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The Evolutionary and Ecological Significance of Stimulus-Specific Habituation in *Mimosa pudica L.*
A Mathematical Modeling Approach

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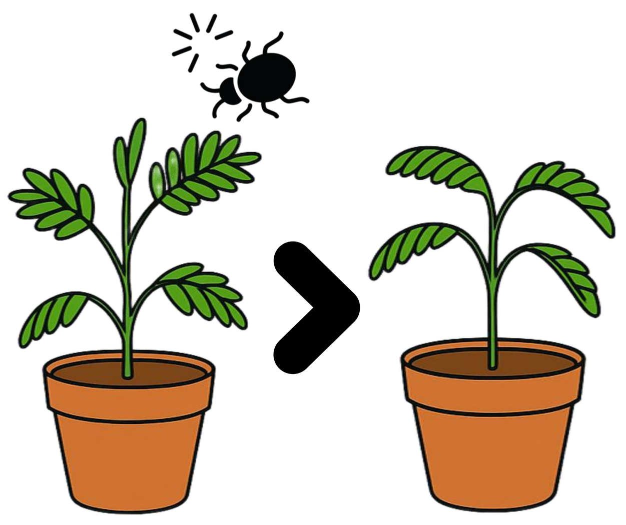
Objective: To evaluate the fitness benefits of habituation in *Mimosa pudica* using a mathematical model



Thigmonasty
Closing leaves in response to stimuli to defend against insect damage. (Braam, 2005)

Advantage
Defend against insect damage (Eisner, 1981; Hagihara et al., 2022)

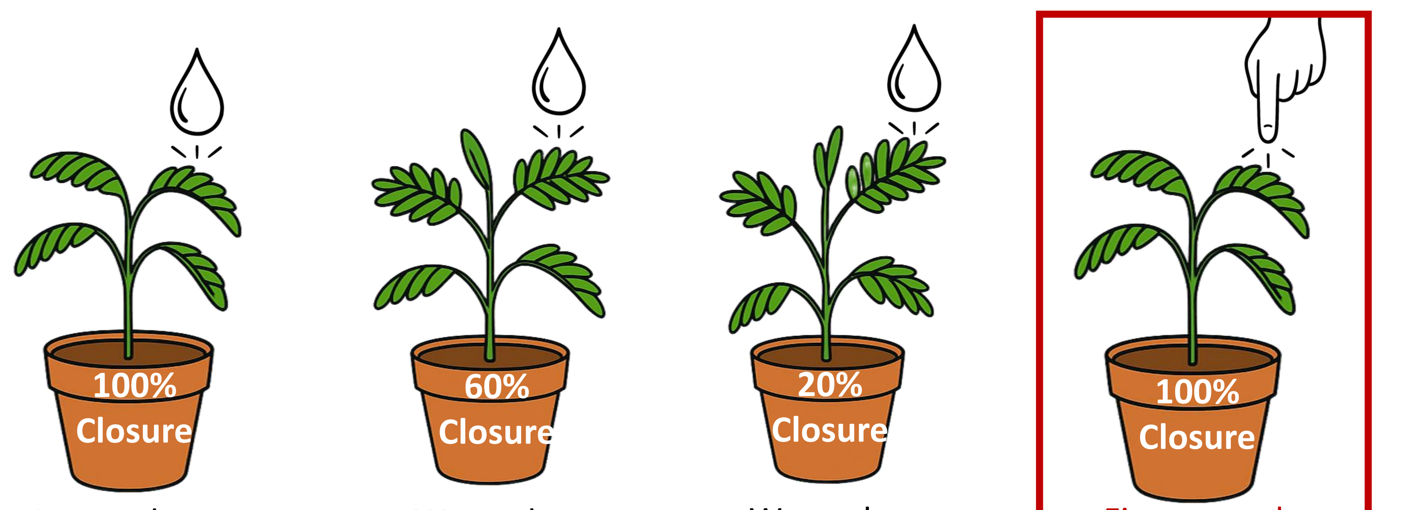
Trade-off

Disadvantage
Inhibition of photosynthesis (Bao et al., 2018)
Physiological cost of Thigmonasty (Hagihara & Toyota, 2020; Tran et al., 2021)

To maximize energy

Habituation
(Applewhite, 1972; Gagliano et al., 2014; Thompson & Spencer, 1966; Wilhelm Pfeffer, 1873)

The phenomenon in which the response to the same stimulus weakens through repeated exposure.



A difference equation model was developed to evaluate the adaptive significance of habituation from an energy balance perspective

Daily Energy Balance

$$X(t) = X(t-1) + e - C_{ds} - C_{nds} \quad \text{(Eq.1)}$$

Previous Day's Energy; Cost of Damaging Stimuli; Total Energy; Energy Gain; Cost of Non-Damaging Stimuli

n_{ds}/day — Damaging Stimuli

$(1-p_1)d_n$	Responsiveness to Damaging Stimuli	$p_1(c_r+d_r)$
React	p_1 (0 – 1)	Doesn't React
d_n Pest damage (upon reaction)		d_r Pest damage (upon non-reaction) — Damage
0 Reactive Cost		c_r Reactive Cost — Cost of Reaction

$$C_{ds} = n_{ds}[(1-p_1)d_n + p_1(c_r+d_r)] \quad \text{(Eq.2)}$$

n_{nds}/day — Non-Damaging Stimuli

$(1-Y_i(t))(0+0)$	Habituation	$(1-Y_i(t))(c_r+c_a)$
React	$Y_i(t)$ Habituation Level (0 – 1)	Doesn't React
0 Habituation Cost		c_a Habituation Cost — Cost of Habituation
0 Reactive cost		c_r Reactive Cost

$$C_{nds} = \sum_{i=1}^{n_{nds}} p_2[(1-Y_i(t))c_r + Y_{max}(1-Y_i(t))c_a] \quad \text{(Eq.3)}$$

Habituation Level: $Y_i(t)$

This represents the value after the i-th stimulus on day t, which increases through learning during the day and decreases through forgetting between days.

Learning

$$Y_i(t) = Y_{i-1}(t) + k\underbrace{(Y_{max} - Y_{i-1}(t))}_{\text{Learning Potential}} \quad \text{(Eq. 4)}$$

Previous Habituation Level (before the i-th stimulus); Maximum Habituation Level; Habituation Level (after the i-th stimulus); Learning Rate (after the i-th stimulus)

Forgetting

$$Y_0(t) = Y_{n_{nds}}(t-1) - l \quad \text{(Eq. 5)}$$

Previous Habituation Level (Final habituation level on day t-1); Habituation Level (Initial habituation level on day t); Habituation Loss

From Eqs. (4) and (5):

$$Y_0(t) = [Y_{max} + (Y_0(t-1) - Y_{max})(1-k)^{n_{nds}}] - l \quad \text{(Eq. 6)}$$

Model Validation: Comparison of the Theoretical Model with Simulation Data for Validation.

Simulation

Method: Stimulus frequency was treated as probabilistic (Poisson distribution).
Conditions: Data is the average of 10 independent 365-day runs.

Theoretical model

Total Energy at Day T

$$X(T) = X(0) + 113.375T - 3465\left(\frac{0.975-(0.99)^{100}}{1-(0.99)^{100}}\right)\left(1-\left((0.99)^{100}\right)^T\right) \quad \text{(Eq.7)}$$

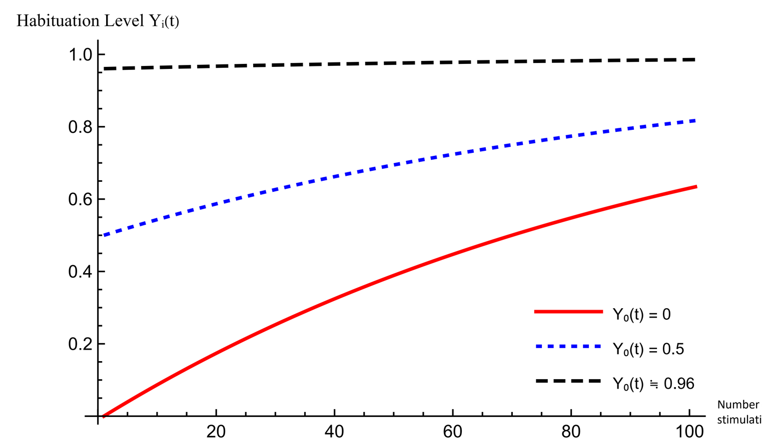


Fig.1 Dynamics of Solutions to Eq. 4 (Eq. 5) for Different Initial Conditions $Y_0(t)$

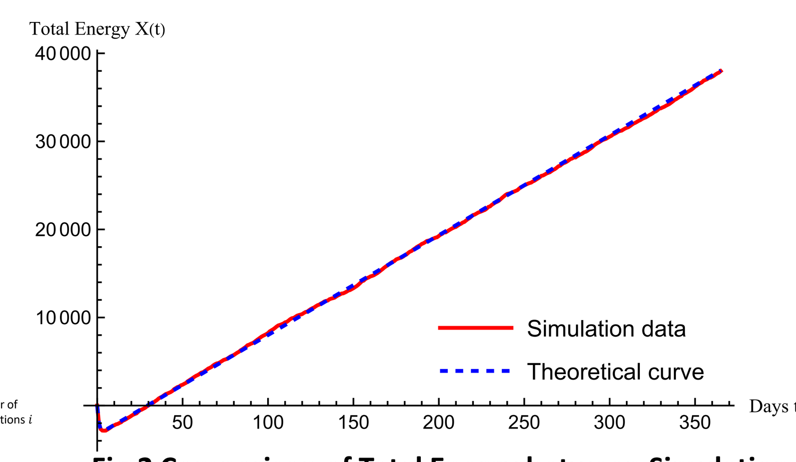


Fig.2 Comparison of Total Energy between Simulation Data and Theoretical Prediction

The model's predictions aligned well with the simulation results, confirming that it accurately represents the plant's energy dynamics

Quantitatively evaluating the adaptive significance of habituation in *Mimosa pudica* by comparing four virtual plant models with different characteristics

1 Non-Habituating Responder (All-Stimuli Responder)
Responds to all stimuli
$p_1 = 1$ (Responsiveness to Damaging Stimuli)
$p_2 = 1$ (Responsiveness to Non-Damaging Stimuli)
$Y_{max} = 0$ (Maximum Habituation Capacity)
$$X(t) = -2800t \quad \text{(Eq.8)}$$

2 Non-Responsive Control (Normal Plants)
Doesn't respond to any stimuli
$p_1 = 0$, $p_2 = 0$, $Y_{max} = 0$
$$X(t) = -100t \quad \text{(Eq.9)}$$

3 Damaging Stimuli Responder (Energetic Ultimate)
Responds only to damaging stimuli
$p_1 = 1$, $p_2 = 0$, $Y_{max} = 0$
$$X(t) = 200t \quad \text{(Eq.10)}$$

4 Habituating Responder (Mimosa Pudica L.)
Habituates to non-damaging stimuli; responds to Damaging ones
$p_1 = 1$, $p_2 = 1$, $Y_{max} = 1$
$$X(t) = X(0) + 113.375t - 3465\left(\frac{0.975-(0.99)^{100}}{1-(0.99)^{100}}\right)\left(1-\left((0.99)^{100}\right)^t\right) \quad \text{(Eq.11)}$$

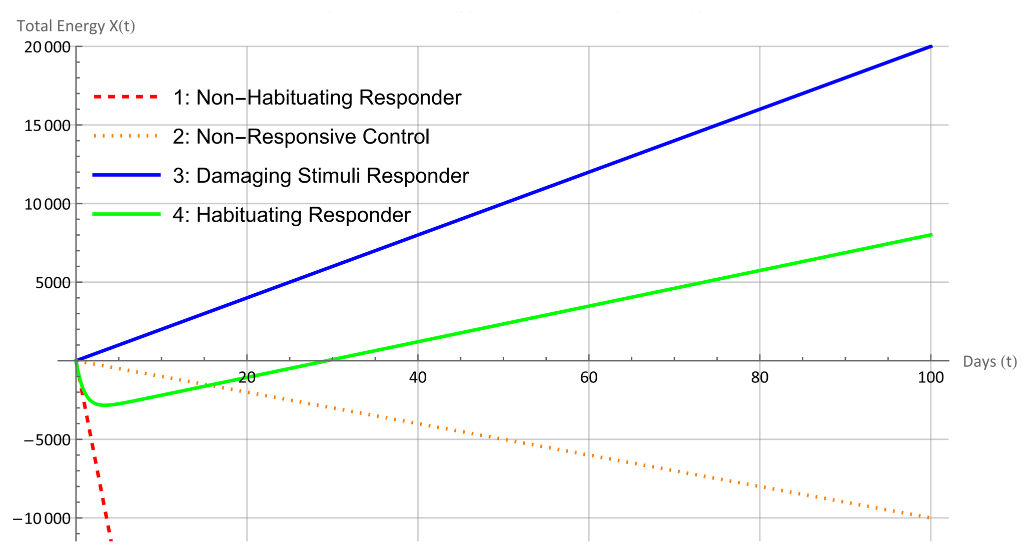


Fig.3 A Comparison of Four Plant Response Types to Damaging and Non-damaging Stimuli: All-Stimuli Response, Non-Response, Damaging-Stimuli-Only Response, and Habituation

The ability of **"habituation,"** learning to ignore harmless stimuli, is an effective adaptive strategy for reducing energy consumption (under certain conditions).

Is the adaptive strategy (Type 4) superior to the error-prone one (Type 3)?

Type 3 may misidentify damaging stimuli as non-damaging stimuli. With a certain probability, damaging stimuli are misidentified as non-damaging stimuli, resulting in d_n damage.

P_e: The Probability of misidentifying damaging stimuli as non-damaging

BEFORE $$C_{ds} = n_{ds}[(1-1)d_n + 1\cdot(c_r+d_r)] \quad \text{(Eq.12)}$$

AFTER $$C_{ds} = n_{ds}[P_e\cdot d_n + (1-P_e)(c_r+d_r)] \quad \text{(Eq.13)}$$

$$X(t) = t(200 - 300p_e) \quad \text{(Eq.14)}$$

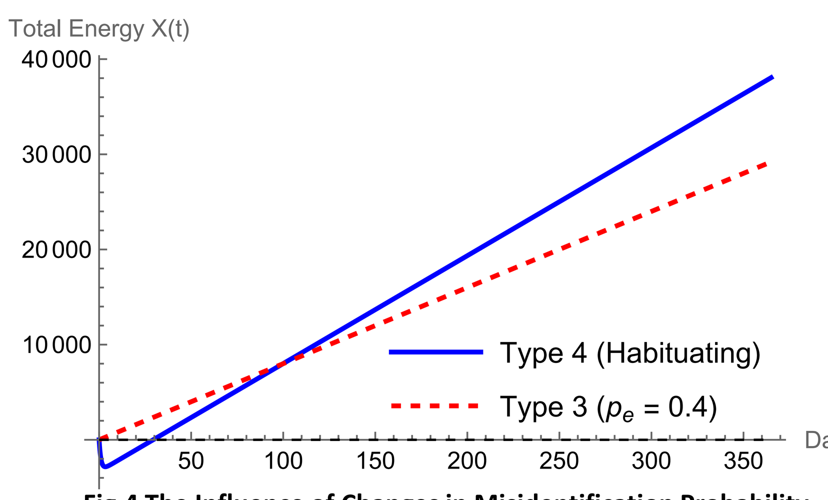


Fig.4 The Influence of Changes in Misidentification Probability (pe) on the Final Energy Advantage between the Habituation Strategy (Type 4) and the Non-Habituation Strategy (Type 3)

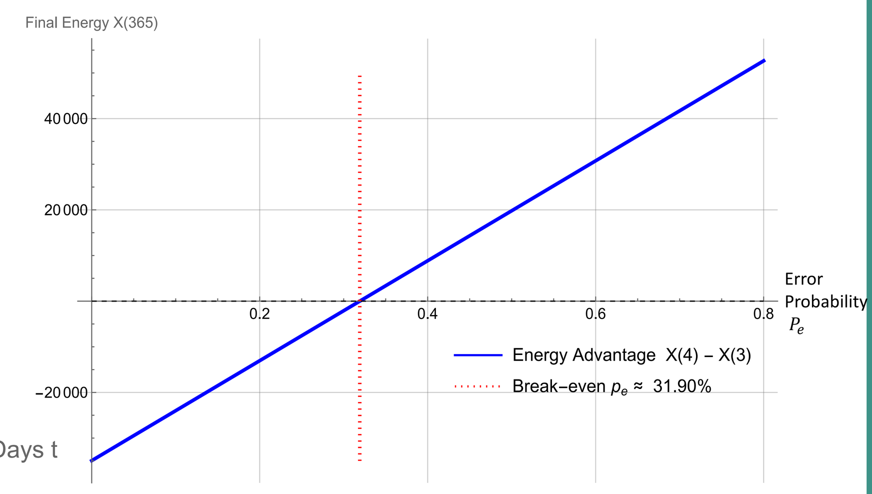


Fig.5 Comparison of Energy Accumulation X(t) between Type 3 and Type 4 at $p_e = 0.4$

The Type 4 strategy offers a greater survival advantage because the Type 3 strategy risks overlooking a genuine threat.

Conclusion: Habituation is the optimal defense strategy for *Mimosa pudica* when the risk of misidentifying stimuli is high.

Reference

1. Abramson, C. I., & Chicas-Mosier, A. M. (2016). Learning in plants: Lessons from Mimosa pudica. *Frontiers in Psychology*, *7*(MAR), 189667. https://doi.org/10.3389/FPSYG.2016.00417/BIBTEX
2. Applewhite, P. B. (1972). Behavioral plasticity in the sensitive plant, Mimosa. *Behavioral Biology*, *7*(1), 47–53. https://doi.org/10.1016/S0091-6773(72)80187-1
3. Bao, T., Roy, G., & Cahill, J. F. (2018). Photosynthetic opportunity cost and energetic cost of a rapid leaf closure behavior in Mimosa pudica. *American Journal of Botany*, *105*(9), 1491–1498. https://doi.org/10.1002/AJB2.1154,
4. Braam, J. (2005). In touch: Plant responses to mechanical stimuli. *New Phytologist*, *165*(2), 373–389. https://doi.org/10.1111/J.1469-8137.2004.01263.X
5. Eisner, T. (1981). Leaf folding in a sensitive plant: A defensive thorn-exposure mechanism? *Proceedings of the National Academy of Sciences of the United States of America*, *78*(1), 402–404. https://doi.org/10.1073/PNAS.78.1.402
6. Gagliano, M., Renton, M., Depczynski, M., & Mancuso, S. (2014). Experience teaches plants to learn faster and forget slower in environments where it matters. *Oecologia*, *175*(1), 63–72. https://doi.org/10.1007/S00442-013-2873-7/METRICS
7. Hagihara, T., Mano, H., Miura, T., Hasebe, M., & Toyota, M. (2022). Calcium-mediated rapid movements defend against herbivorous insects in Mimosa pudica. *Nature Communications*, *13*(1). https://doi.org/10.1038/S41467-022-34106-X
8. Hagihara, T., & Toyota, M. (2020). Mechanical Signaling in the Sensitive Plant Mimosa pudica L. *Plants 2020, Vol. 9, Page 587*, *9*(5), 587. https://doi.org/10.3390/PLANTS9050587
9. Kirkman, C. (2025). *A Study of Habituation Behavior and Pavlovian Conditioning in the "Mimosa pudica" Plant*. https://doi.org/10.23668/PSYCHARCHIVES.16174
10. Thompson, R. F., & Spencer, W. A. (1966). Habituation: A model phenomenon for the study of neuronal substrates of behavior. *Psychological Review*, *73*(1), 16–43. https://doi.org/10.1037/H0022681
11. Tran, D., Petitjean, H., Chebli, Y., Geitmann, A., & Sharif-Naeini, R. (2021). Mechanosensitive ion channels contribute to mechanically evoked rapid leaflet movement in Mimosa pudica. *Plant Physiology*, *187*(3), 1704–1712. https://doi.org/10.1093/PLPHYS/KIAB333
12. Wilhelm Pfeffer. (1873). *Physiologische Untersuchungen* (Vol. 238). Internet Archive. https://archive.org/details/physiologischeu03pfefgoog/page/n13/mode/2up

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