

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- | | | |
|-------------------------------------|-------------------------------------|--|
| ☐ | ☒ | The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☒ | ☐ | The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ | A description of all covariates tested |
| ☒ | ☐ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☒ | ☐ | For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ | Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection

Geometry optimizations in the gas phase were initially carried out using global hybrid functional M06-2X with Karlsruhe-family basis set of double- ζ valence def2-SVP for all atoms as implemented in Gaussian 16 rev. A.03. Minima and transition structures on the potential energy surface (PES) were confirmed as such by harmonic frequency analysis, showing respectively zero and one imaginary frequency, at the same level of theory.

Data analysis

Single point (SP) corrections were performed using M06-2X functional and def2-TZVP6 basis set for all atoms. The implicit SMD continuum solvation model was used to account for the solvent effects of diethylether (DEE) on the overall free energy PES. Gibbs energies were evaluated at the room temperature, as was used in the experiments, using a quasi-RRHO treatment of vibrational entropies. Vibrational entropies of frequencies below 100 cm⁻¹ were obtained according to a free rotor description, using a smooth damping function to interpolate between the two limiting descriptions. The free energies were further corrected using standard concentration of 1 mol/L, which was used in solvation calculations. SMD(DEE)-M06-2X/def2-TZVP//M06-2X/def2-SVP Gibbs energies are given and quoted in kcal mol⁻¹ throughout. Unless otherwise stated, these solvent-corrected values are used for discussion throughout the main text and in this supporting information. Non-covalent interactions (NCIs) were analyzed using NCIPLOT calculations. The .wfn files for NCIPLOT were generated at M06-2X/def2-SVP level of theory. NCI indices calculated with NCIPLOT were visualized at a gradient isosurface value of $s = 0.5$ au. These are colored according to the sign of the second eigenvalue (λ_2) of the Laplacian of the density (∇^2) over the range of -0.1 (blue = attractive) to $+0.1$ (red = repulsive). All molecular structures were visualized using PyMOL software.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

X-ray crystallographic data for compound 3k, 7 and 8 was available free of charge from the Cambridge Crystallographic Data Centre under CCDC 2351572, 2352637 and 2352635. Full experimental details for the preparation of all new compounds, and their spectroscopic and chromatographic data, can be found in the supplementary materials. Geometries of all DFT-optimized structures have been deposited and uploaded to <https://zenodo.org/records/15537308> (DOI: 10.5281/zenodo.15537308).

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender	NA
Reporting on race, ethnicity, or other socially relevant groupings	NA
Population characteristics	NA
Recruitment	NA
Ethics oversight	NA

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

- ☒ Life sciences ☐ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

Sample size	This is not relevant to our study because we do not carry out statistic study.
Data exclusions	No data were excluded from analysis.
Replication	All the experiments were repeated for at least trice, and all of them are reproducible following the detailed experimental procedures described in the main text or in the supplementary information.
Randomization	This is not relevant to our study because we do not carry out statistic study.
Blinding	This is not relevant to our study because we do not carry out statistic study.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involvement in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involvement in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks

We did not use seed.

Novel plant genotypes

We did not produce novel plant.

Authentication

We did not use plant.