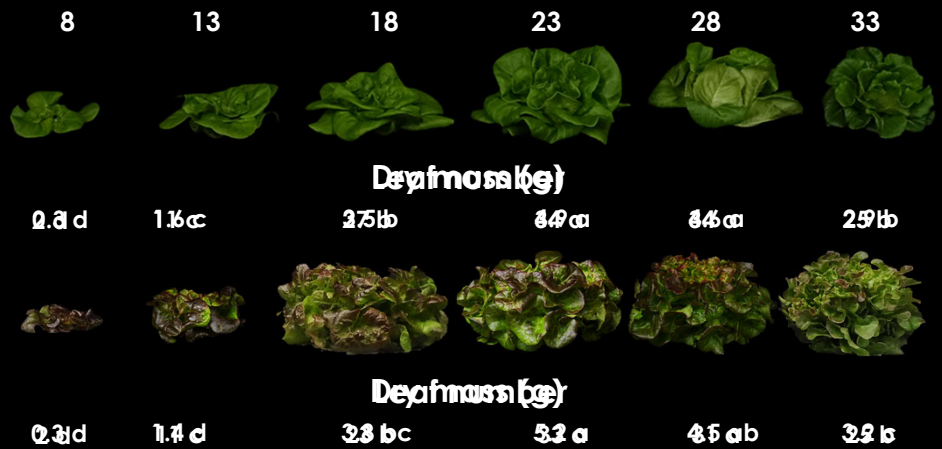
## Lettuce 'Rex' and 'Rouxaï RZ'

Mean daily temperature (°C)




29 d 'Rex', 32 d 'Rouxaï RZ'; target VPD of 1.0

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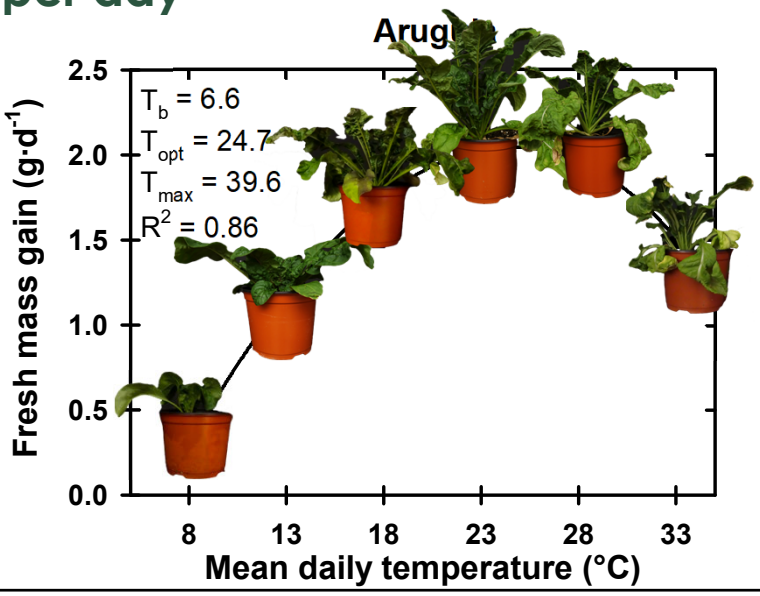
## Fresh mass gain per day

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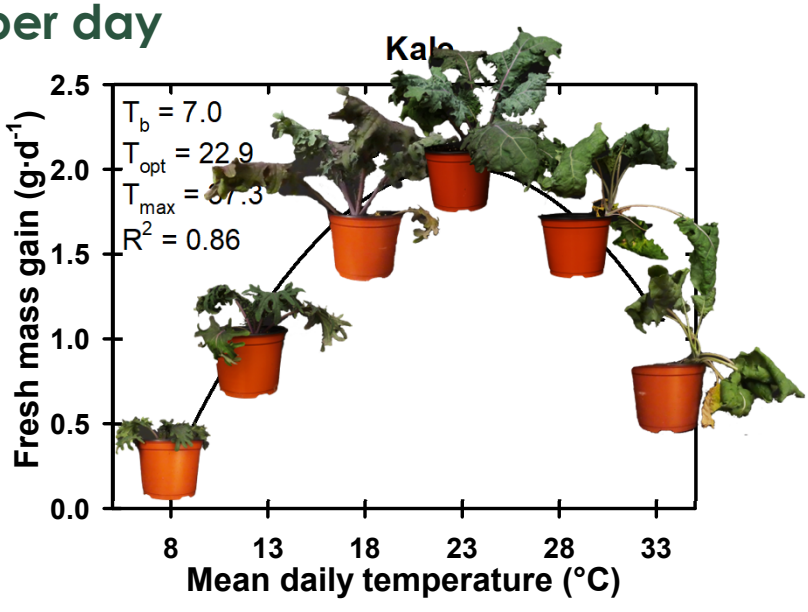
## Fresh mass gain per day

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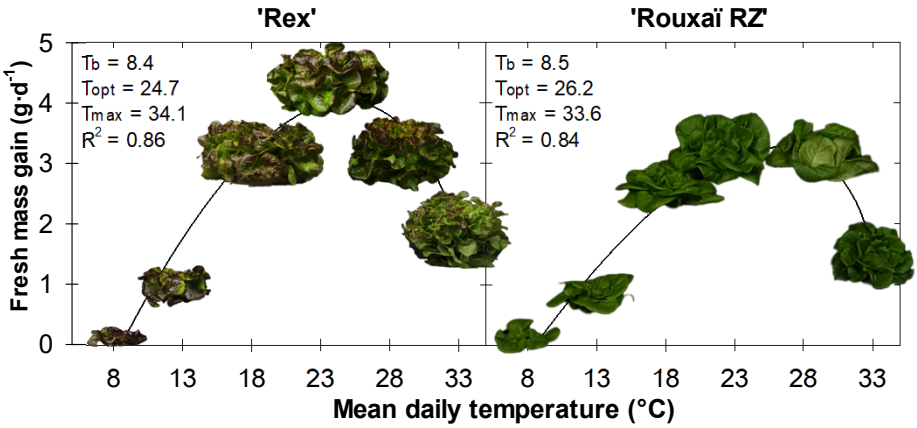
## Fresh mass gain per day

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## Base temperature

- Cold-sensitive greenhouse crops: base temperature of 46 °F (8 °C) or higher
  - Lettuce 'Rouxaï RZ' $T_b$ 47.8 °F
  - Kale 'Red Russian' $T_b$ 46.4 °F
  - Tomato $T_b$ 46.4 °F
  - Sweet basil $T_b$ 52 °F
- Cold-temperate greenhouse crops: base temperature between 40 and 45 °F (5 to 7 °C)
  - Lettuce 'Rex' $T_b$ 44.8 °F
  - Arugula 'Astro' $T_b$ 43.9 °F

Cold-tolerant greenhouse crops: base temperature of 39 °F (4 °C) or lower

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## Temperature Versus Light

- Can be difficult to separate effects of temperature & light
  - High light → higher air, substrate and plant temperatures

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## Temperature and Daily Light Integral (DLI) Interact to Control Growth and Development

**Temperature:**

- Time to unfold a leaf
- Time to flower
- Leaf size
- Flower size
- Dry and fresh weight
- Flower and fruit color

**Light:**

- Photosynthesis (growth)
- Plant temperature
- Lateral branching
- Stem diameter
- The leaf (node) number at which plants are induced to flower
- Flower number
- Dry and fresh weight
- Leaf thickness and size
- Flower size
- Yield (cut flowers, fruits, and vegetables)

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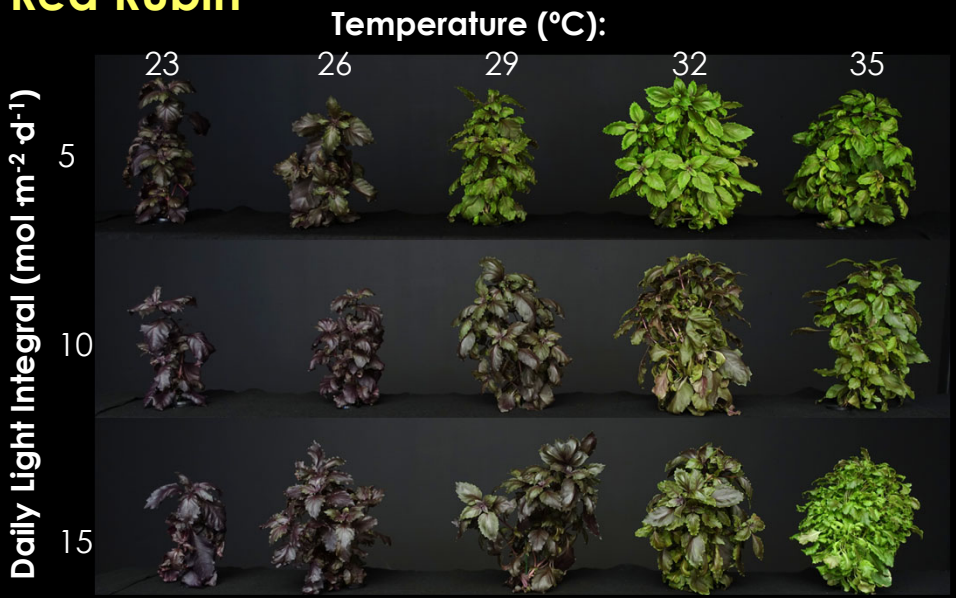
## Basil 'Red Rubin'

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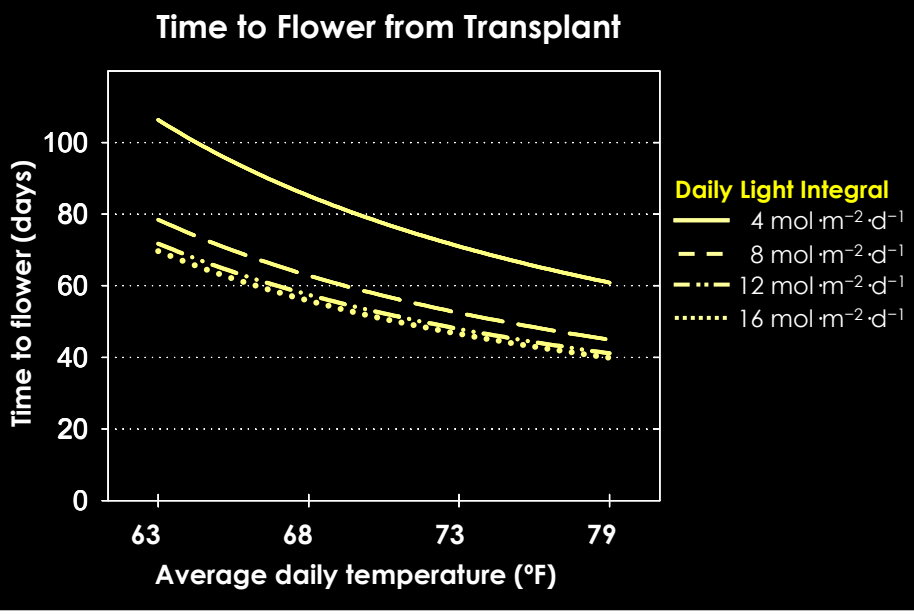


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## Important Temperatures to Consider:

- Air
- Water/Media
- Plant


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## Measuring Air Temperature

- Most common temperature measured
- Easiest to measure
- The best single indicator
- Not always the most important

**An aspirated thermocouple (thermometer) measures air temperature.**

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## Measuring Air Temperature

- Sensor must be shaded
- Sensor must be aspirated
  - Air moved across
- Sensor should be at appropriate location, typically at plant height

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## The Important Temperature is the Temperature of the Plant Component in Question




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## Infrared Radiometers (IR sensors)

- When selecting an IR thermometer, consider the following:
  - Accuracy
  - Ease of use
  - Price
  - Temperature range
  - Field-of-view
  - Target dimensions
  - Calibration
- "Good" sensors start at $250 and can be $5000 or higher

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## Measuring Plant Temperature

- Thermocouples or thermistor connected to dataloggers (media, leaf, shoot-tip)
- Soil temperature probe
- Infra-red (IR) sensor

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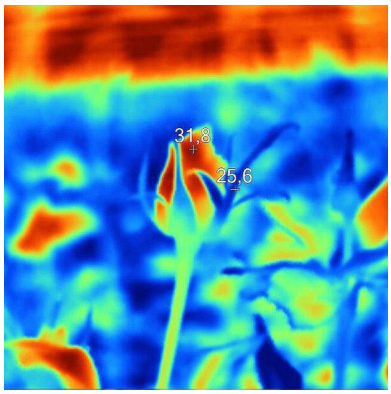
## Thermal Imaging Cameras

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## Measuring Substrate Temperature

**Soil temperature probe**

**IR thermometer**


**Probe to measure water temperature**

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## Contributions to Plant Temperature

- Air temperature
- Light intensity
- Glazing (or sky) temperature
- Vapor pressure deficit (VPD) [humidity]
- Wind
- Water and media temperature

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## Summary

- Temperature is an important tool used in CEA to manipulate the growth and development of crops
- It has a great impact on plant quality due to its effects on crop timing, leaf and flower size

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# Thank you!

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