A Bio-Based Chiroptical Overcrowded Alkene From Flavanone: Photoreactivity and Theoretical Investigation

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Abstract

Light-driven overcrowded alkenes are the core of chiroptical molecular switches and rotary motors, but making them enantiopure usually requires long, complex syntheses. Here, the enantiopure flavanone (–)-isolonchocarpin (**1**), isolated from *Tephrosia vogelii* pod peels, was used as a bio-based chiral building block. A single McMurry homocoupling gave overcrowded alkene **2** (86%, *E*:*Z* = 71:29). Under 365–405 nm light, (*M,M*)-(*E*)-**2** undergoes *E/Z* photoisomerization followed by oxidative 6π-electrocyclization (Mallory reaction) to the fluorescent phenanthrene-like chromophore **3** (λ_{em} = 438/465 nm, Φ ≈ 5%). Spin-flip TDDFT calculations show that the two stereocenters inherited from the natural product make the clockwise and counterclockwise rotation pathways inequivalent (19.2 kJ mol^{-1} between conical intersections), biasing the direction of motion. This offers a short, sustainable route to bio-based photoresponsive molecular systems.

Keywords: overcrowded alkene, flavanone, photoisomerization, Mallory photocyclization, SF-TDDFT, molecular switch.

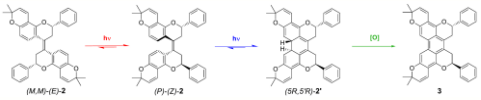
Introduction

Overcrowded alkenes combine a sterically crowded central C=C bond with a stable helical shape. Light-induced *E/Z* isomerization switches them between geometries, which has made them the basis of photochromic materials, molecular machines and smart materials. Controlling the direction of their rotation, however, normally depends on multistep enantioselective syntheses.

Phenanthrenes are valuable chromophores for solar cells, phototransistors, organic thin-film transistors, OLEDs and triplet photosensitizers, yet they are usually prepared from reactive phenanthrenequinones or with electrochemical, photocatalytic, Lewis-acid or transition-metal methods.

Natural secondary metabolites are attractive alternatives: they are often enantiopure and readily available. (–)-Isolonchocarpin (**1**), the main flavanone of *T. vogelii*, carries an aryl ketone that can be dimerized by McMurry coupling into a stilbene-like overcrowded alkene. For an achiral olefin, clockwise (CR) and counterclockwise (CCR) rotation have identical energy profiles; the stereocenters of **1** could break this symmetry.

Aim: (i) build a chiral overcrowded alkene and a phenanthrene chromophore from **1** in minimal steps, (ii) map its photoreactivity, and (iii) explain the directional bias computationally.

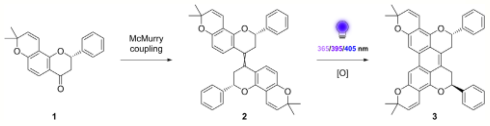


Picture 1. Concept: light-driven E/Z isomerization, 6π-electrocyclization and oxidation of the bio-based overcrowded alkene (M,M)-(E)-2 to chromophore 3.

Research Method

Isolation. Dried *T. vogelii* pod peels were macerated in acetone; **1** was purified by vacuum liquid chromatography and recrystallized from *n*-heptane.

Synthesis. McMurry homocoupling of **1** ($TiCl_4$, Zn, pyridine, THF, 70 °C, 3 h) gave **2**. (*E*)-**2** was isolated by precipitation and (*Z*)-**2** by recrystallization from methanol. Photocyclization of **2** (395 nm, acetone, 6 h) gave **3**, isolated by preparative TLC.

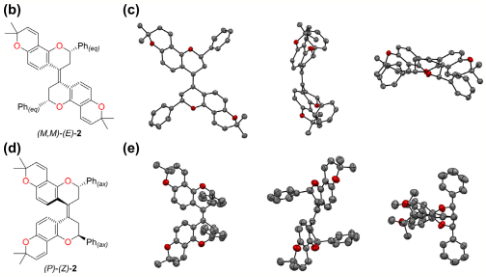


Picture 2. Synthetic route from (–)-isolonchocarpin (1) to overcrowded alkene 2 and phenanthrene-like chromophore 3.

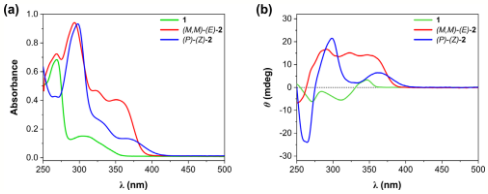
Characterization. Structures and absolute configurations were assigned by ^{1}H/NOESY NMR, single-crystal XRD, HRMS and comparison of experimental with calculated CD spectra.

Photochemistry. Solutions of (*M,M*)-(*E*)-**2** and (*P*)-(*Z*)-**2** (20 μM, DCM, 25 °C) were irradiated at 365, 395 and 405 nm and followed by UV-Vis, CD and ^{1}H NMR until the photostationary state (PSS). Emission of **3** was recorded.

Computation. Ground-state geometries and CD spectra: DFT (ωB97X-D4/cc-pVDZ, DCM). S_1/S_0 potential energy surfaces, minima, saddle points and conical intersections (CIs) for *E/Z* isomerization (CR vs. CCR) and 6π-electrocyclization: collinear spin-flip TDDFT (SF-TD-BHandHLYP/cc-pVDZ), which describes CI topology more reliably than linear-response TDDFT.



Picture 3. Structures (b, d) and X-ray crystal structures (c, e) of (M,M)-(E)-2 (phenyl equatorial) and (P)-(Z)-2 (phenyl axial).



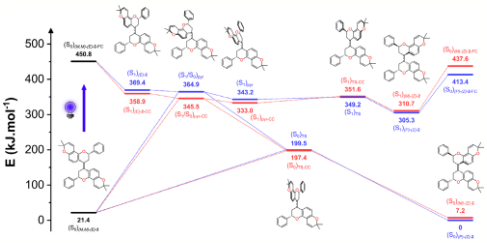
Picture 4. UV-Vis (a) and CD (b) spectra of 1, (M,M)-(E)-2 and (P)-(Z)-2 (20 μM in DCM, 25 °C).

Discussion & Result

Synthesis and structure. McMurry coupling gave **2** in 86% yield (*E*:*Z* = 71:29) with both stereocenters retained, giving (2*S*,2′*S*)-(*M,M*)-(*E*)-**2** (phenyl equatorial) and (*P*)-(*Z*)-**2** (phenyl axial). Upfield shifts of H_c–H_f confirm conversion of the ketone into the alkene, and the extended π-system red-shifts the absorption.

Photoreactivity. Irradiating (*M,M*)-(*E*)-**2** first gives clean isosbestic points (255 and 379 nm at 365 nm), matching formation of (*P*)-(*Z*)-**2**. New absorption at 400–575 nm and the loss of isosbestic behavior then reveal successive photocyclization and oxidation (PSS ≈ 60 min at 365 nm; ≈ 90 min at 395/405 nm). The CD signal falls as planar **3** forms, and in ^{1}H NMR the H_f doublet becomes a singlet. Isolated **3** (50%) absorbs at 308–349 nm, with weaker bands at 403/426 nm, and fluoresces at 438 and 465 nm (Φ ≈ 5%).

Theoretical insight. DFT shows that the *E* and *Z* isomers prefer opposite helicities and phenyl orientations. SF-TDDFT pathways run from the Franck–Condon point through twisted, pyramidalized CIs. The CR and CCR CIs differ by **19.2 kJ mol^{-1}**: in $(S_1/S_0)_{pyr}$ the pseudo-axial phenyl meets the pyramidalized C4 in a 1,3-di-pseudo-axial interaction that is absent in $(S_1/S_0)_{pyr\text{-}CC}$. Stereocenters far from the fjord region therefore bias the rotational direction.



Picture 5. S1/S0 energies along clockwise (blue) and counterclockwise (red) isomerization of (M,M)-(E)-2 (SF-TD-BHandHLYP/cc-pVDZ).

Conclusion

An enantiopure bio-based flavanone was converted in one McMurry step into a chiral overcrowded alkene that undergoes *E/Z* photoisomerization and oxidative photocyclization to a fluorescent phenanthrene-like chromophore. SF-TDDFT reveals that the natural stereocenters break the CR/CCR symmetry and introduce a directional bias. β-Substituted natural products thus offer a sustainable, step-economical route to photoswitches, molecular machines and optoelectronic chromophores.

Ref.: D. H. Limawan et al., Chem. Eur. J. 2026, 32, e71180. doi:10.1002/chem.71180