A Nanobionic Light-Emitting Plant

Research topics and seminar 510

Presented by
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A Nanobionic Light-Emitting Plant

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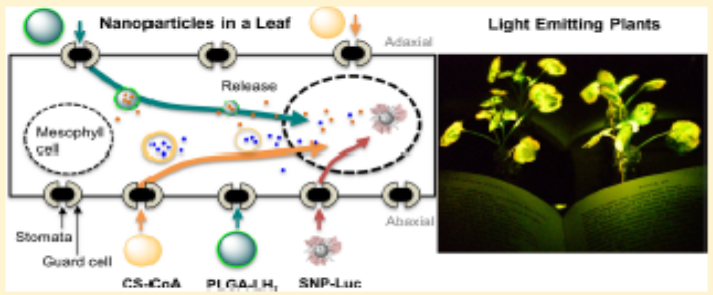
Supporting Information

ABSTRACT: The engineering of living plants for visible light emission and sustainable illumination is compelling because plants possess independent energy generation and storage mechanisms and autonomous self-repair. Herein, we demonstrate a plant nanobionic approach that enables exceptional luminosity and lifetime utilizing four chemically interacting nanoparticles, including firefly luciferase conjugated silica (SNP-Luc), D-luciferin releasing poly(lactic-*co*-glycolic acid) (PLGA-LH_2), coenzyme A functionalized chitosan (CS-CoA) and semiconductor nanocrystal phosphors for longer wavelength modulation. An in vitro kinetic model incorporating the release rates of the nanoparticles is developed to maximize the chemiluminescent lifetimes to exceed 21.5 h. In watercress (*Nasturtium officinale*) and other species, the nanoparticles circumvent limitations such as luciferin toxicity above 400 μM and colocalization of enzymatic reactions near high adenosine triphosphate (ATP) production. Pressurized bath infusion of nanoparticles (PBIN) is introduced to deliver a mixture of nanoparticles to the entire living plant, well described using a nanofluidic mathematical model. We rationally design nanoparticle size and charge to control localization within distinct tissues compartments with 10 nm nanoparticles localizing within the leaf mesophyll and stomata guard cells, and those larger than 100 nm segregated in the leaf mesophyll. The results are mature watercress plants that emit greater than 1.44×10^{12} photons/sec or 50% of 1 μW commercial luminescent diodes and modulate "off" and "on" states by chemical addition of dehydroluciferin and coenzyme A, respectively. We show that CdSe nanocrystals can shift the chemiluminescent emission to 760 nm enabling near-infrared (nIR) signaling. These results advance the viability of nanobionic plants as self-powered photonics, direct and indirect light sources.



KEYWORDS: *Plant nanobionics, nanoparticles, pressurized bath infusion of nanoparticles (PBIN), light-emitting plant, chemiluminescence*

Light-Emitting Plants

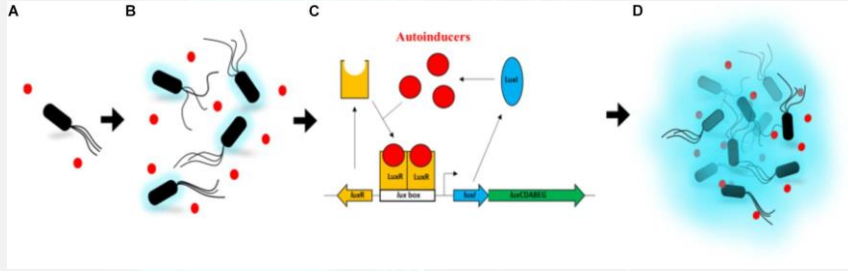
- Previously the focus on genetic manipulation either by

-Firefly luciferase gene

or

-Bacterial *lux* operon.

https://discover.hubpages.com/education/Lightning-Bugs-Fireflies-and-Fire-Bees



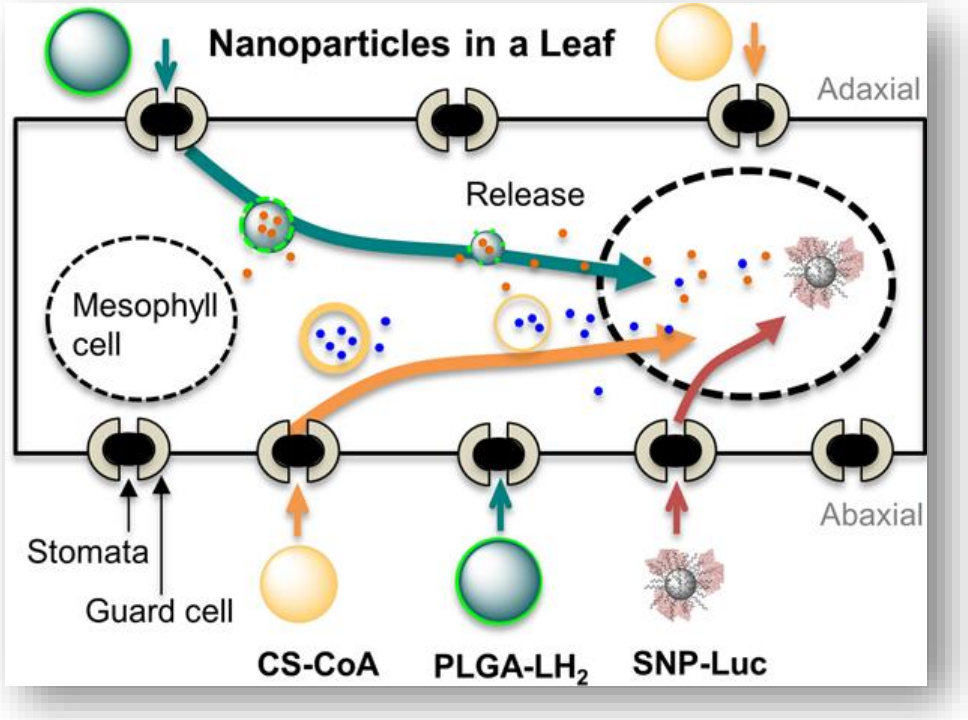
https://blog.hardydiagnostics.com/2017/09/how-bio-luminescence-will-light-our-way-to-a-brighter-future/
https://www.frontiersin.org/articles/10.3389/fmicb.2019.00365/full

Light-Emitting Plants

- Limitation of genetically engineered plants:
  - Colocalization.
  - Addition of luciferase
  - Toxicity
  - Short time of chemiluminescence

Nanobionic approach

- Using a combination of :
  - Different nanoparticles.
  - Different molecules.
  - Different concentrations.
  - Different localization.



Aim

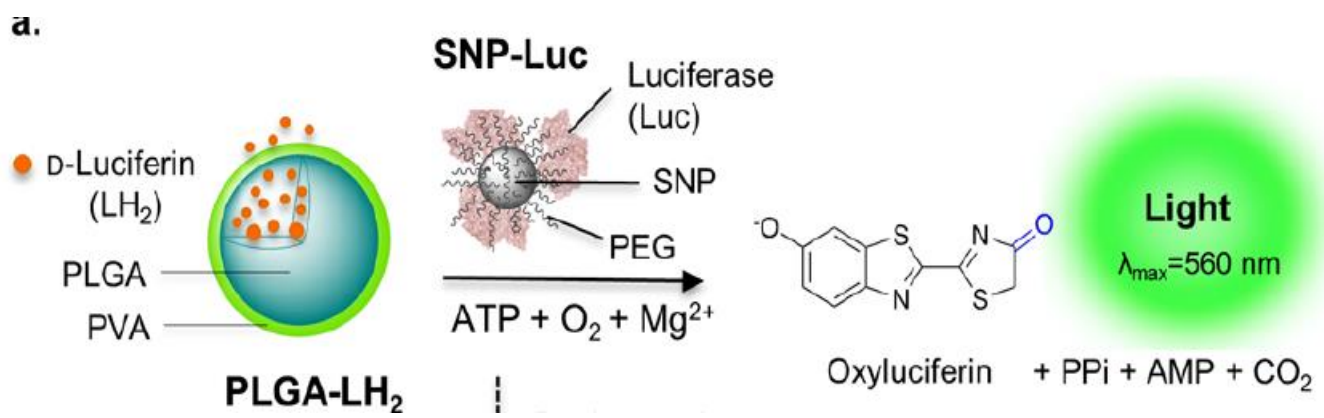
- Generating Light-Emitting plant with:
  - Localized tissue.
  - Less toxicity to the plant.
  - Long time chemiluminescence production.
  - High intensity of the light.
  - Using nanobionic approach

Design the experiment

$$LH_2 + ATP + O_2 \xrightarrow[Mg^{2+}]{\text{Luciferase}} \text{Oxyluciferin} + AMP + PPi + CO_2 + h\nu\ (\text{Light})$$

Design the experiment

- Silica Nanoparticles-Luciferase (SNP-Luc)
- Poly(lactic-co-glycolic acid) (PLGA)

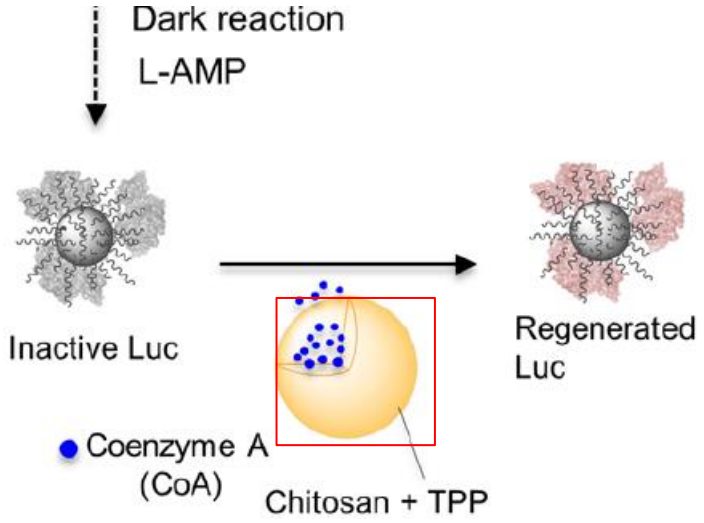


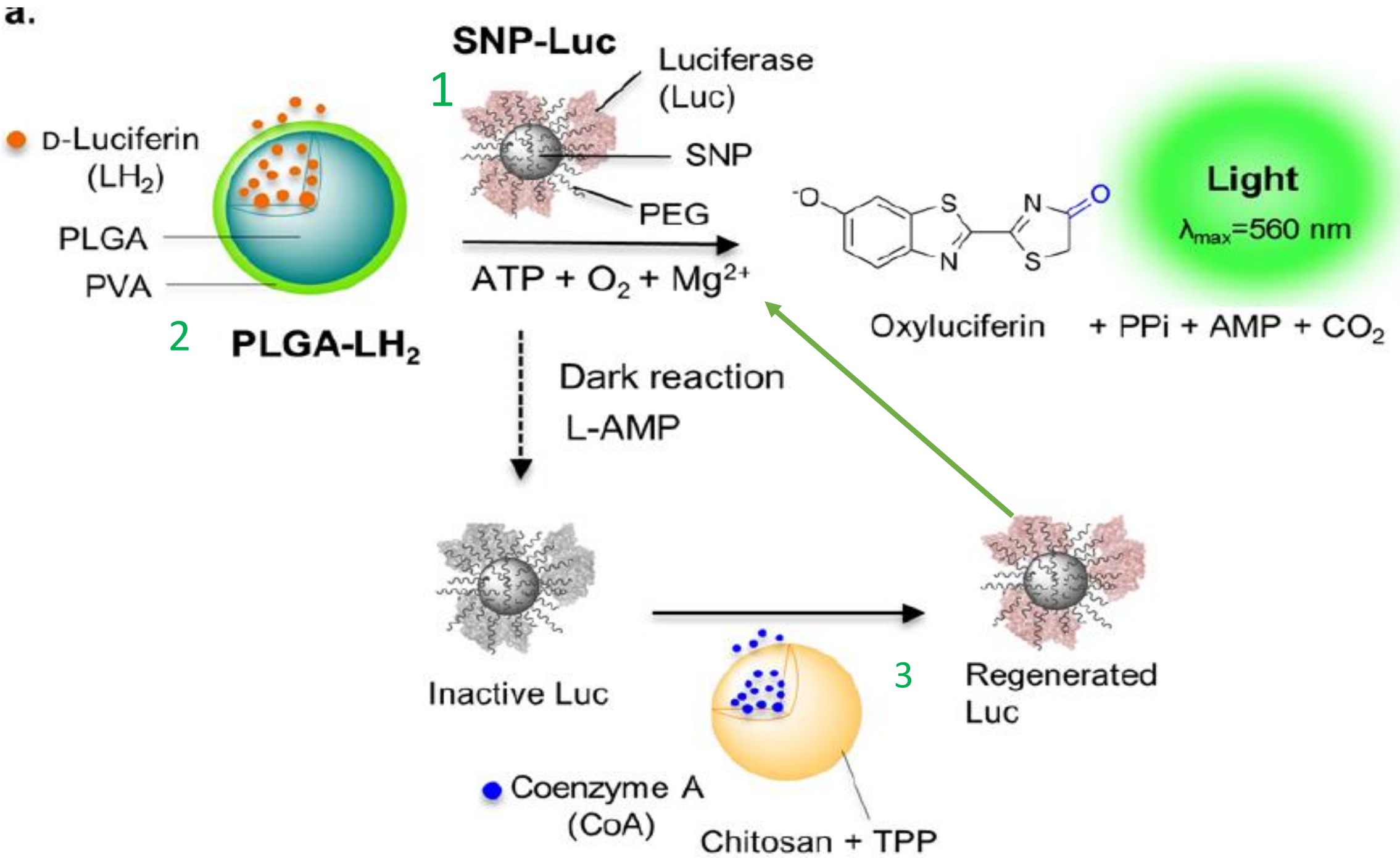
Design the experiment

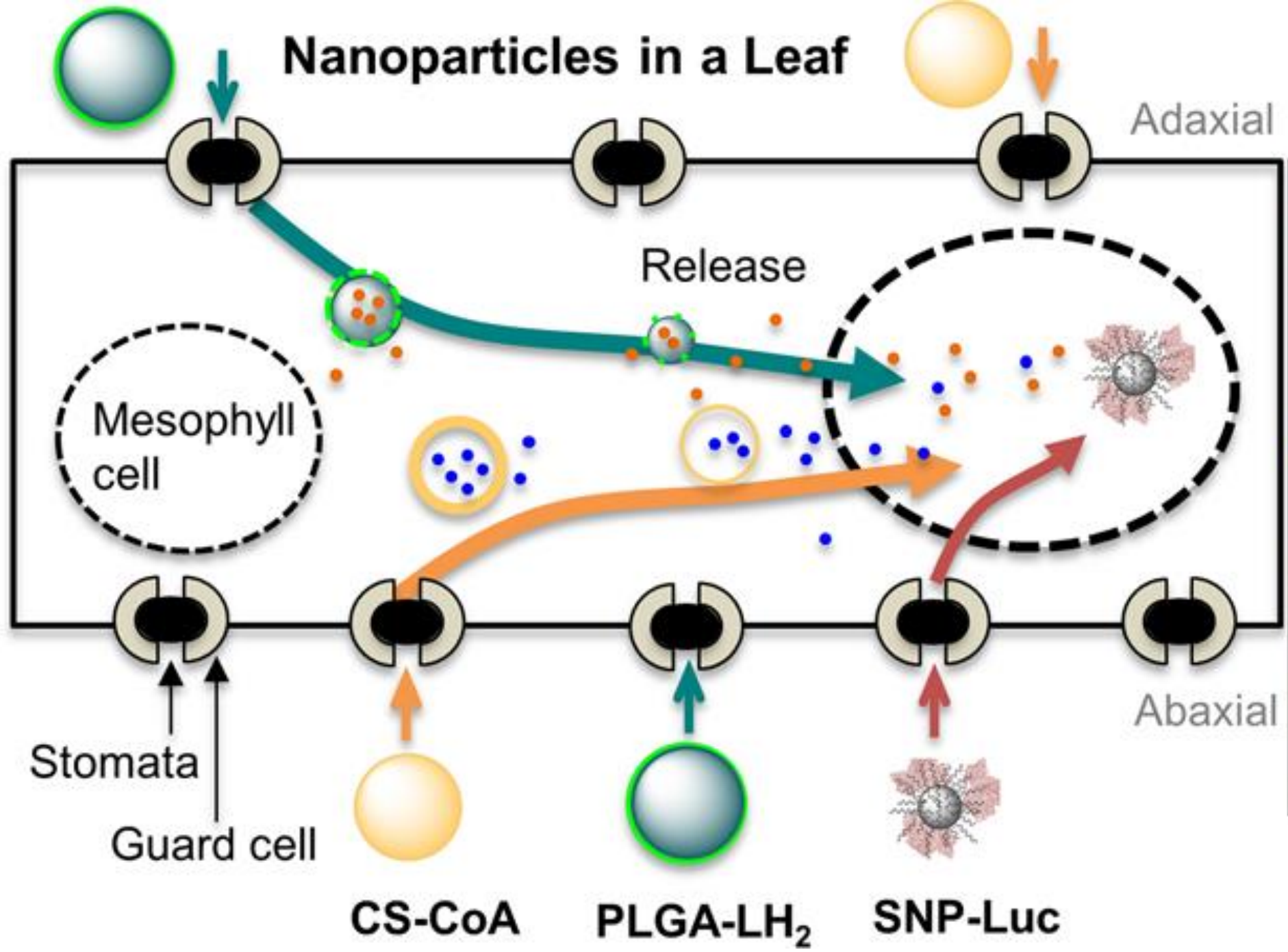
$$\text{Luciferase-L-AMP} \xrightarrow{\text{CoA}} \text{Luciferase} + \text{L-CoA} + \text{AMP}$$

- Luciferase-L-AMP (L-AMP) produced as by product as inactive form of Luciferase.

- Coenzyme A (CoA) needed to activate the Luciferase.
- Chitosan nanoparticles (CS-CoA)




a.
SNP-Luc
1
Luciferase
(Luc)
SNP
PEG
D-Luciferin
(LH2)
PLGA
PVA
2
PLGA-LH2
ATP + O2 + Mg2+
Oxyluciferin
+ PPi + AMP + CO2
Light
λmax=560 nm
Dark reaction
L-AMP
Inactive Luc
3
Regenerated
Luc
Coenzyme A
(CoA)
Chitosan + TPP


Nanoparticles in a Leaf
Adaxial
Release
Mesophyll cell
Stomata
Guard cell
Abaxial
CS-CoA
PLGA-LH2
SNP-Luc

Methodology

- Using four different plants in the experiment:
  - Spinach (*Spinacia oleracea*)
  - Arugula (*Eruca sativa*)
  - Watercress (*Nasturtium officinale*)
  - kale (*Brassica oleracea)*

Methodology

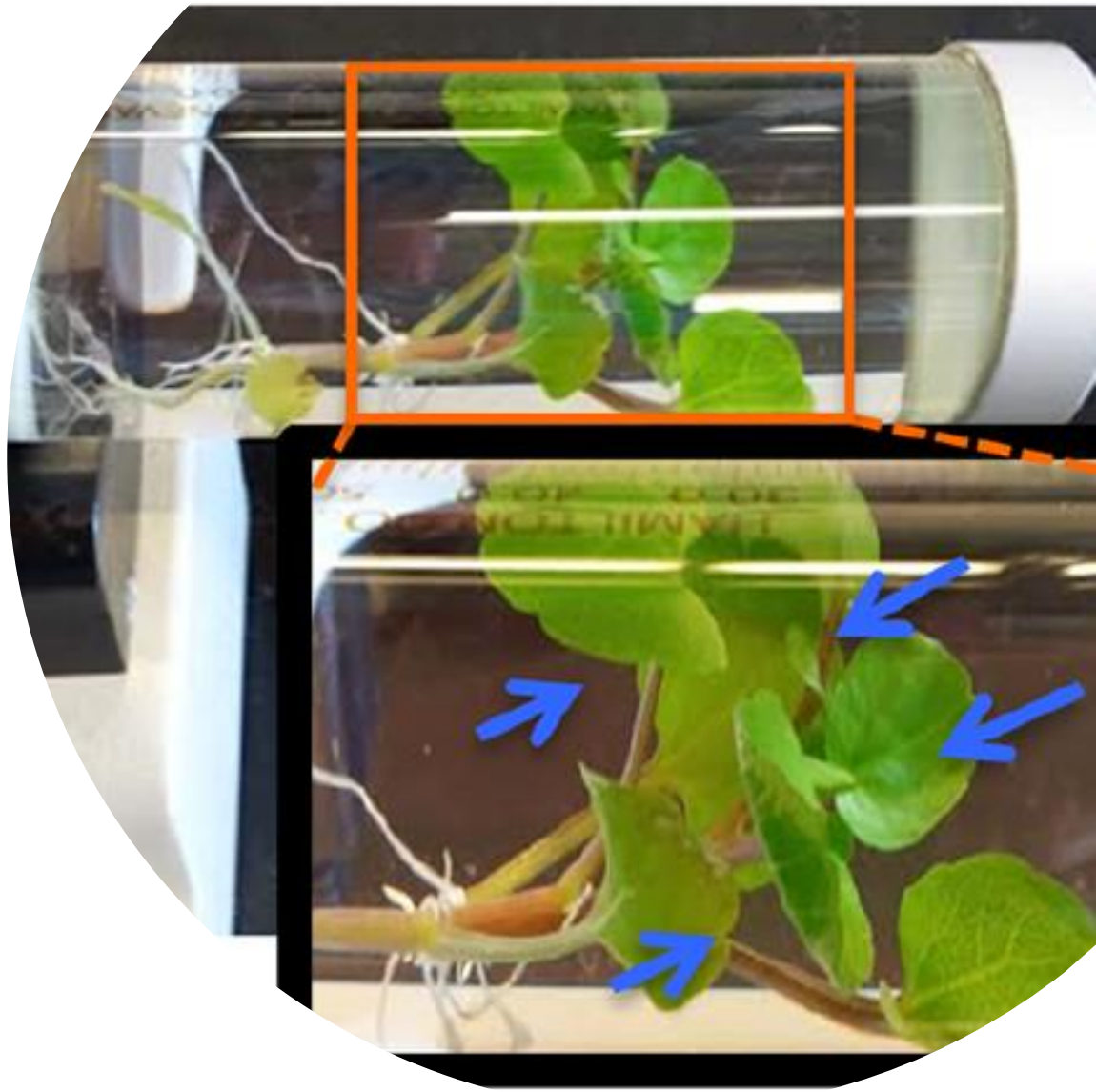
- In vitro testing

SNP-Luc, PLGA-LH_2	200 nM SNP-Luc, 625 μM CS-CoA
SNP-Luc, PLGA-LH_2, CS-CoA	200 nM SNP-Luc
SNP-Luc	4 μM SNP-Luc
SNP-Luc, CoA	4 μM SNP-Luc, 625 μM CS-CoA
Free luciferase	4 μM SNP-Luc, 1.25 mM CS-CoA
Free luciferase, CoA	

Methodology

- To insert the nanoparticle mixture into the whole plant pressurized bath infusion of nanoparticles (PBIN) were used.

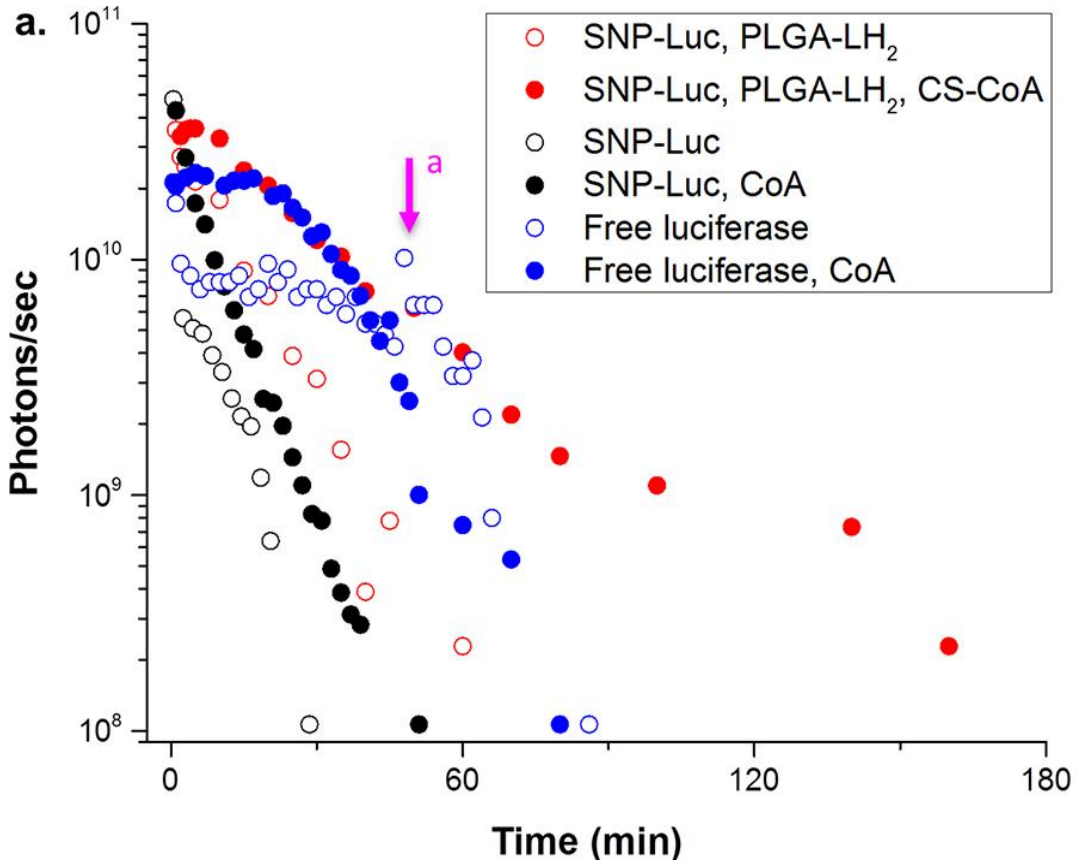
- Using stomatal pores within the leaves.

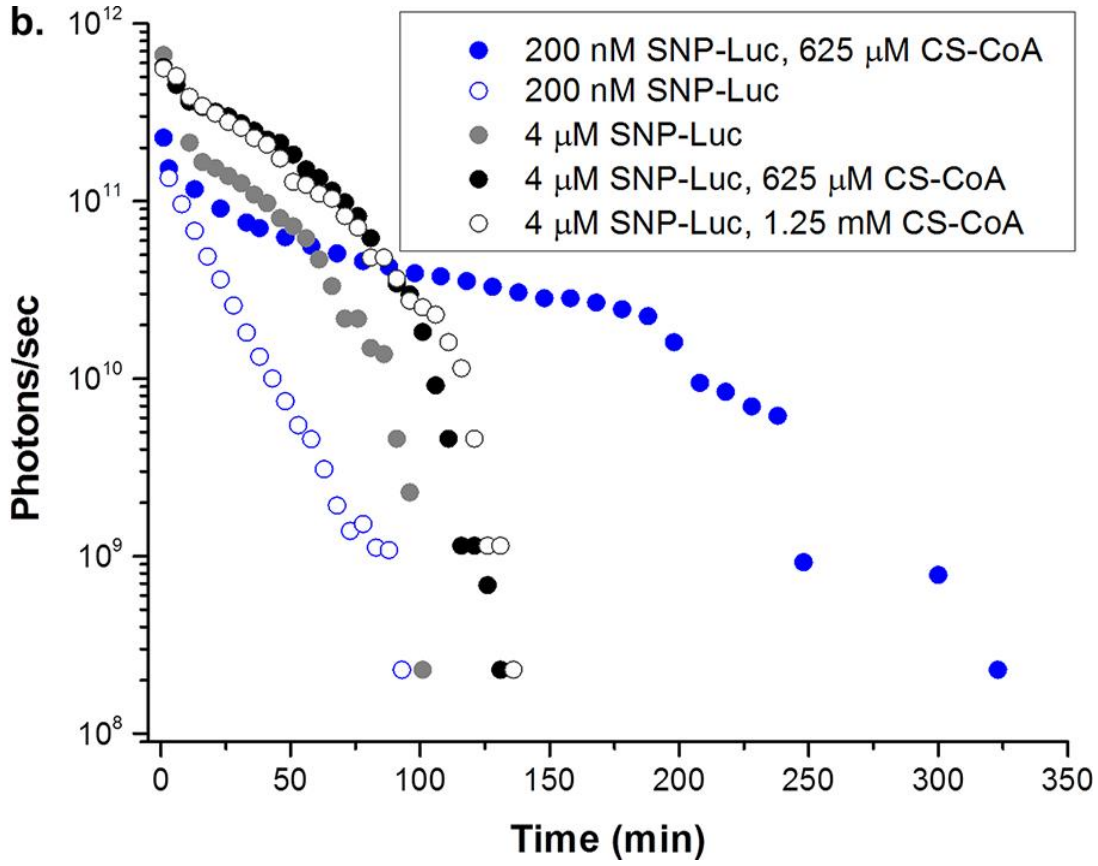


Methodology

- The plant put in PBIN the chamber filled with water and nanoparticle solution.
- Pressure applied with different power in different chambers
- 0.4 bar/s was applied.
- 0.04 bar/s was applied.
- 0.02 bar/s was applied.

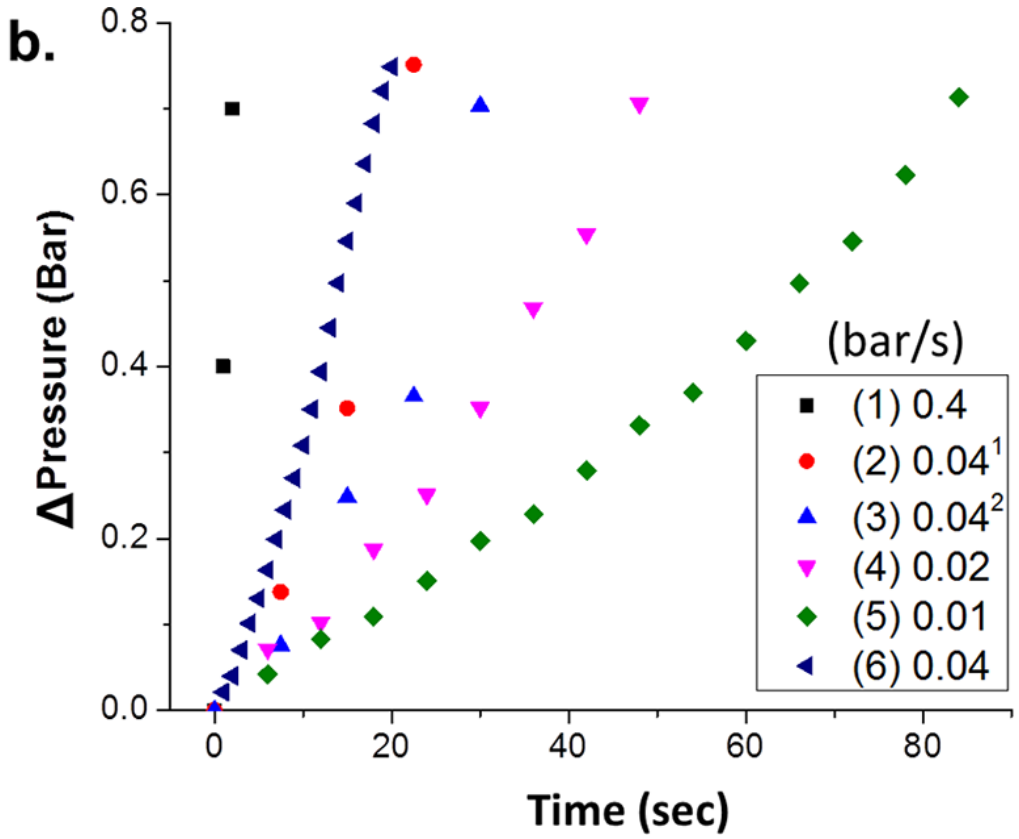
Results


a.
Photons/sec
Time (min)
SNP-Luc, PLGA-LH2
SNP-Luc, PLGA-LH2, CS-CoA
SNP-Luc
SNP-Luc, CoA
Free luciferase
Free luciferase, CoA
a

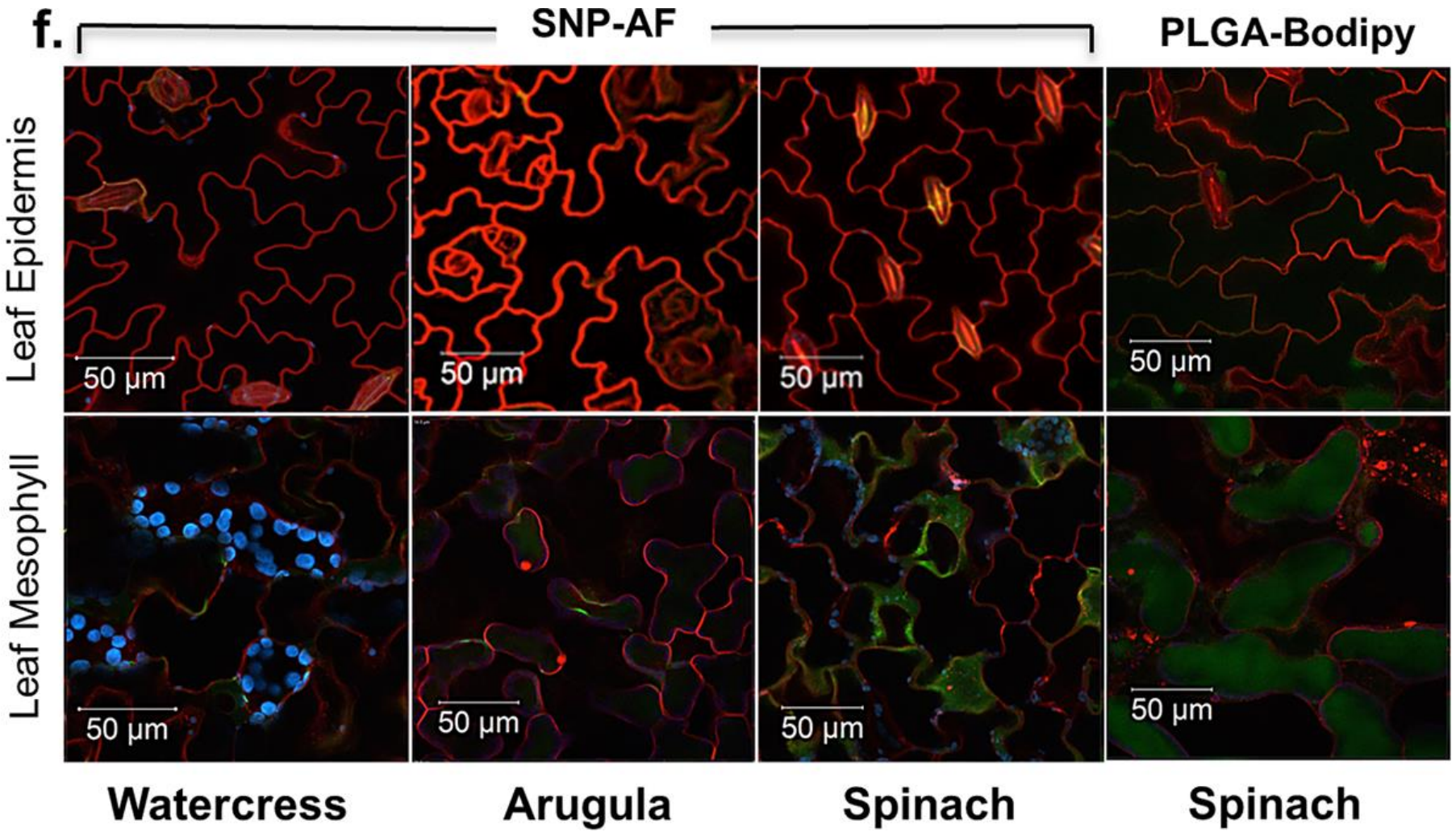

b.
Photons/sec
Time (min)
200 nM SNP-Luc, 625 μM CS-CoA
200 nM SNP-Luc
4 μM SNP-Luc
4 μM SNP-Luc, 625 μM CS-CoA
4 μM SNP-Luc, 1.25 mM CS-CoA

Results

- With 0.4 bar/s the infiltration and integration done but:
  - Damage to the mesophyll
  - cell membranes ruptured
- While other ratios show no ruptures to any organelles but slow rate of infiltration

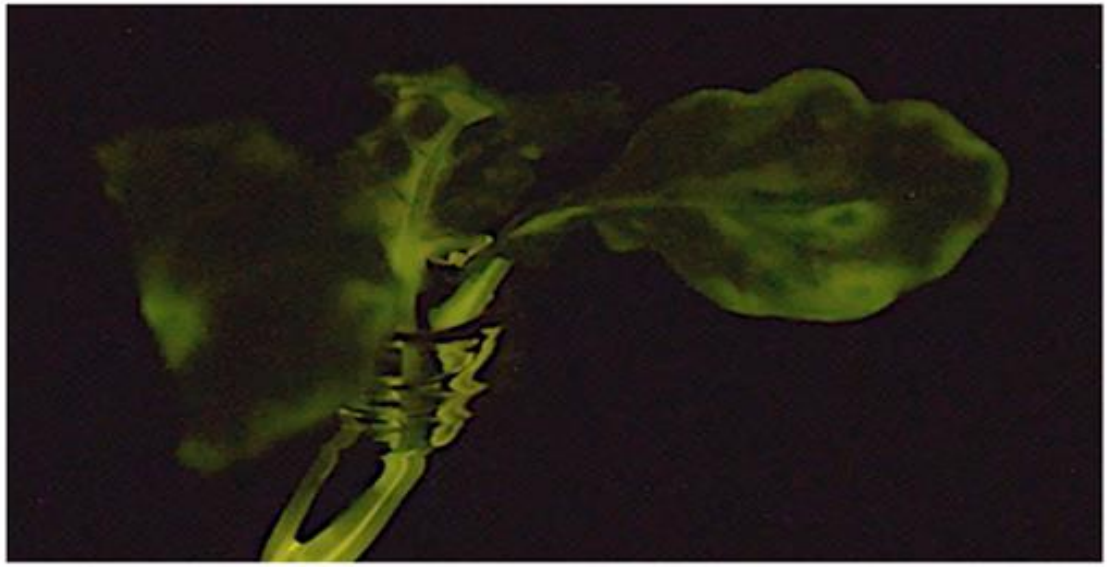


Results

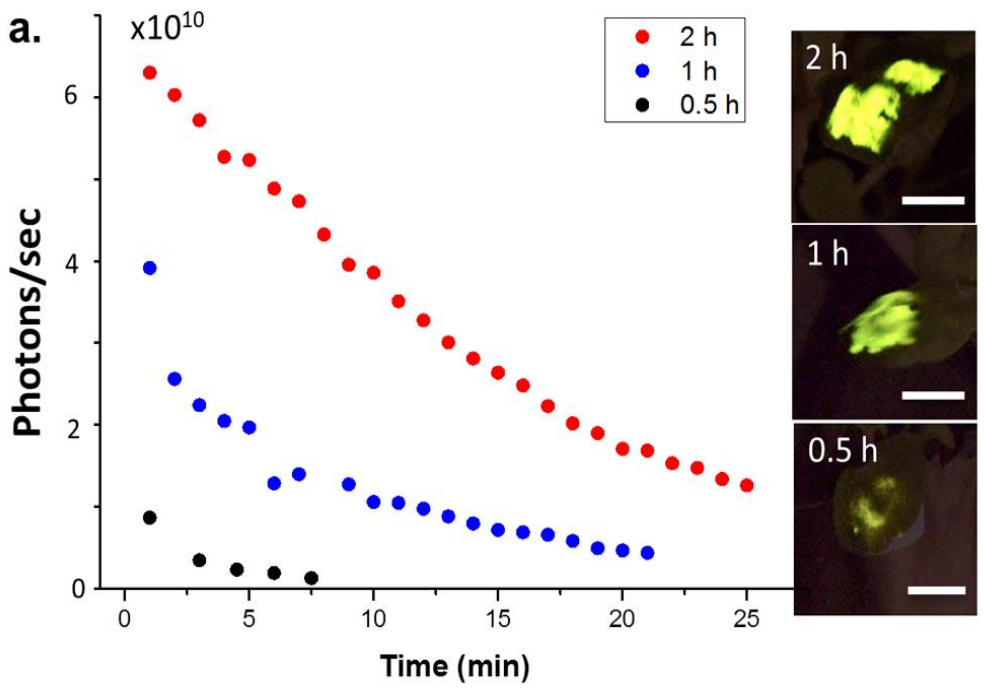

f.
SNP-AF
PLGA-Bodipy
Leaf Epidermis
Leaf Mesophyll
50 µm
Watercress
Arugula
Spinach
Spinach

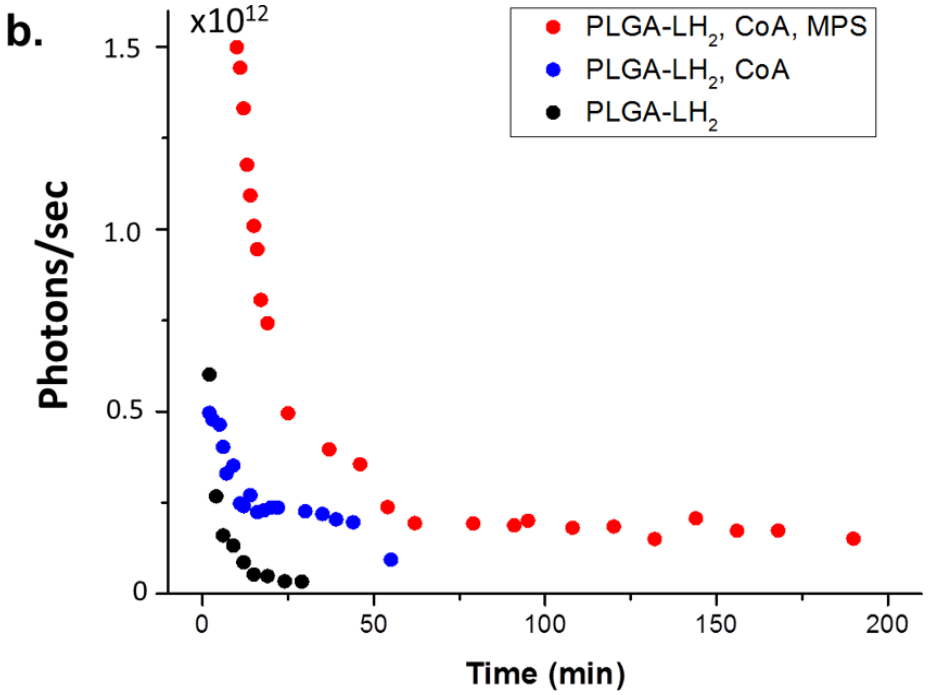
Results

Optical image of 3-week-old kale plant

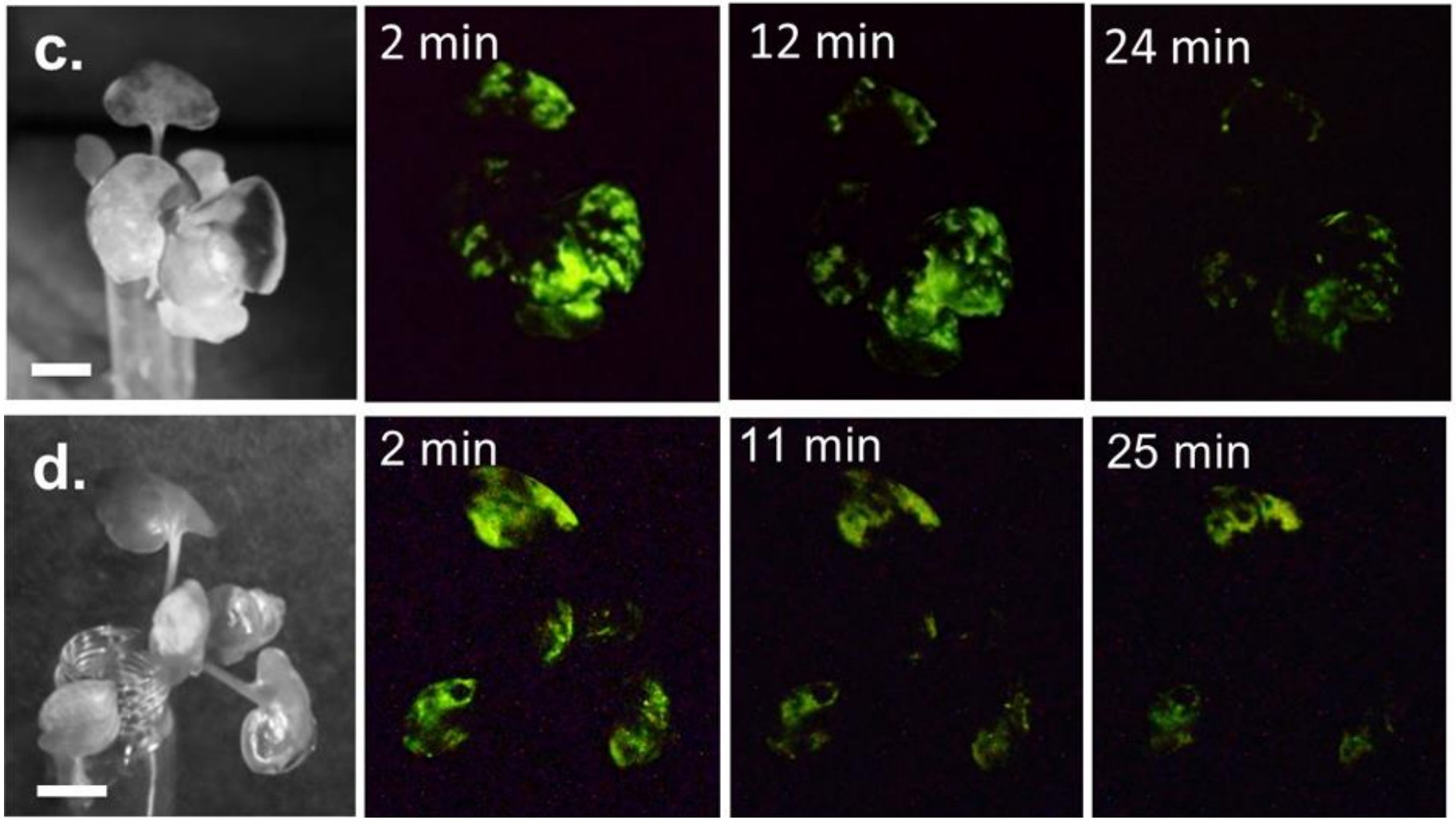


Results

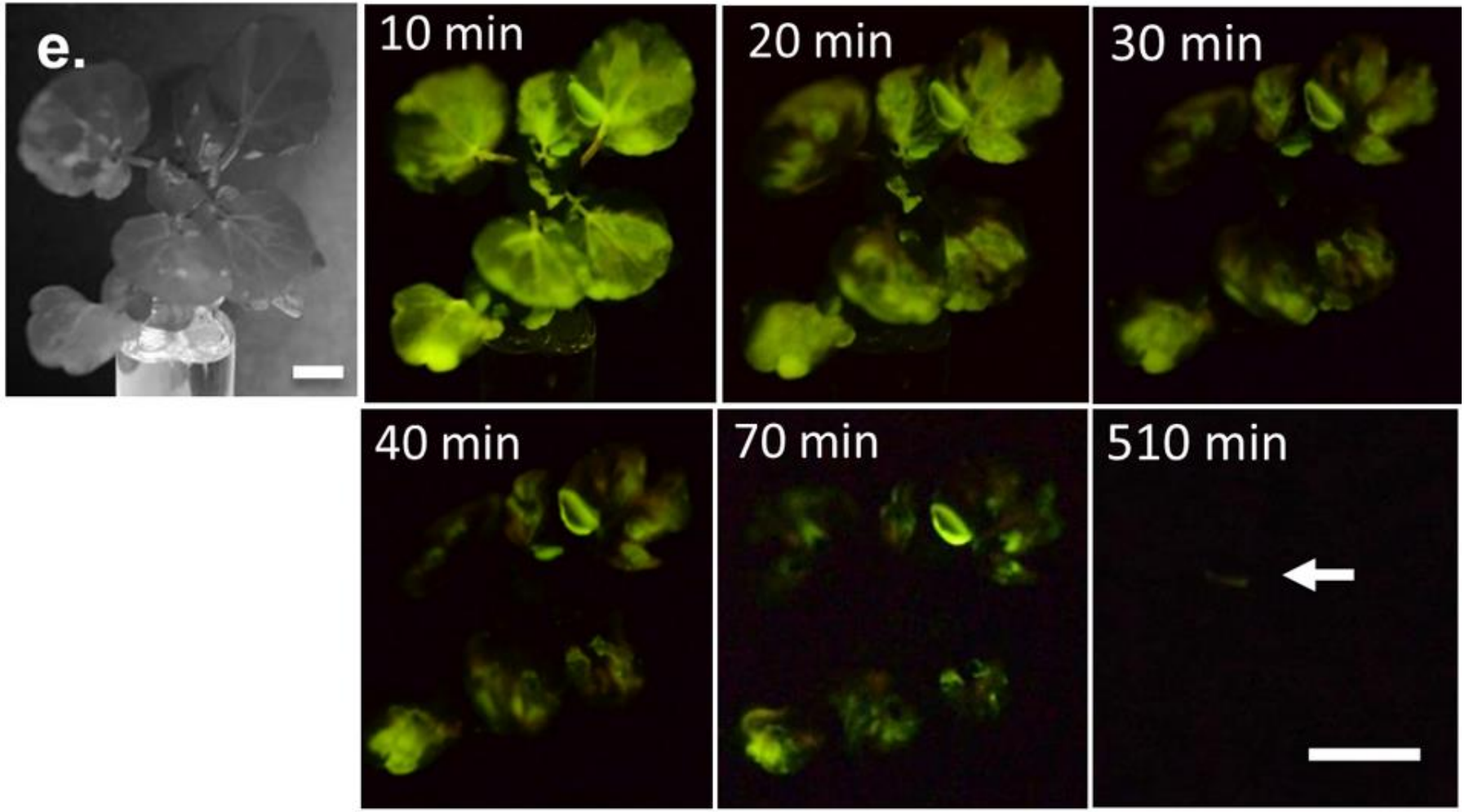

a.
x10^10
Photons/sec
Time (min)
2 h
1 h
0.5 h
2 h
1 h
0.5 h


b.
x10^12
Photons/sec
Time (min)
PLGA-LH2, CoA, MPS
PLGA-LH2, CoA
PLGA-LH2

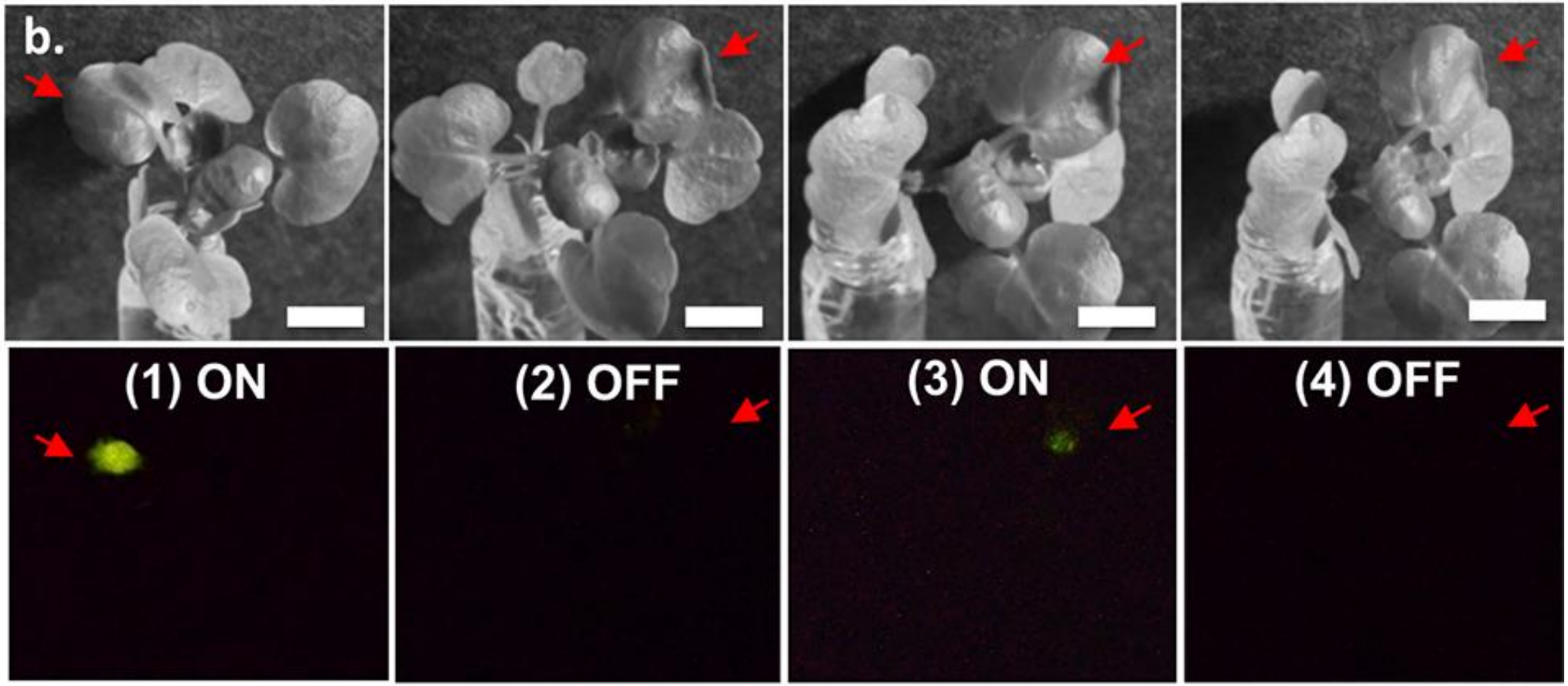
Results



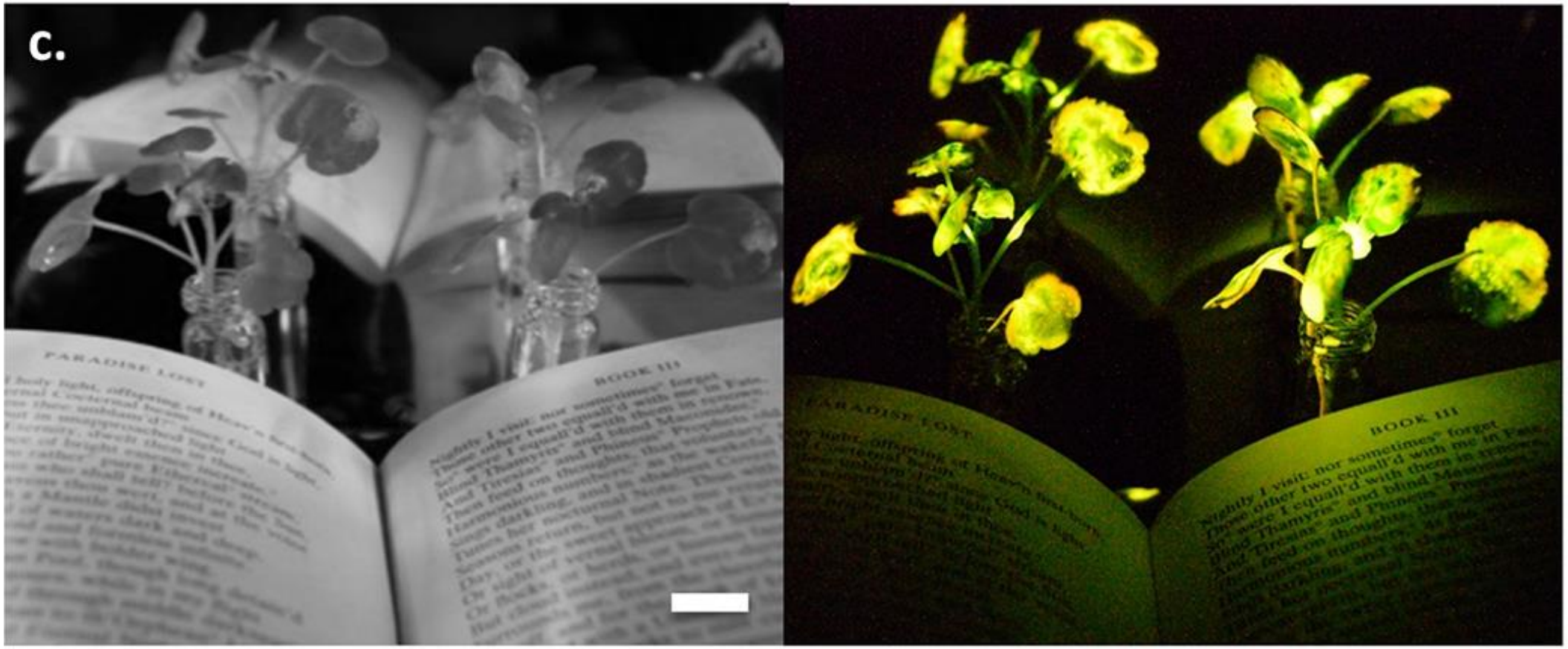
Results



Results



Results


C.
PARADISE LOST
BOOK III
Nightly I visit nor sometimes forget
Those other two equall'd with me in Fate,
So were I equall'd with them in renown,
Blind Thamyris and blind Maeonides,
And Tiresias and Phineus Prophets old,
Then feed on thoughts, that voluntary
Harmonious numbers as the wakeful
Sings darkling, and in shadiest Covert
Hums her nocturnal Note. Thus with
Day, or the sweet approach of Ev'n or morn,
Or sight of vernal bloom, or summer's Rose,
Or flocks, or herds, or human face divine;
But cheer'd within, and without, the wakeful

Discussion

- The best combination of the nanoparticles to be localized and active is SNP-Luc, PLGA-LH and CS-CoA.

- The most effective concentration for nanoparticles is 200nM SNP-Luc,625µMCS-CoA, with incubation for 2 hours.

Discussion

- The plants can be controlled on/off mechanism.

- The produced plants can emit light for four hours.

Benefits and possible uses in daily life


Thank you