# Using GrowBots to Study Heat and Nutrient Stress in Basil

**Rishav Bose**
*Center for Playware, Technical University of Denmark, Building 326,*
*2800 Kongens Lyngby, Denmark*

**Henrik Hautop Lund**
*Center for Playware, Technical University of Denmark, Building 326,*
*2800 Kongens Lyngby, Denmark*
*E-mail: boserishav@gmail.com, hhl@playware.dtu.dk*
*https://www.elektro.dtu.dk/*

**Abstract**

We present how a novel type of robot called a food computer can be used to simulate abiotic stresses and study their impact on hydroponically grown Italian basil, Ocimum basilicum. The food computer called the GrowBot is a tabletop sized robotic greenhouse for growing edible food plants. The GrowBot's actuators were used to alter the environmental conditions in the growth chamber to study different aspects of plant growth and food production in varying climate scenarios. The experiments show how we can used the LED lights to control the temperature to a certain, desired range (29ºC – 35ºC) for the heat stress experiments, while measurements show that we can simultaneously obtain the photosythetically active radition (PAR) values to be in the ideal range for growth of the basil plants.

*Keywords*: Artificial Life, Biology, Cyber Agriculture, Food Computing

## 1. Introduction

Abiotic stresses are the negative impact of non-living factors on plants in a specific environment. Abiotic stress factors, or stressors, are the naturally occurring, intangible, and inanimate factors such as intense sunlight, temperature, or wind. Extremities in temperature, inadequate or excessive water, etc. are hostile to plant growth and development, leading to crop yield penalties. Different abiotic stressors typically occur simultaneously in nature [1].

The growth and development of the plants are greatly affected by a series of morphological, biochemical, and physiological changes resulting from high-temperature stress. Heat stresses can be due to both chronic and abrupt heating. Heat stress reduces the number, mass, and growth of the roots. This curtails the supply of water and nutrients to the shoot system of the plant. High temperatures may also cause scorching of the twigs and leaves along with visual symptoms of sunburn, leaves senescence, growth inhibition, and discolouration of fruits and leaves [2].

A few studies have made attempts to replicate and understand the impact of heat and nutrient stresses in a controlled environment. For example Ukrit Watchareeruetai et al. performed a study in which nutrient deficiencies of calcium (Ca), iron (Fe), magnesium (Mg), nitrogen (N), and potassium (K) were induced on a set of black gram plants [3]. A study at Cornell University grew sweet basil 'Genovese' in nutrient solutions deficient in individual macro and micro-nutrients. The study recorded the visual symptoms of the different deficiencies [4-5]. Melis Mengutay et al. investigated the role of adequate magnesium (Mg) nutrition in mitigating the detrimental effects of heat and light stresses on wheat and maize [6].

## 2. GrowBot Hardware and Software

The GrowBot [7] (see figure 1) is a robotic system that can control the growth of natural life in the form of edible food plants. It allows its users to parameterize growth conditions for plants in terms of temperature, light cycle, the colour of grow light, fertilization, etc. Such a parameterization is called a recipe. Different recipes bring about different growth patterns in plants in the GrowBot. Hence the GrowBot can not only be utilized to test hypotheses in order to provide new knowledge about natural life, but it can contemporaneously control and optimize the growth of life.

Fig. 1. The GrowBot

Inside the growth chamber, there is room for a water tray with a lid with 16 holes arranged in a 4x4 grid (see figure 2). The seeds of the plants can be sown into small rockwool cubes that are laid down into cups. The cups are then placed into the aforementioned holes. On the front side of the chamber is a door, which can be tightened when closed to ensure an airtight space inside the chamber.

The control parameters are recorded as recipes, and figure 3 shows an example of a recipe. A recipe is composed of two types of rules - time rule and condition rule. In a time rule, we enter the time duration we want

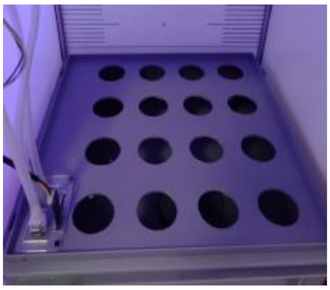

Fig. 2. Water tray in the growth chamber

an actuator to be on for. In figure 3, we are turning on the white light at 100% intensity for a period of 8 hours. In a condition rule, the value of a selected sensor is monitored,

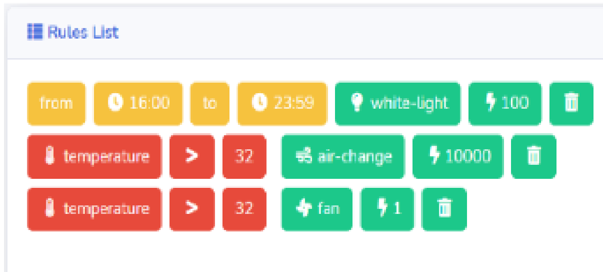


Fig. 3. Example of a recipe

and action is taken based on the sensor reading. In figure 3, we are monitoring the value of the temperature sensor, based on which the air change and fan actuators are turned on.

## 3. Experimental setup

In our experiments, we induced a combination of heat and nutrient stresses. Heat stresses were induced by using the LEDs. The full spectrum LEDs were used at 100% intensity, while a combination of the full spectrum and UV LEDs were used at 50% intensity each. We induced three types of nutrient stresses - Magnesium (Mg), Potassium (K), and Nitrogen (N). Table 1 shows the nutrients present in the potassium deficient solution and the quantities used in 10 litres of water. Three nutrient solutions, each deficient in the individual elements were created. The other parameters of the experiment were as follows:

- Amount of water in the growth tray: 10 litres
- pH range: 5.5 – 6
- Electric conductivity (EC) range: 1.0 - 1.6 mS/cm

- Temperature range: 29ºC – 35ºC
- Photoperiod - 24 hours
- Time duration of experiment: 7 days
- Number of plants in each GrowBot: 2

The growth chamber was maintained in the aforementioned temperature range because according to a study from Iowa State University, phenotypes like plant height, number of branches, fresh and dry mass accumulation rate, and internode length were negatively impacted at temperatures above 29ºC in different basil cultivars. The study noted that above 35ºC, the plants would end up dying [8]. The choice for the ranges pH and EC was based on our literature review [9]. We used a 24-hour photoperiod because it has been noted that constant daylight has a positive effect on basil growth [10]. Another factor taken into consideration while selecting the lighting intensity and photoperiod was that basil requires high photosynthetic photon flux density (PPFD) values of around 500 µmol.$m^{-2}$.$s^{-1}$ [11].

Table 1: Solution to induce potassium (K) deficiency

| Nutrients present | Quantity |
|---|---|
| N(17%) | 1.5ml |
| N(2.2%)-Ca(2.8%) | 1.5ml |
| P(17%) | 1.5ml |
| Mg(7%) | 0.5ml |
| Mg, S | 0.5 grams |
| Ca(12%) | 1.5ml |
| Ca, S | 0.33 grams |
| Fe(0.1%) | 1.5ml |
| B, Cu, Fe, Mn, Mo, Zn | 4ml |

For our study, we purchased pre-grown Italian basil plants from Irma's Infarm hydroponic system. This was done to save time on growing the plants from scratch, as we were interested in studying the impact of stresses on mature plants only.

We used BioBizz Bio pH Minus and BioBizz Bio pH Plus to maintain the pH of the nutrient solutions. To measure the pH and EC values of the nutrient solution, we used the HI98107 pH meter and HI98304 CE tester, respectively.

## 4. Results

In order to maintain the temperature within 29ºC - 35ºC, we performed a vast number of experiments varying the LED light intensities, as we noticed that the growth chamber temperature was affected by the intensity of the

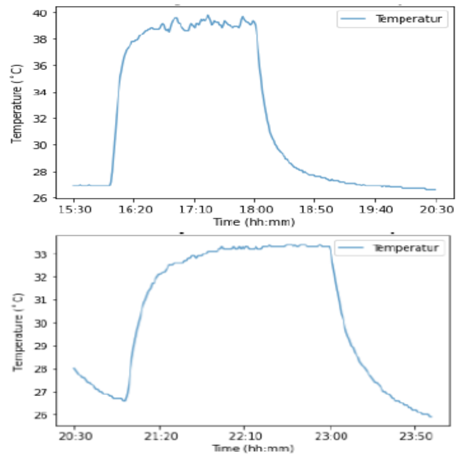


Fig. 4. Heating effect of white and blue light combination at 100% intensity each (top) and at 50% intensity each (bottom)

LEDs. In figure 4, we can see an example of how the growth chamber temperature was modified over a two hour period by using the LEDs at different intensities. In the graph at the top, we can see that the temperature range is not being maintained. However, when the intensities were changed, it was possible to maintain the temperature in the required range, as we can see in the bottom graph in figure 4.

A number of such experiments helped us come to the conclusion that the following lighting settings should be used for keeping the temperature in the desired range:

- Mono-lighting
  - White (W) - 100% intensity
  - Blue (B) - 100% intensity
  - Red (R) - 100% intensity
- Multi-lighting
  - White-Blue-Red (WBR) - 33% intensity (each)
  - White-Blue (WB) - 50% intensity (each)
  - White-Red (WR) - 50% intensity (each)
  - Red-Blue (RB) - 50% intensity (each)

Our next step was to use an Apogee MQ-500 full-spectrum quantum photosynthetically active radiation (PAR) meter at different locations and heights in the growth chamber. This was done to ensure the PPFD values at different points in the GrowBots. We saw in the last section that basil grows best at an irradiance of around 500 µmol.$m^{-2}$.$s^{-1}$. Figure 5 shows the example of one such measurement in a GrowBot at 17.2cm from the bottom of the growth chamber. We measure the PPFD values at five locations - lower left (LL), top left (TL),

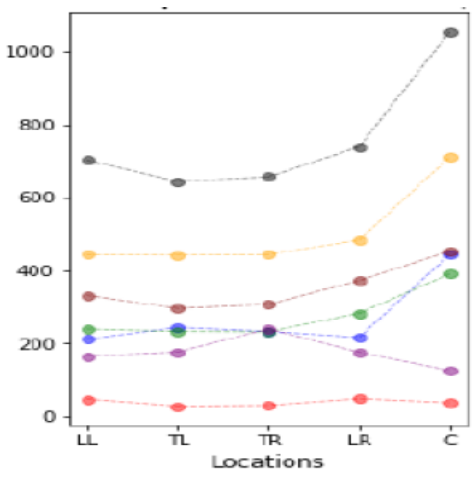


Fig. 5. Variation of PPFD values in one of the GrowBots

top right (TR), lower right( LR), and centre (C). From the graph, we can see that the PPF requirements are approximately satisfied by white light at 100% and a combination of white and blue light at 50% each. The basil plants that we used had an average height of approximately 15cm high. So, 17.2cm was an appropriate height to take these measurements. In this manner, we ensured that the temperature was maintained in the interval 29ºC-35ºC while satisfying the PPFD requirement for basil.

In figure 6, we can see the image of the growth chamber from the potassium and heat stress experiment taken using the camera of one of the GrowBot. The image on the top is from the first day of the experiment. The image at the bottom is from the last day of the experiment. We can see interveinal chlorosis in a large number of the leaves and some necrotic spots in the older leaves.

One of the things noted in the experiments was that even though the plants were in experiencing heat and nutrient stress, the weights of the plants increased. This gave us an important insight into the `dilution effect' - an inverse relationship between yield and nutrient concentration in food [10]. This was observed across all the stress experiments. Table 2 shows the weights of the plants before and after the heat and potassium stress test.

Fig. 6. Plant canopy images at the start (top) and end (bottom) of the heat and potassium stress experiment

Table 2: Weight of the plants before and after the heat and potassium stress test

| Before stress test | | After stress test |
|---|---|---|
| Plant | Weight (g) | Weight (g) |
| P1 (Right) | 51 | 60 |
| P2 (Left) | 59 | 82 |

## 5. Discussion and conclusions

The GrowBots allows their users to parameterize life growth conditions for plants through the recipes in terms of temperature, light cycles and intensities, colour of grow light, irrigation and fertilizing, etc. Different recipes will lead to different growth patterns. These experiments show how the GrowBot can be utilized to test hypotheses in order to understand different aspects about natural life. These types of stress experiments can be used on newly created genetically modified crops to test their resilience in the seemingly unpredictable climate scenario that we are facing.

**Acknowledgements**

We would like to thank the project partners - DTU Food, DTU Skylab, and Københavns Professionshøjskole. We also express our gratitude towards the funding bodies - Nordea Foundation and Novo Nordisk Foundation.

**References**

1. Mei He, Cheng-Qiang He, and Nai-Zheng Ding. “Abiotic stresses: general defenses of land plants and chances for engineering multistress tolerance”. In: Frontiers in plant science 9 (2018), p. 1771.
2. Shah Fahad et al. “Crop production under drought and heat stress: plant responses and management options”. In: Frontiers in plant science 8 (2017), p. 1147.
3. Ukrit Watchareeruetai et al. “Identification of plant nutrient deficiencies using convolutional neural networks”. In: 2018 International Electrical Engineering Congress (iEECON). IEEE. 2018, pp. 1–4.
4. Neil Mattson. “Magnesium Deficiency of Hydroponic and Container Grown Basil”. In: e-Gro Edible Alert 3 (2018).
5. Neil Mattson and Tanya Merrill. “Symptoms of Common Nutrient Deficiencies in Hydroponic Basil”. In: e-Gro Research Update, Cornell University (2016).
6. Melis Mengutay et al. “Adequate magnesium nutrition mitigates adverse effects of heat stress on maize and wheat”. In: Plant and soil 368.1 (2013), pp. 57–72.
7. Lund, H. H., Exner, M., Jensen, N. E., Leggieri, M., Outzen, M., Ravn-Haren, G., Sehested, M. v., Væring, A., Andersen R. (2022) Robotics for Growing Life. ibid
8. Kellie Jean Walters. “Quantifying the effects of hydroponic systems, nutrient solution, and air temperature on growth and development of basil (Ocimum L.) species”. In: (2015).
9. Hardeep Singh and Dunn Bruce. “Electrical conductivity and pH guide for hydroponics”. In: Oklahoma Cooperative Extension Fact Sheets, HLA-6722. Oklahoma State University, Division of Agricultural Sciences and Natural Resources (2016), p. 5.
10. Arielle J Johnson et al. “Flavor-cyber-agriculture: Optimization of plant metabolites in an open-source control environment through surrogate modeling”. In: PLoS One 14.4 (2019), e0213918.
11. Angela R Beaman, Richard J Gladon, and James A Schrader. “Sweet basil requires an irradiance of 500 µ mol· m- 2· s- 1 for greatest edible biomass production”. In: HortScience 44.1 (2009), pp. 64–67.

**Authors Introduction**

Mr. Rishav Bose

Rishav Bose is a Research Assistant at the Center for Playware, Technical University of Denmark (DTU). He completed his masters degree in Electrical Engineering from DTU in October 2021, where he wrote his master’s thesis on Optimizing Plant Growth Recipes in Growbots with Machine Learning. His main research interests are food computing, cyber agriculture, and computer vision.

Prof. Henrik Hautop Lund

Professor, Ph.D. Henrik Hautop Lund, Center for Playware, Technical University of Denmark, is World Champion in RoboCup Humanoids Freestyle 2002, and has more than 200 scientific publications and 5000 citations. He was awarded the Most Outstanding Healthcare Innovator in the World in 2019. Over the last year, he received international awards in Tokyo, Singapore, and London. He has developed shape-shifting modular robots, presented to the emperor of Japan, and has collaborated closely on robotics and AI with companies like LEGO, Kompan, BandaiNamco, Microsoft, Mizuno. He is the inventor of the Moto Tiles (www.moto-tiles.com), which are used by seniors all around the world.