PROMOTING SUSTAINABLE SCIENCE EDUCATION
AND
RESEARCH DEVELOPMENT

Lab in a Suitcase

Equipment Characterisation Data

Promoting Sustainable Science Education and Research Development (PSSE&RD) is a research and capacitation project funded by the Merck Family Foundation and the Oeiras Municipality, and coordinated by the Instituto Gulbenkian de Ciência (IGC).

Learning Science through hands-on, experimental training is fundamental to develop critical thinking and engage in the scientific process. Likewise, scientific research is strongly dependent on laboratory infrastructure. The Lab in Suitcase project puts forward an integrative approach to both teaching and research by developing and implementing a low-cost, portable, and serviceable experimental kit.

The Lab in a Suitcase (LiS) is a "plug and play" equipment kit composed of adapted, existing modules or modules built from scratch. These modules allow the production of custom-made portable labs aimed at university-level teaching and research.

In this document we have compiled all the data collected during the equipment performance characterisation done in comparison to commercially available equipment and to ensure experiments could be easily and safely performed. We did not perform thorough testing of the Bento Lab, which has been developed and tested by the company Bento Bioworks.

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The kit

The research output of the Open Science movement is freely available in scientific journals, thus making the development of low-cost equipment openly accessible to the scientific and teaching communities. Due to the varying quality of the equipment available, we reproduced and tested equipment curated by our team. Those which met our quality standards were then selected to be included in the Lab in a Suitcase, such as the magnifying lens and the Bento Lab.
Our team has developed, independently, the following unique components:

- An incubator;
- An optical density (OD) reader;
- An OD reader application for Android and desktop computers.

The complete kit (figure 1), suitable to carry out cellular and molecular biology experiments, includes:

1. Bento Lab
   a) Thermal cycler
   b) Microcentrifuge
   c) Blue LED transilluminator
   d) Gel electrophoresis system
   e) Tube rack
2. Android phone Xiaomi Redmi 9AT
3. Incubator
4. Magnifying lens
5. Optical density reader
6. Optical density reader mobile application
7. Suitcase integrating all the equipment
8. The LiS GitHub, a repository where all the technical designs, circuits, and 3D printing instructions are available, making it possible for anyone to reproduce the equipment developed at the IGC
9. A webpage with all the project resources, operating instructions, video-tutorials and webinar recordings

Figure 1. The Lab in a Suitcase kit.

Densitometer

Taking advantage of having low-cost mobile phones with a white LED and camera, we developed a portable densitometer (figure 2). The device includes a 3D-printed support for a cuvette and a mobile application (progressive web app running in a browser) that, like a spectrophotometer, measures the optical density of solutions based on the Beer-Lambert absorption law, providing an estimation of the concentration of bacteria or other cells/molecules in a liquid solution contained in the cuvette.
The 3D-printed support holds a light-guide (figure 2 a1), a light filter (figure 2 a2) and a cuvette (figure 2 a3 and b). The light guide takes the phone LED illumination to the cuvette before reaching the phone rear camera (figure 2 b). In spectrophotometry, the optical density of a sample is measured at a wavelength of 600 nm. For this reason, our densitometer includes an orange filter, ensuring the correct wavelength passes through the sample.

The OD reader application (figure 2 c) reads the images captured by the phone camera, performs quantitative image analysis using a JavaScript framework, and outputs the corresponding optical density values. The application has been designed to, once installed, run without requiring internet access, making it particularly suitable for field work and use in remote locations. The application can take and store multiple sequential measurements. Stored values can be digitally exported to an Excel file and emailed to the user.

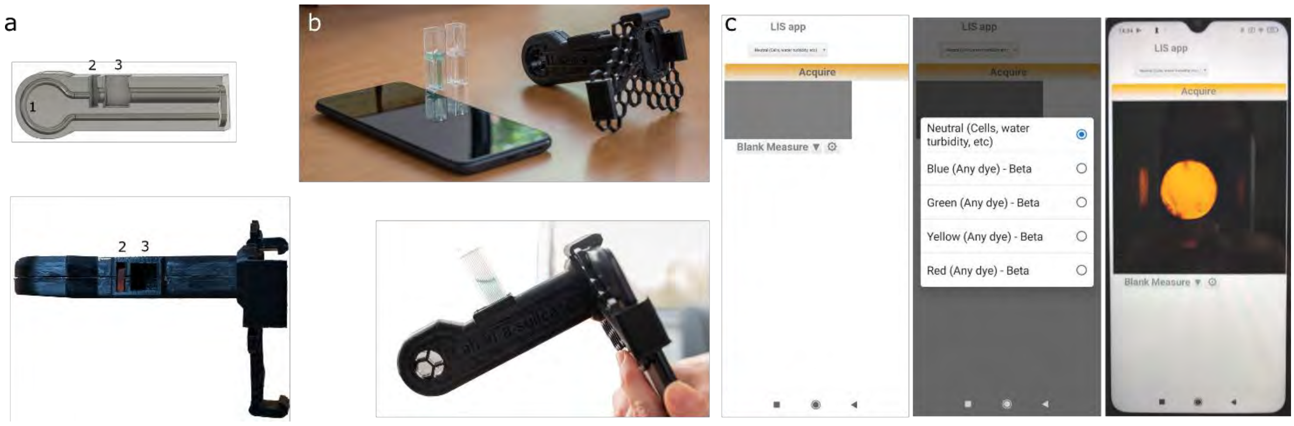

Figure 2. Optical density reader consisting of a 3D-printed cuvette holder and a data analyser application. The holder includes a light-guide **(a1)**, a filter slot **(a2)** and a cuvette slot **(a3, 4)**. The light guide takes the mobile phone LED illumination to the cuvette before reaching its back camera **(b)**. The measured light is indirectly proportional to the density (degree of opacity) of the test sample held in the cuvette. Image analysis, OD measurement and value output is performed by the LiS optical density reader mobile application **(c)**.

The LiS team and a group of beta-testers at IGC have tested the OD reader performance by using different cell cultures and comparing the obtained measurements with those of commercially available spectrophotometers. The performance of the LiS OD reader is comparable to that of commercial benchtop equipment (figure 3).

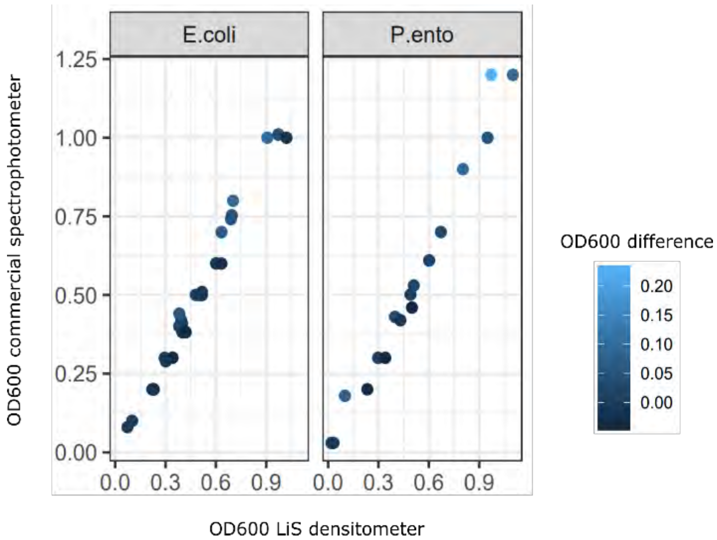

Figure 3. Correlation between optical density measurements taken at a wavelength of 600 nm (OD600) with the LiS densitometer and a commercially available benchtop spectrophotometer. *Escherichia coli* (*E. coli*, n=30) and *Pseudomonas entomophila* (*P. ento*, n=12) cultures were used in these tests. There was an average difference of 0.011 (*E. coli*) and 0.018 (*P. ento*) between the OD600 measurements taken with each piece of equipment, indicating a high-level performance of the LiS densitometer.

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Magnifying lens

The Lab in a Suitcase kit includes a pocket microscope that can be attached to a mobile phone to capture images with the rear camera (Figure 4). This is equivalent to a powerful stereoscope or low magnification microscope, enabling the identification and classification of anatomical features as well as microscopic structures that would otherwise be impossible to accurately carry out with the naked eye during research field work (figure 5).

We tested and compared the magnification power and image quality of the pocket microscope with those of an Olympus benchtop stereo microscope. The pocket microscope together with the mobile phone rear camera provide comparable magnification power and image quality to those of the benchtop stereo microscope (figure 6).

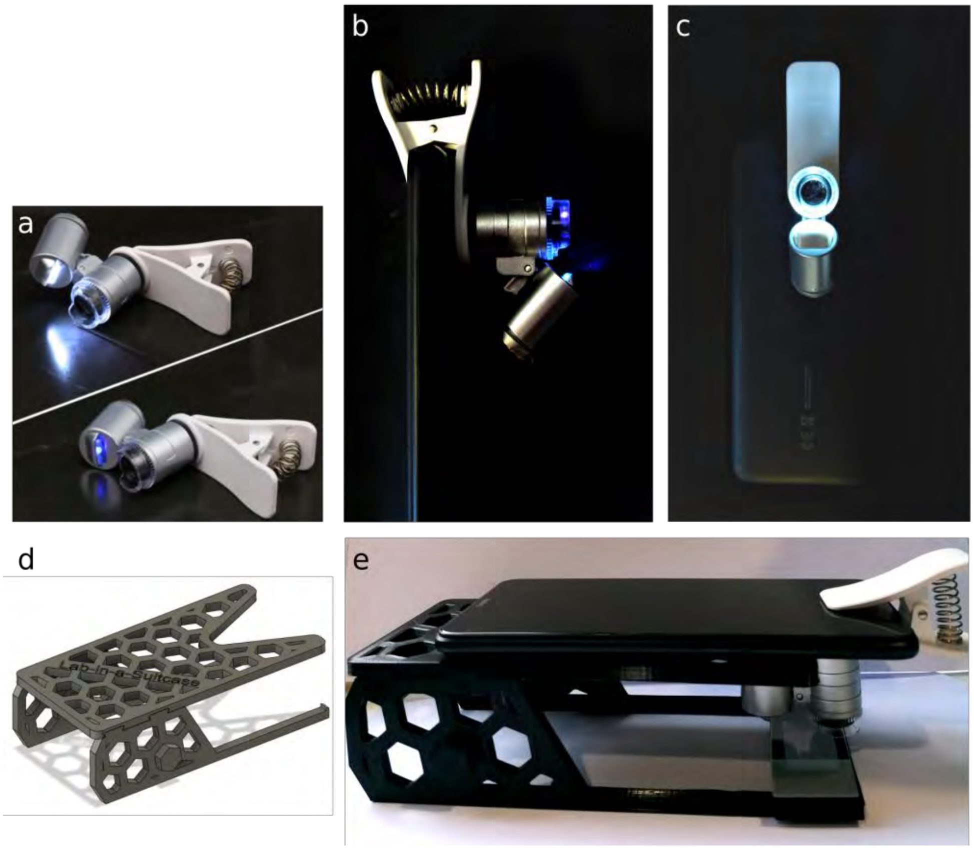

Figure 4. Portable lens with 60x magnification power and two light settings – white and blue light **(a)**. The lens can be attached to the mobile phone to capture images with the back camera **(b, c)**. A 3D-printed support has been created **(d)** in order to provide stability when capturing images of samples **(e)**.

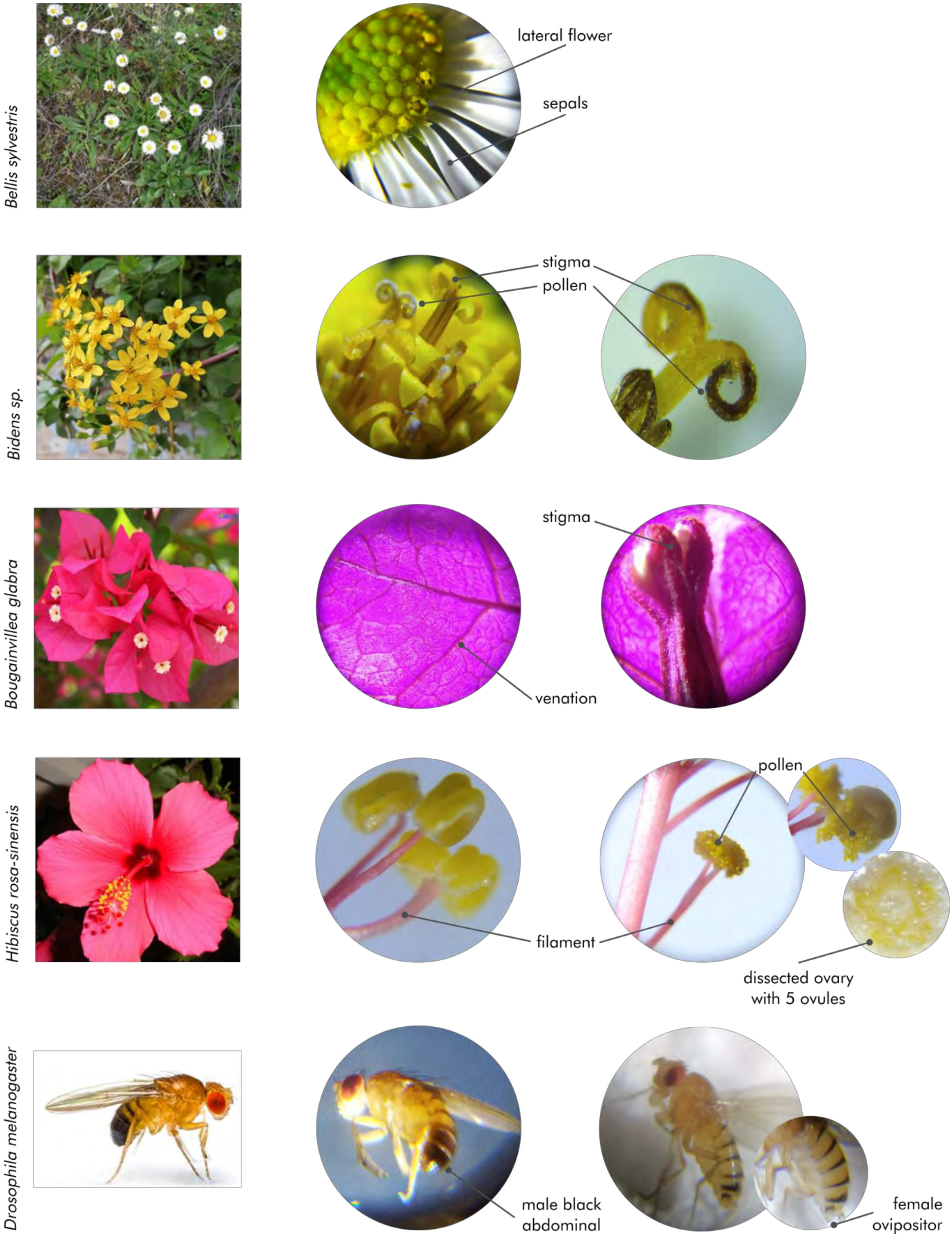

Figure 5. The portable lens attached to the back camera of the mobile phone enables the clear observation and identification of plants' and animals' macro- and microscopic anatomical features.

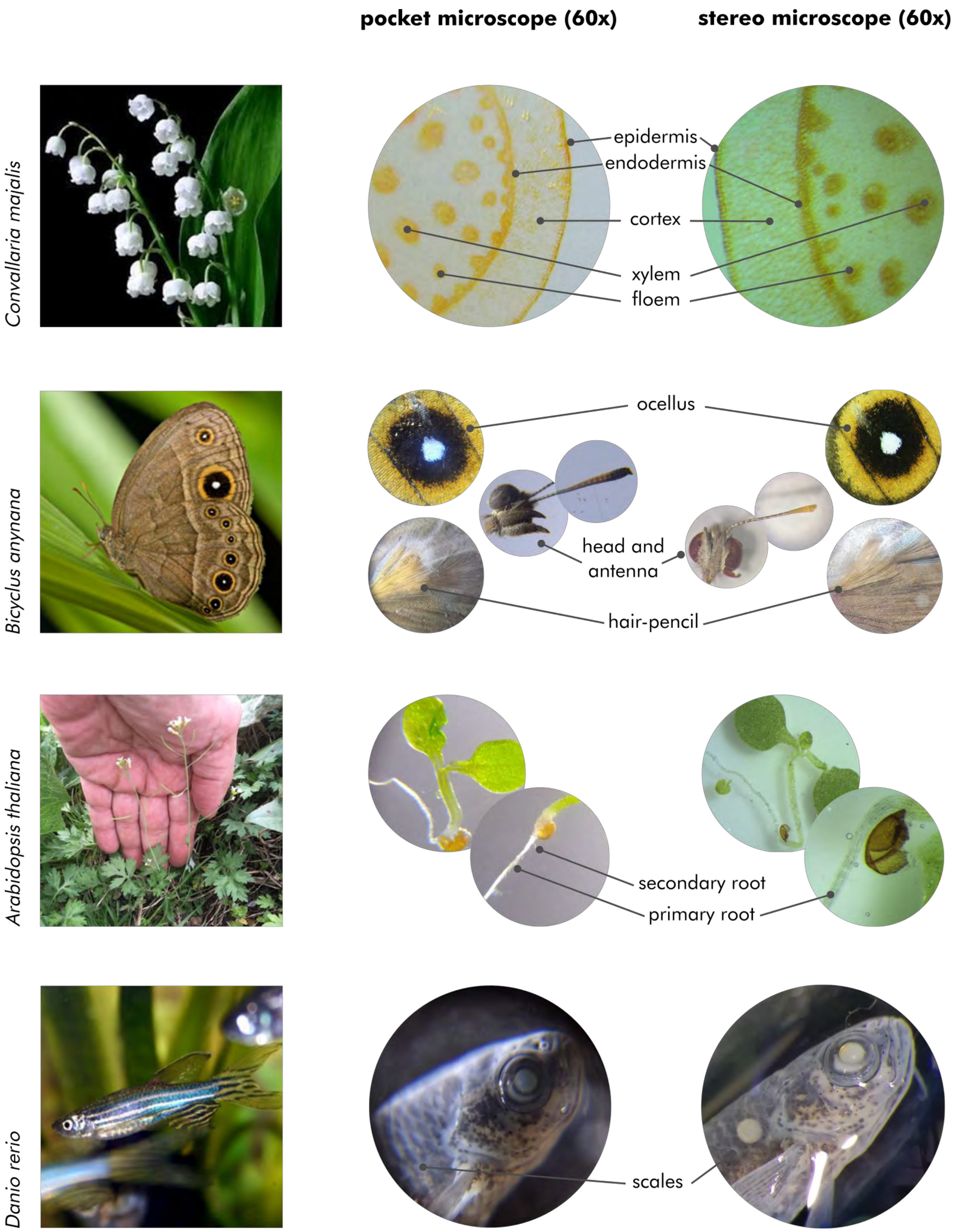

Figure 6. The pocket microscope enables the observation and identification of microscopic features with a quality level comparable to a benchtop stereo microscope. Examples include observation of rhizome's cellular structure, gender determination in small animals, observation of small anatomical features in model organisms.

Incubator

The incubator consists of a) a regular Styrofoam thermal box, b) a micro-fan and resistors for heating the air, c) a temperature and humidity sensor, d) an Arduino-based PID (proportional integral derivative) controller (figure 7). This system ensures the set temperature remains constant inside the box.

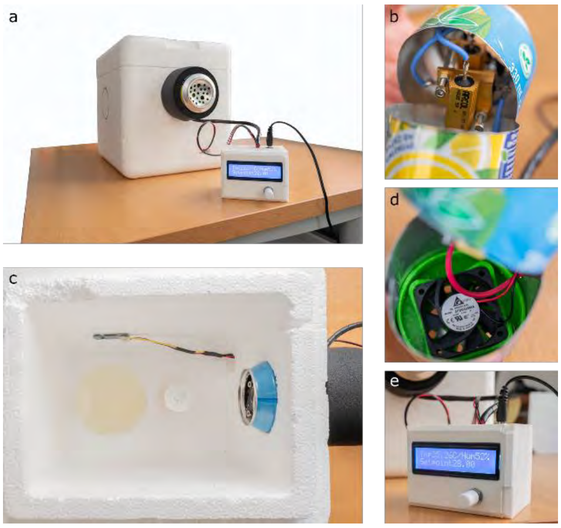

Figure 7. The incubator consists of a Styrofoam box **(a)** connected to a series od resistors **(b)**, a temperatura and humidity sensor **(c)**, and a micro-fan **(d)**. This circuit is controlled by an Arduino-based PID (proportional integral derivative) controller ensuring the set temperature remains constant inside the box.

The performance of the incubator was tested with 3 sensors placed inside it. It shows a quick heating profile, taking approximately 13 minutes to heat up, and a difference of approximately 1°C is observed between the 3 sensors (figure 8).

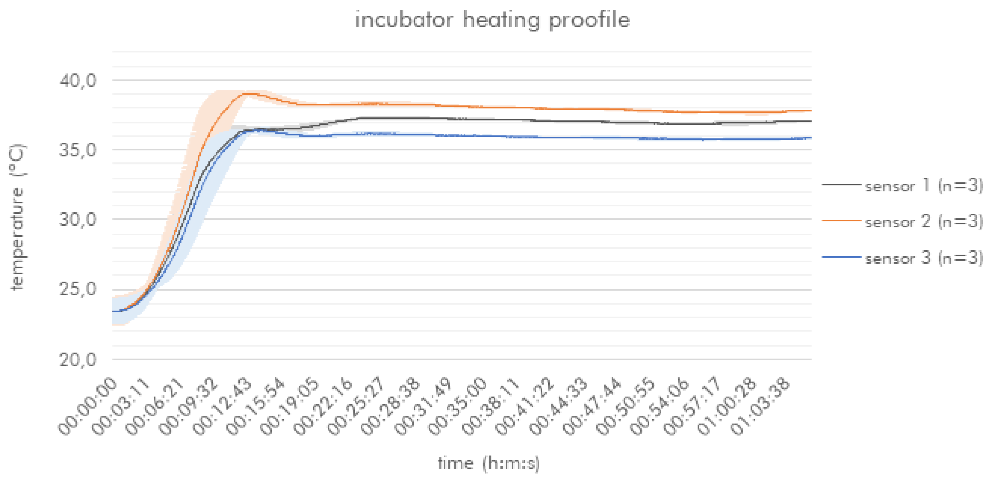

Figure 8. Heating profile of the incubator. The temperature reaches the set temperature (37°C, in this case) within approximately 13 minutes and remains constant at the 3 sensor points (mean +/- SEM; n=3/sensor).

When compared to a commercial incubator (in this case, we used a Labotect Inkubator C16), the performance of the LiS incubator is comparable regarding the temperature stability over time. The incubator can be used continuously for extended periods of time and the temperature remains stable (figure 9).

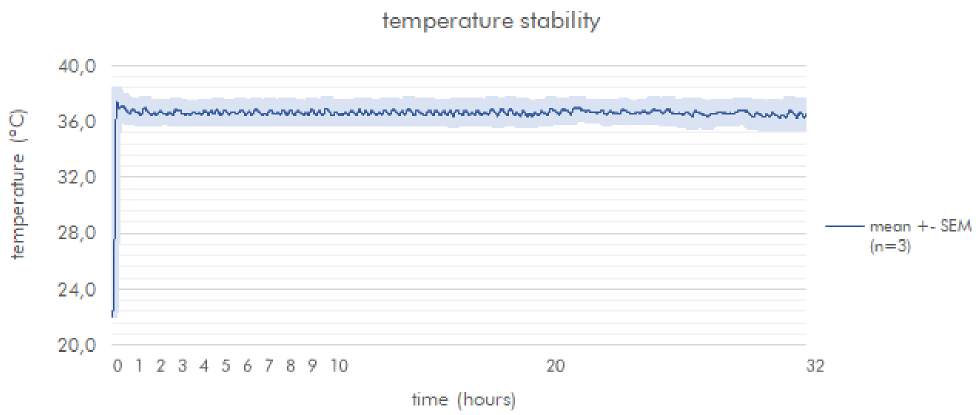

Figure 9. Temperature stability profile of the incubator. The temperature remains stable over extended periods of time (mean +/- SEM; n=3).

The reliability of the temperature controller and sensor feedback system has also been tested. At room temperature (21 + 2°C), the incubator reaches setpoints of 25°C, 30°C, 35°C with a standard deviation of 0.12°C, an average offset of 0.09°C, and a maximum temperature amplitude of 0.71°C. For a setpoint of 50°C, the temperature took longer to be reached, indicating this is the upper temperature limit of the incubator (figure 10). For higher incubation temperatures, the system can be adapted to include more resistors installed in series.

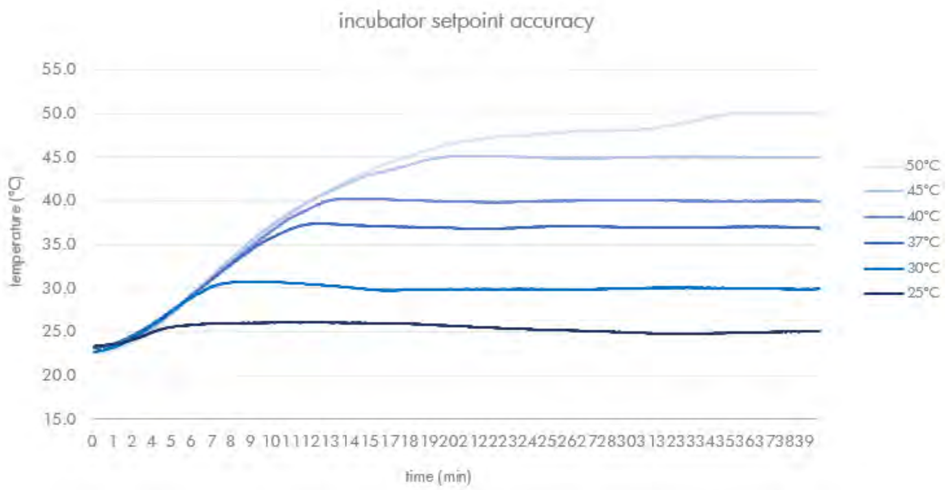

Figure 10. Incubator setpoint accuracy. The set temperature was reached in all cases, with an upper limit of 40°Cexcept for the setpoint of 40°C, indicating this is the upper temperature limit of the system.

To confirm the incubator provided the necessary conditions for cell cultures to grow in, we grew three different types of bacterial cells at 37°C - *Pseudomonas putida, Pseudomonas entomophila*, and *Escherichia coli* (figure 11). All three cell types grew within the expected time frame and the colony density also appeared as expected.

Figure 11. Cultures of three bacterial cell types - *Pseudomonas putida (P. putida), Pseudomonas entomophila* (*P.ento*), and *Escherichia coli* (*E. coli*) - grown in the LiS incubator, confirming cultures grow normally, as expected.

All the equipment tests showed they perform reliably and accurately, within the ranges they were built to operate in.

The components developed by the LiS team may be adapted by users according to the open license Attribution-NonCommercial-ShareAlike CC BY-NC-SA and to the exclusion of warranty and limitation of liability terms stated at the end of this document.

Exclusion of warranty and limitation of liability

The components of the Lab in a Suitcase were developed at the Instituto Gulbenkian de Ciência, with the exception of the Bento Lab, the magnifying lenses and pipettes.

The Lab in a Suitcase is intended to be used by professionals (such as researchers and teachers), both for their research activities (whether typically "bench" or "field" activities) as well as for teaching and communicating science to the public.

Unless stated otherwise, the IGC provides the Lab in a Suitcase as Licensed Material on an "as-is" and "as-available" basis, and provides no warranties with respect to the Licensed Material, whether express, implied, statutory or otherwise. This includes, but is not limited to, warranties as to rights, commercialisation, adaptation for a particular purpose, non-infringement, lack of latent or other defects, accuracy, or the existence or absence of errors, whether these were previously or not known or detectable.

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