# Water storage capacity of compliant plant leaves

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## Introduction

### Goal of the study?

- Establish a relationship that links leaf storage capacity to leaf compliance
- Verify it through experiments


### Which leaves?

→ Compliant petiole and rigid planar blade

### What is the storage capacity?

$\mu$ = Maximum volume of water per surface area ~ Mean height of water on the leaf

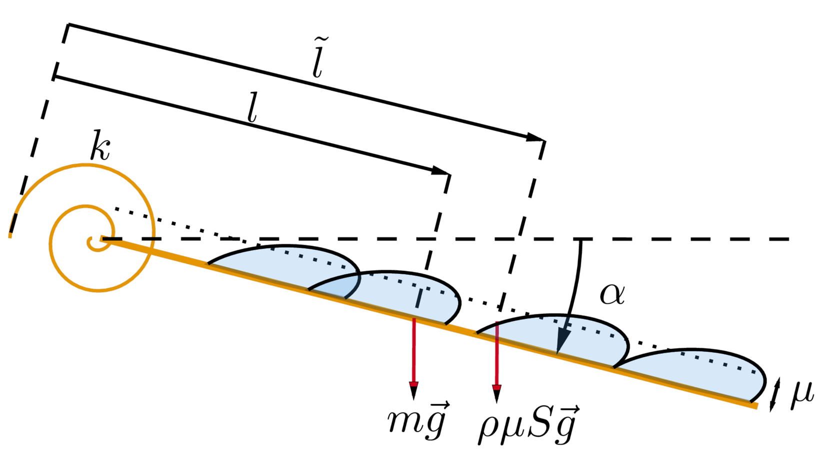
## Model

### Parameters involved

- $\mu$ = storage capacity
- $k$ = leaf torsional stiffness
- $m$ = leaf mass
- $l$ = leaf lever arm
- $S$ = leaf surface
- $\tilde{l}$ = drops lever arm
- $g$ = gravity acceleration
- $\rho$ = water density
- $\sigma$ = surface tension
- $V$ = drop volume

### 2D linear torsion spring model

Petiole clamped horizontally




$$\boxed{\frac{\rho\mu_\star S}{m} = \frac{\alpha_\star}{\cos(\alpha_\star)}\frac{k}{mlg} - 1}$$

**Eq. 1** : Torque balance at roll off for a uniform leaf loading ($\tilde{l} = l$).

### Key parameters

$$\frac{k}{mlg}, \frac{\rho\mu_\star S}{m}, \alpha_\star$$

- $\frac{k}{mlg}$: Ratio between petiole torsional stiffness and blade torque
- $\frac{\rho\mu_\star S}{m}$: Dimensionless fluid mass
- $\alpha_\star$: Roll-off inclination angle, the angle at which the drops slip

## Experimental approach

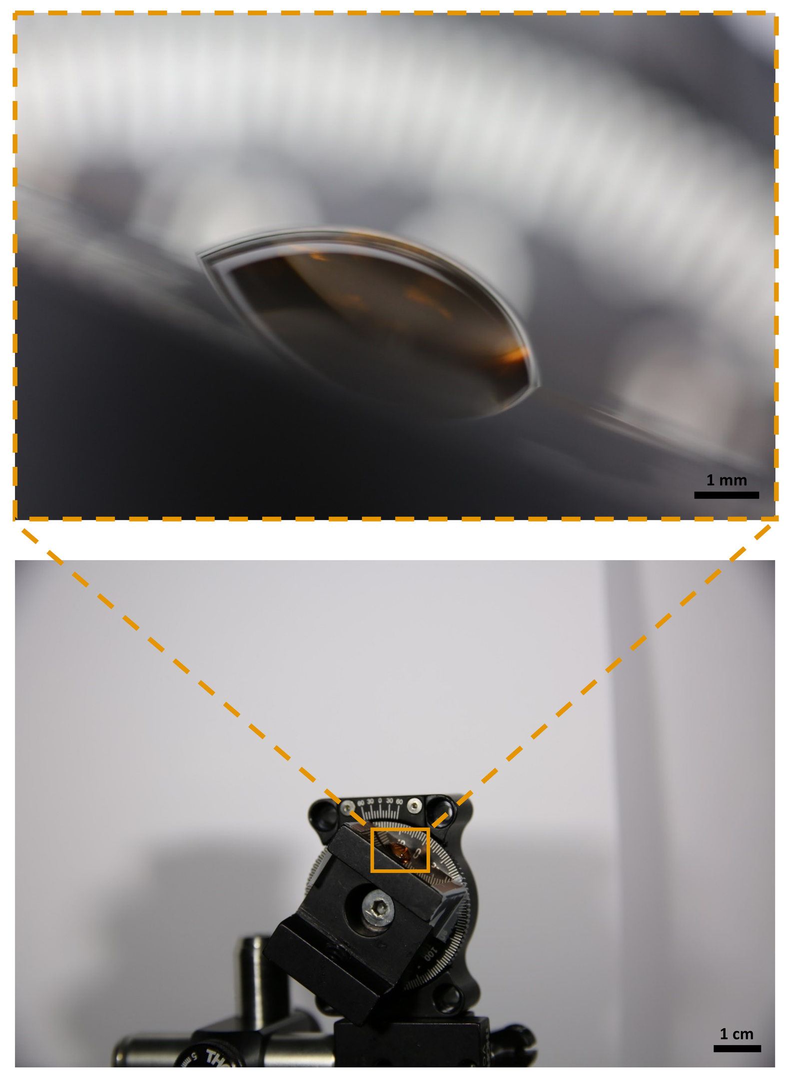



**Fig. 1** : Experimental setup for the roll-off angle measurement.

### Roll-off angle measurement

- Droplet placed on a rotative support (cf. **Fig. 1**)

→ Roll-off angle measured

→ Experiment repeated for different droplet volumes

### Model verification

- Droplets are loaded quasi-statically on an artificial leaf made of Kapton (cf. **Fig. 2**)

→ Experiment stops when the first droplet slips

→ Storage capacity deduced from mass measurement

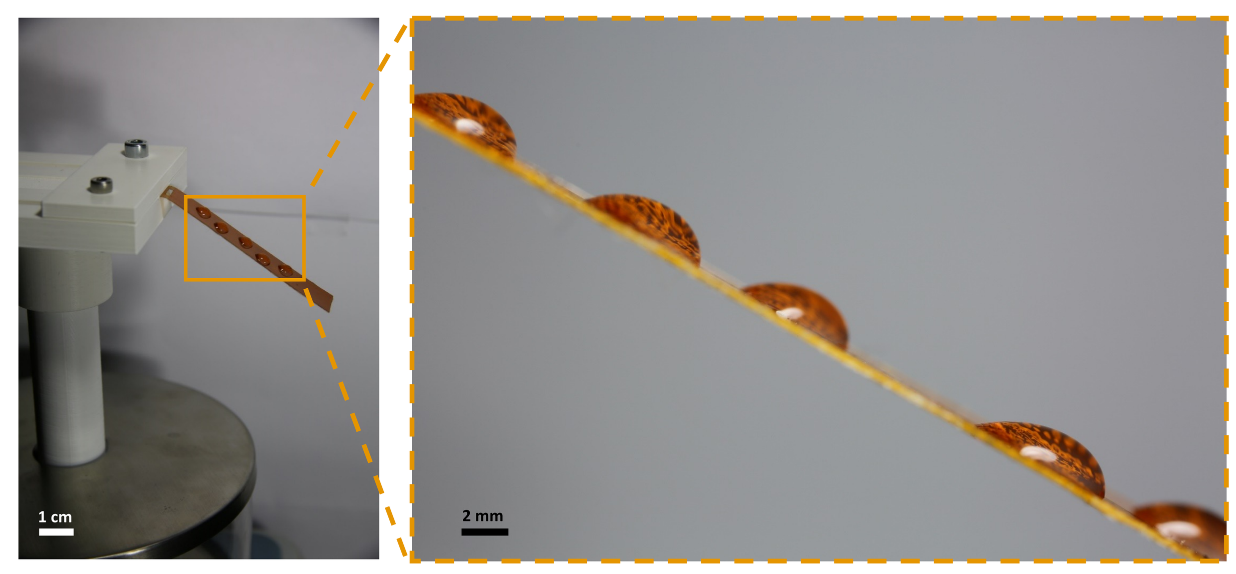



**Fig. 2** : Experimental setup for the validation of the theoretical model.

## Results

### Model validation

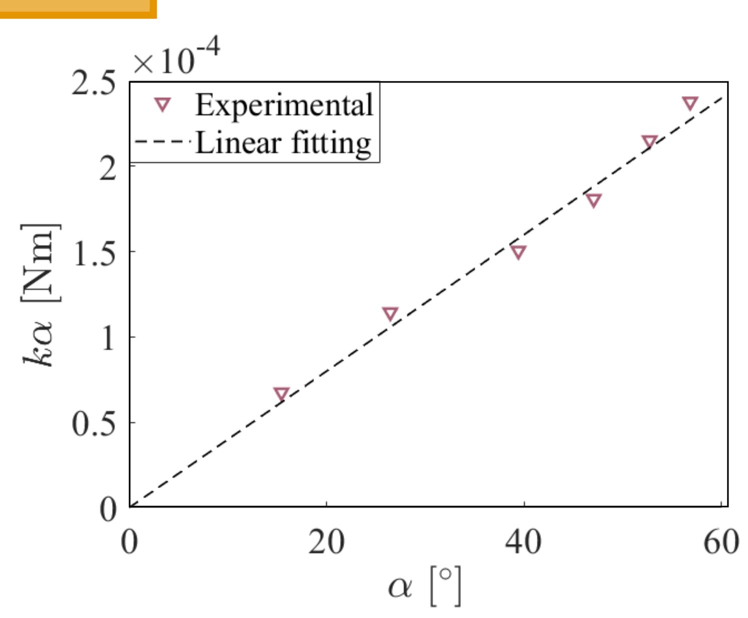



**Fig. 3** : Validation of linear torsion spring model.

Petiole torque deduced from $m \cdot l \cdot g \cdot \cos(\alpha)$ measurement

→ Artificial leaves behave like linear torsion spring

### Roll-off angle measurement

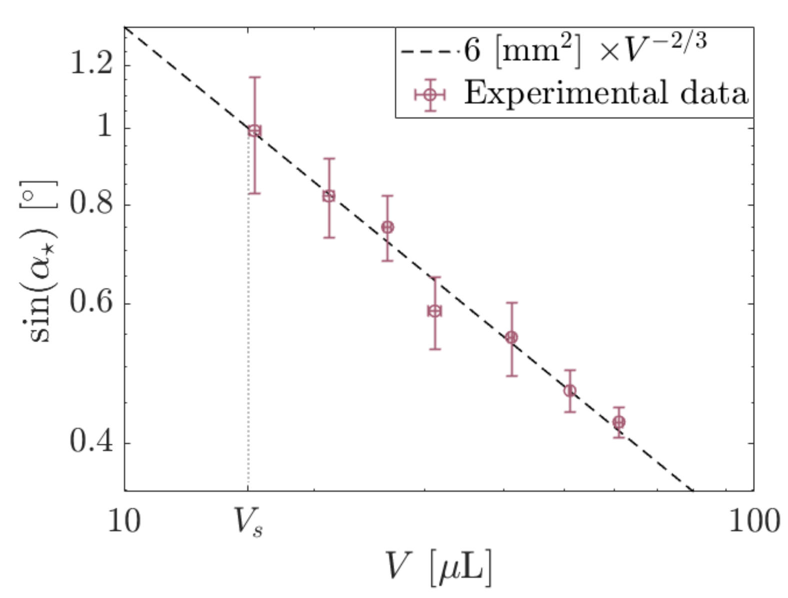



**Fig. 4** : $\sin(\alpha_\star)$ vs. volume of a water droplet on kapton.

- $\sin(\alpha_\star) = A^2 \cdot V^{-2/3}$, $A \approx \sqrt{6}$ [mm]
  → Valid for $V > V_s \approx 15$ [$\mu$L]
- $\Delta\alpha_\star \gg \Delta V$
  → Droplet geometry has an influence
- $\alpha_\star$ decreases as $V$ increases
  → $\frac{\rho\mu_\star S}{m}$ decreases as $V$ increases

### Saturation phenomenon → $\mu_s = B \cdot V^{1/3}$ → $\frac{\rho\mu S}{m} = \min\left(\frac{\rho\mu_\star S}{m}, \frac{\rho\mu_s S}{m}\right)$

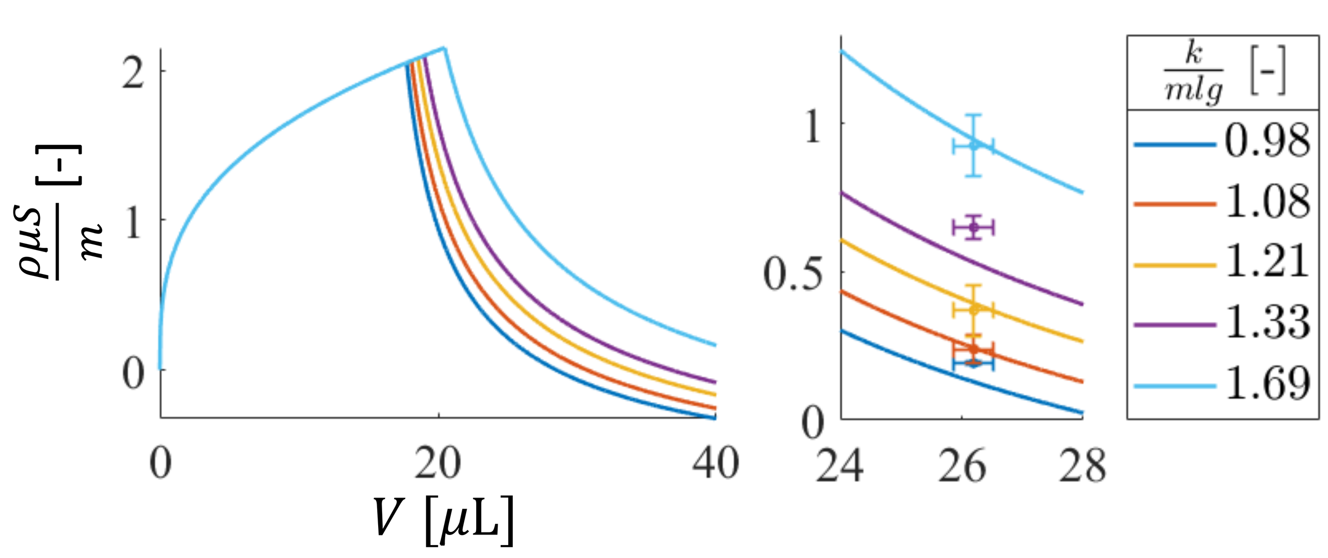



**Fig. 5** : $\frac{\rho\mu S}{m}$ vs. volume of a water droplet on kapton for different values of $\frac{k}{mlg}$.

- Model verified by experiments
- Hemisphere approximation
  → $B \approx 0.47$
- Existence of an optimal volume $V$ such that $\mu_\star = \mu_s$ → $\mu = \mu_m$

### Maximum capacity and leaf compliance

Defining $C = \frac{\rho SAB}{m}$ and $x = \frac{\rho\mu_m S}{m}$

→ $\frac{k}{mlg} = \frac{\sqrt{1-(C/x)^4}}{\sin^{-1}((C/x)^2)}(ABx + 1)$

$$\begin{cases} \frac{k}{mlg} \ll 1 \rightarrow \frac{\rho\mu_m S}{m} \approx C \rightarrow \mu_m \approx AB \\ \frac{k}{mlg} \gg 1 \rightarrow \frac{\rho\mu_m S}{m} \propto \left(\frac{k}{mlg}\right)^{1/3} \end{cases}$$

## Conclusion

- The roll-off angle varies with:
  → The size of the droplets
  → The geometry of the droplet which may be slightly different even if the volume is constant
- Model verified through experiments
- $\begin{cases} \frac{\rho\mu_\star S}{m} \searrow \text{ as } V \nearrow \\ \frac{\rho\mu_s S}{m} \nearrow \text{ as } V \nearrow \end{cases}$ → $\exists\ \frac{\rho\mu_m S}{m}$, $\forall \frac{k}{mlg}$
- $\frac{\rho\mu_m S}{m}$ lower-bounded, scales with $k/mlg$

### Future work

- Establish $\mu_s(V)$ properly
- Extend the model to non rigid or curved plant leaves