COHA Webinar
17 February 2022

Temperatures within horticultural plants: Stems and Flowers.

Explaining rapid growth by micrometeorology, morphology and physiology

Presented by Dr. Peter Kevan & Charlotte Coates
School of Environmental Sciences
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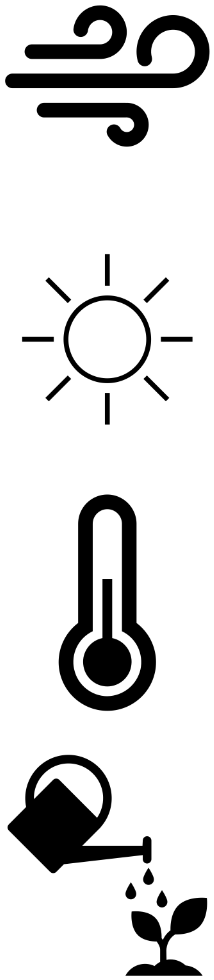


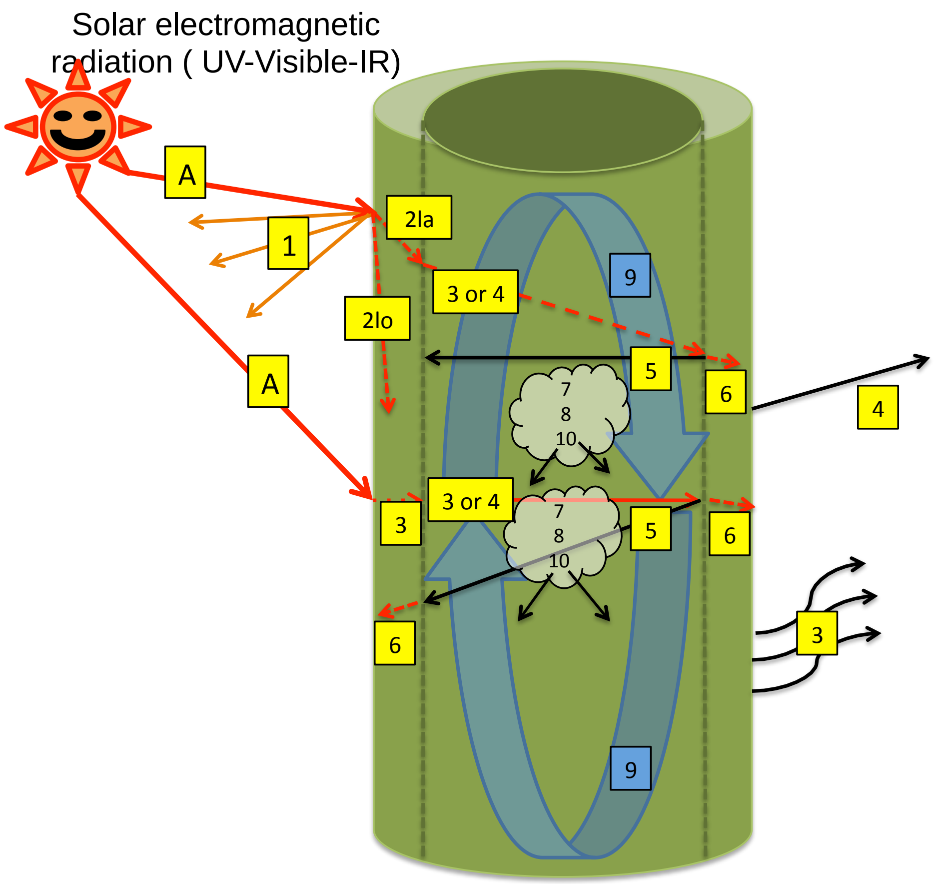
Introduction to *Endo*micrometeorology in Plants

- Micrometeorology = Climate near the ground
- Micrometeorology around plants is well studied
  - atmospheric movements (wind, convection, etc.)
  - light conditions & radiation
  - temperature & heat
  - humidity (moisture) & precipitation

What micrometeorological conditions exist within plant parts?

What micrometeorological conditions exist *within* plant parts?

- **Unknown: Atmospheric conditions** within plant parts (flowers, stems, fruits, galls) little studied
  - plant parts enclose air, especially **hollow structures**
- **Known: Transpiration** in leaves causes evaporation which leads to cooling of plant tissue
- **Known: Metabolic heating**



From: Kevan et al. 2018. *International J. Biometeorology*

Complex Mechanisms of Microgreenhouse Heating

Solar radiation (UV-Visible-IR) (A):

Some Reflected (1),

Some Absorbed (2),

Some Transmitted (3) (translucence).

Absorbed radiation Conducted (2la; 2lo).

Some lost (radiation (3)/conduction (4)) in/out of (lumen) stem.

Transmitted (3)/conducted (4) heat adds energy to the lumen.

Within, radiant energy (3), can be a) reflected (5), b) absorbed (6),

and also

Absorbed by atmosphere in lumen (7), then exchange by Conduction (8) , Convection (9) and Reradiation (10).

= Greenhouse Effect

Heat in stems liberated by radiation (Emissivity; 3) & conduction (4) to environment. Some conducted away by phloem & xylem; 2lo). Some is used in photosynthesis, and metabolism (not shown).

Methods & Mechanisms of Heating in Enclosed Flowers, Fruits & Stems

- **Temperature measurements** (thermocouples)- Work analyzing long-term data on **elevated temperature of up to 13 degress C** in *Gerbera, Cucurbita,* Milkweed, *Amaryllis,* Daffodil, *Physallis*, Japanese Knotweed, *Phragmites,* Sweet pepper,
- **Shape & Form Measurements**
  - Physical dimensions – *Over 500 plant specimens catalogued*
  - Growth rate measurements on model organisms
  - Reflectance & Absorbance spectrophotometry (including IR) – Continue *spectrophotometry work summer 2021* in *Curcubita*
  - Histology (morphology cellular & subcellular)
- **Light & Electron microscopy** (cell & cellular morphology)
- **IR thermography (Heat)** Use of thermal camera in horticulture methods for improved accuracy of plant surface temperature presented in Byerlay et al. 2020
- **Thermal Conductance** experiments on hold due to COVID-19 restrictions

Grasses

- Model organism: Phragmites
- Ease of access
- Invasive wetland species
- Morphological characteristics:
  - Hollow, thick wall stemmed
  - Septate

Phragmites,
Roadside of
Arboretum,
University
of Guelph
Campus

Model organisms 2020 set up:

Gerbera jamesonii

and

Cucurbita pepo

Gerbera daisies at Van Geest Brothers Ltd., Grimsby, ON

Pumpkins at Strom’s Farm, Guelph, ON

Improved environmental data monitoring

Wind meter

Humidity sensor

Ambient temperature probe

Radiation shield

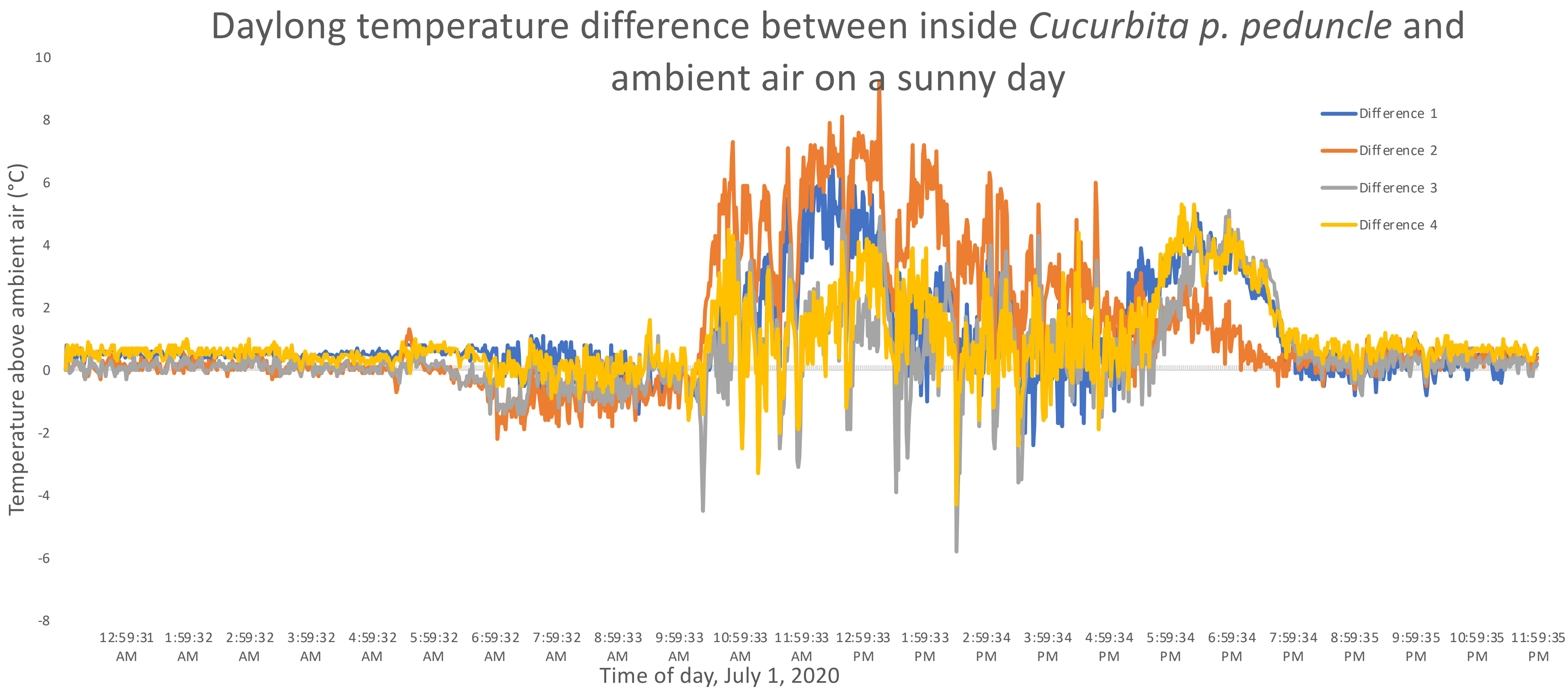
Solar radition meter (PACE)

CR1000 datalogger

Sunny

vs.

Shaded plots



- Daily analysis of individual squash peduncles show higher temperatures than ambient during the period from 10AM-6PM, with internal temperatures overnight from 8PM-9AM closer to ambient air temperature.
- On July 1 the maximum difference :6.5°C , 9.2 °C, 5.1 °C, 5.3 °C rom peduncles 1-4 respectively.

	T-test result (n=1441)	Anova	Dof (btwn, within)	p(same)
peduncle 1 & Air 1	t=26.9 , p= 4.3E-129	peduncles 1,2,3,4	3, 5760	p = 0.05
peduncle 2 & Air 2	t=22.1 , p=1.2E-93	Air 1,2,3,4	3, 5760	p = 1.7E-3
peduncle 3 & Air 3	t=14.0 , p=4.5E-42	Difference 1,2,3,4	3, 5760	p = 3.0E-39
peduncle 4 & Air 4	t=29.4 , p=2.5E-149			

Results

- **Ambient air and peduncle temperature** differences are **statistically significant** for all 4 study peduncles.
- The **4 study peduncles were not statistically different temperature**, and the **4 ambient air thermocouples were also not statistically different** from each other. The temperature differences between the peduncles and air were statistically different (p=3.0E-29)

Decorative gourds, squash varieties

- Grown in Lakefield, ON at a joint research site with Dr. Susan Willis-Chan.
- Untreated with neonicotinoid

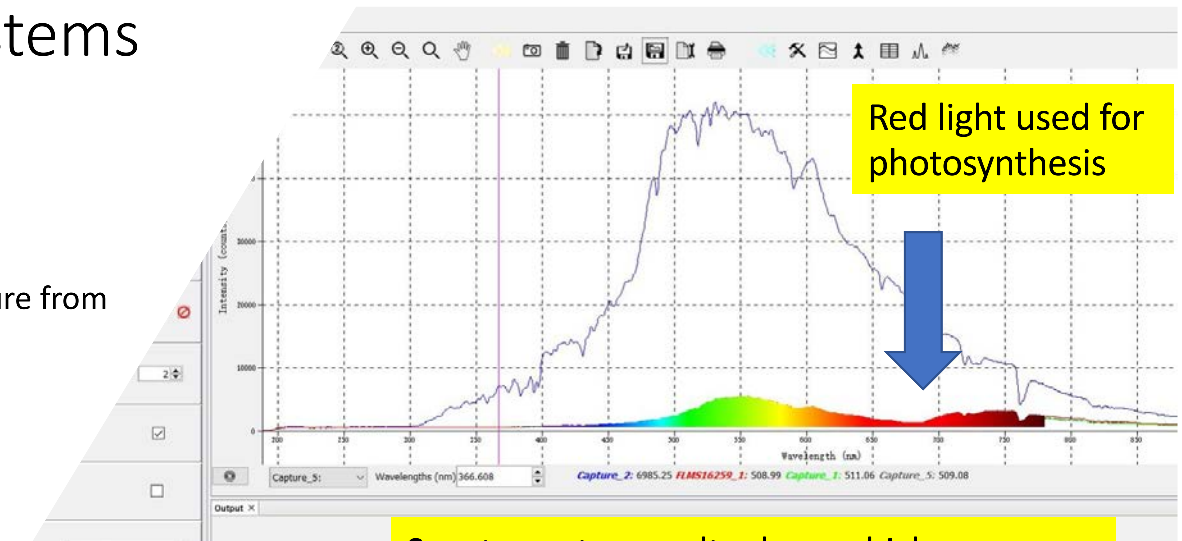
- Decorative gourds--C. pepo subsp. ovifera
- Butternut--C. moschata
- Acorn squash--C. pepo subsp. ovifera
- Zucchini--C. pepo subsp. pepo
- Hubbard--Cucurbita maxima

Lakefield,ON

- Cucumber beetle pests
- Competition pressure – lack of resources to maintain weed free plots
- Temperature results- in process of statistical analysis
- Inconsistent yield from plants to determine temperature effects

Pumpkin *(Cucurbita pepo)* stems

- Varieties: Large vs. Small pumpkins
- Plots: Sun vs. Shade, 2 plants per plot
- Recorded internal & ambient air temperature from June-August
- Collected plant growth data daily



Red light used for photosynthesis

Spectrometer results show which wavelengths of light are present inside the stem

The microgreenhouse effect within hollow pumpkin *Cucurbita pepo* peduncles

22nd International Congress of Biometeorology, Sept.20-22nd, 2021

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Abstract

Plants are generally considered to take on the temperature of their surroundings. However, it has recently been proposed that hollow structures of herbaceous plants can collect heat from the sun passively by the "microgreenhouse effect". The microgreenhouse effect occurs when incoming electromagnetic (EM) radiation from the sun or other source passes through plant tissue, allowing heat to be trapped within the hollow plant part. In preliminary research, we have observed temperatures in hollow structures of plants, such as peduncles (leaf stalks), stems, flowers and fruits, up to 8 °C warmer than the surrounding environment. Our project is one of the first to investigate the micrometeorological conditions within hollow plant parts throughout their life cycles. In particular, we have studied the phenomenon in Cucurbita pepo varieties (pumpkins) grown commercially in Ontario and that have large, hollow peduncles physically and nutritionally supporting the flowers and fruit. Our results indicate that ambient air temperature and radiant heat, atmospheric movement, humidity and precipitation all play parts in the microclimatic regimes in the peduncles. CR1000X dataloggers, infrared cameras and other multiple event micrometeorological techniques were used to determine the true temperature range of plants in sunny and cloudy weather. Temperatures within the peduncles range up to 9 degrees C warmer than the ambient air. Our results demonstrate that plants do not always take on the ambient temperature. Micrometeorological monitoring is important to understanding how crops succeed and understand why they may fail. Refining knowledge of the processes and extents of microclimatic regimes within plants is providing more precision in predictive models for plant growth, maturation, reproduction and survival in managed and natural environments.

Introduction and Hypotheses

Heat can influence the metabolic processes of a plant, and in turn affect the quality of the crop. With the proper application of knowledge, plant parts' surface temperature can identify pathogens, stress, and disease (McCaskill et al. 2016). Fruits can have sunburn damage caused by high surface temperatures can be due to solar radiation or another source (Yazici & Kaynak, 2009). On the other hand, frost damage in has been found to be correlated with the lowest leaf temperature, not the lowest air temperature. Fengjin et al. 2010 studied the cold tolerance *Cucurbita pepo L.* varieties by measuring the difference between leaf and air temperatures. Temperature differences between flower and air have been reviewed by van der Kooi (2019) et al., demonstrating how the morphology of plants can create microclimates within their enclosed air spaces.

Our research objective is to document the parameters relating to the microgreenhouse effect in gerbera and pumpkin, using the framework laid out by Kevan et al. (2018).

To accomplish this objective, the following hypotheses to be tested are:

H1: Hollow squash peduncles always do not take on the same temperature as the ambient air.

H2: Internal temperature of hollow peduncles is dependent only on the ambient environmental temperature. Temperature differences between inside and outside pumpkin peduncles are not due to combined factors of a) incidence of solar radiation and the b) morphology (developmental stage, wall thickness (mm), hollow volume (mL), percentage hollowness, surface textures) and c) optical properties of the tissue (spectral qualities of light transmission, absorption, reflection).

Methodology

In 2018 Kevan et al. presented the microgreenhouse model of solar heating in plants. Figure 1 depicts how plants with translucent tissue may passively generate and hold excess heat in enclosed air spaces (Kevan et al. 2018). The microgreenhouse effect is hypothesized to occur when there are sunny conditions, and incoming solar radiation is transmitted through the walls of the plant organ and is reflected as longwave radiation within the hollow plant part (Kevan et al. 2018). The transmission of light through the plant tissue depends on many factors including the origin of the light source, plant morphology such as the thickness and pigmentation, and the light scattering qualities of the plant tissue (Vogelmann 1993, Kevan et al. 2018).

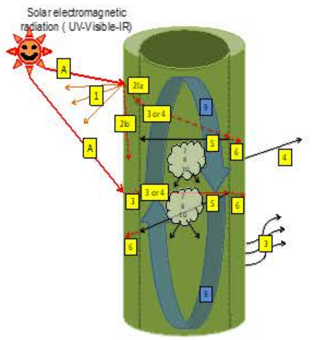

Fig 1. Depiction of greenhouse effect in a hollow peduncled plant, from Kevan et al 2018.

Solar radiation (UV-Visible-IR) (A): Reflected (1), Absorbed (2), Transmitted (3) (translucence).

Absorbed radiation Conducted (2la; 2lo). :Some lost (radiation (3)/conduction (4)) in/out of (lumen) peduncle. Transmitted (3)/conducted (4) heat adds energy to the lumen.
Within, radiant energy (3), can be a) reflected (5), b) absorbed (6),

Absorbed by atmosphere in lumen (7), then exchange by Conduction (8) , Convection (9) and Reradiation (10).
= Greenhouse Effect
Heat in peduncles liberated by radiation (Emissivity; 3) & conduction (4) to environment. Some conducted away by phloem & xylem; 2lo). Some is used in photosynthesis, and metabolism (not shown).

Throughout the life span of commercially grown pumpkins, the below parameters will be collected.
Cucurbita pepo var. Babyboo, Cannonball, Cronus, Rhea, Kratos, and Wolf were grown commercially Strom's Farm in Guelph, ON. The fruits of these varieties range in from small pie pumpkins to large decorative pumpkins, with leaf size and peduncle size varying as well.

Table 1-3. List of microgreenhouse parameters and method to measure.

Environmental parameters	Method to measure (Kevan et al. 2018)
Irradiance & orientation of stem	Spectrometer & direct measurement
Ambient air temperature & Internal stem temperature	Wire thermocouples & datalogger
Wind speed	Anemometer
Ambient humidity	Handheld meters, CR1000 datalogger sensors

Plant morphology parameters	Method to measure (Vogelmann 1993; Kevan 2018)
Peduncle diameter and length	Calipers and tape measure
Peduncle wall thickness	Calipers
Hollow volume	Direct measurement
Inside & outside wall texture	Qualitative observation – hairs, spike density

Plant tissue optics parameter	Method to measure (Omori et al. 2000, Vogelmann 1993)
Transmission of light	Spectrometer, Ocean Optics
Absorption	
Reflection	
Emissivity	

References

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Yazici, K. and Kaynak, L. (2009). Effects of air temperature, relative humidity and solar radiation on fruit surface

Results

Daily analysis of individual squash peduncles show higher temperatures than ambient during the period from 10AM-6PM, with internal temperatures overnight from 8PM-9AM closer to ambient air temperature.
From July 1, 2020 (data shown below Fig 2.) the maximum difference was 6.5°C , 9.2 °C, 5.1 °C, 5.3 °C from peduncles 1-4 respectively.

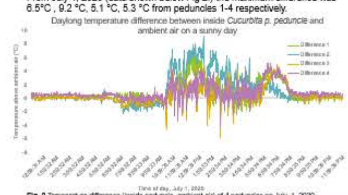

Fig. 2 Temperature difference (inside peduncle -ambient air) of 4 peduncles on July, 1, 2020.

	T-test result (n=1441)	Anova	Dof (btwn, within)	p(same)
peduncle 1 & Air 1	t=26.9 , p= 4.3E-129	peduncles 1,2,3,4	3, 5760	p = 0.05
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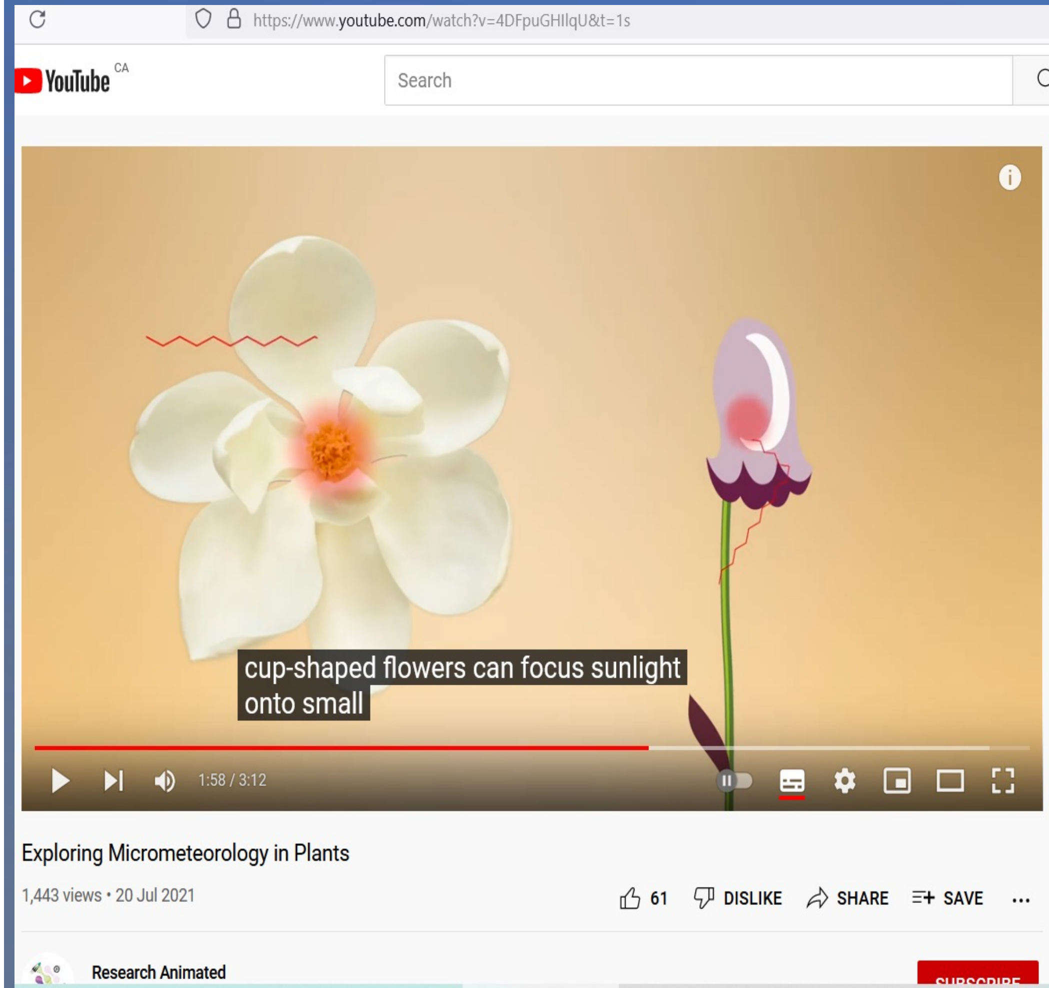
Table 4. By comparing the peduncle and air temperatures differences (graphed above) by t-tests, and ANOVA we see the differences are statistically significant for all 4 study peduncles.
The 4 study peduncles were not statistically different temperature, and the 4 ambient air thermocouples were also not statistically different from each other. The temperature differences between the peduncles and air were statistically different (p=3.0E-29)

Conclusion

Temperatures within hollow parts of plants can reach statistically significant higher temperatures than the ambient air temperature. More detailed statistical analysis is needed to determine the environmental and morphological factors responsible for the variation in temperature difference between study peduncles.

As average temperatures across the globe rise, it is essential to know how plants' internal temperatures may be affected and how they could affect a plants' ability to survive. By investigating the microgreenhouse effect, we will increase our understanding of how plants' physical attributes allow them to adapt and respond to fluctuations in the environment.

By further studying the passive solar heating of plants', we may come to a better understanding of how temperature influences plant water relations, fertilizer requirements, mitigating effects of plant diseases and pests, aesthetic appearances, and shelf-life. Commercial growers that cultivate plants with hollow parts will benefit from knowing the actual temperature ranges their crops take on and how temperature regimes contribute to their yields.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cup-shaped flowers can focus sunlight
onto small
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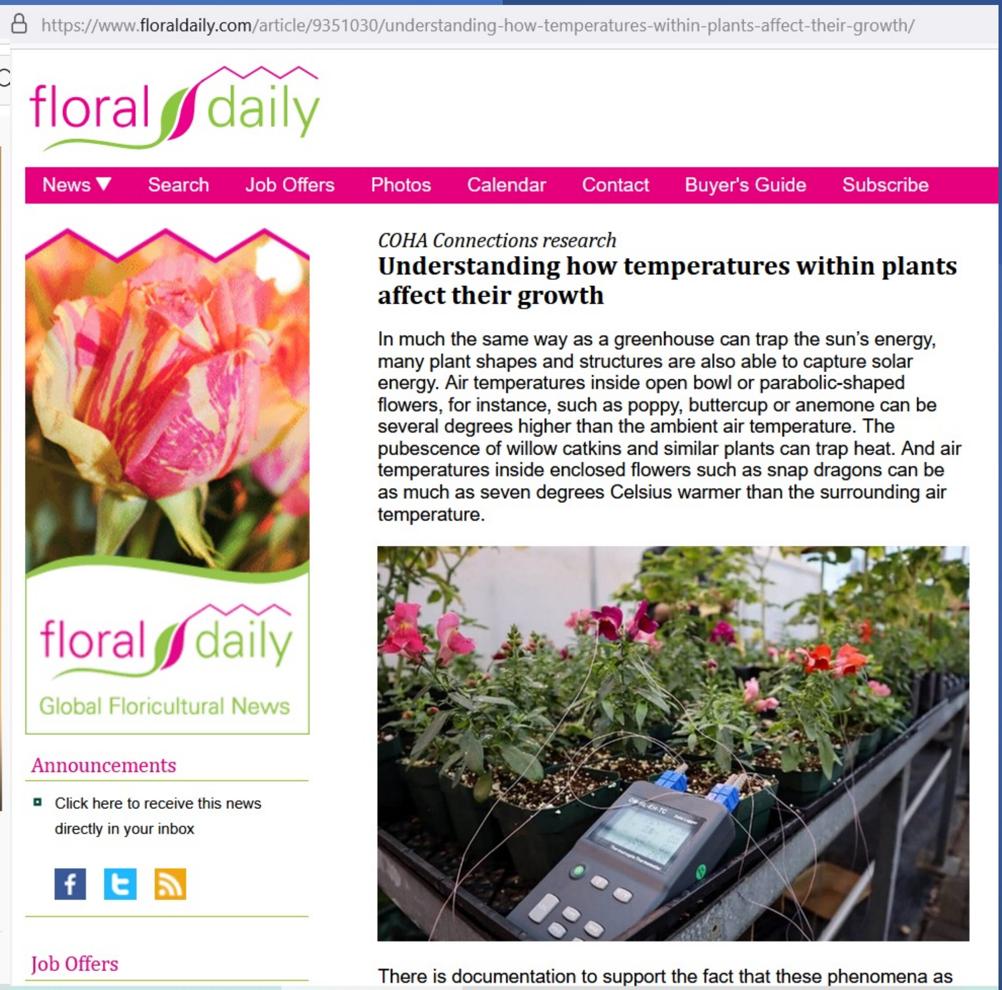
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COHA Connections research
Understanding how temperatures within plants affect their growth
In much the same way as a greenhouse can trap the sun's energy, many plant shapes and structures are also able to capture solar energy. Air temperatures inside open bowl or parabolic-shaped flowers, for instance, such as poppy, buttercup or anemone can be several degrees higher than the ambient air temperature. The pubescence of willow catkins and similar plants can trap heat. And air temperatures inside enclosed flowers such as snap dragons can be as much as seven degrees Celsius warmer than the surrounding air temperature.
There is documentation to support the fact that these phenomena as

Understanding the microgreenhouse effect

Models can predict how a hollow stems internal temperature affected by:

1. **Ambient air** around the stem
2. **Solar** radiation
3. **Plant tissue properties**

- Results useful to growers environmental management plan
- Provide theoretical basis for **effects of extreme weather conditions on hollow plants**

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