Photoswitching Hydrazones Based on Benzoylpyridine

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1 Synthesis

General Methods

¹H and ¹³C NMR spectra were recorded at 600 or 300 MHz for ¹H nuclei, and 150 or 75 MHz for ¹³C nuclei. Chemical shifts are reported in δ units, parts per million (ppm); signals are referenced to TMS as an internal standard. Coupling constants (*J*) are given in Hz and multiplicity is abbreviated as: s (singlet), d (doublet), dd (doublet of doublets), t (triplet), qd (quartet of doublets), m (multiplet). Reactions were monitored by thin-layer chromatography (TLC) carried out on silica plates (Merck silica gel 60 F-254), visualized by irradiation with UV light. Infrared spectra were recorded at Nicolet 6700 FT-IR spectrometer (ATR technique). Commercially available reagents were used without further purification. Synthesis of starting materials was performed according to literature procedures or as specified below.

Synthesis of alcohols

(4-nitrophenyl)(pyridin-2-yl)methanol:



A solution of dry THF (15 ml) and 2-bromopyridine (2.35 g, 15 mmol) was slowly added dropwise to the stirred solution of dry THF (10 ml) and magnesium powder (1.2 equiv, 435 mg, 18 mmol) at 70 °C. After initiated the reaction, oil bath was removed and the dropping rate of 2-bromopyridine solution was adjusted to maintain the reaction system refluent. After the dropwise addition, heated the system continued to reflux for 30 more minutes. Addition resulted to hardened solution. This solution was transferred by a syringe dropwise to the stirred solution of THF (20 ml) and 4-nitrobenzaldehyde (0.8 equiv, 1.89 g, 12.5 mmol) at 0 °C. The reaction mixture was warmed up and left to stir at r.t. for 18 h. After 18 h the solvent was removed by distillation under reduced pressure and the residue was dissolved in CH₂Cl₂(60 ml) and washed by saturated ammonium chloride solution NH₄Cl (3×30 ml). The organic layer was dried over anhydrous Na₂SO₄ and next the solvent was removed by distillation under reduced pressure. The residue was subjected to silica column gradient flash chromatography (from 3:1 hexanes/EtOAc to 2:1 hexanes/EtOAc to afford alcohol **6** as a red solid (yield 2 g, 70 %). Compound was recrystallized from MeOH/H₂O (1:3); **6** m.p. 108-111 °C; ¹H NMR (300 MHz, CDCl₃) δ : 8.58 (dd, *J* = 4.9 Hz, 2.4 Hz, 1H), 8.19 (d, *J* = 8.6 Hz, 2H), 7.67 (td, *J* = 7.8 Hz, 1.2 Hz, 1H), 7.59 (d, *J* = 8.6 Hz, 2H), 7.26-7.24 (m, *J* = 7.1 Hz, 5.4 Hz, 2H), 7.17 (dd, *J* = 7.9 Hz, 0.5 Hz, 1H), 5.85 (s, 1H), 5.39 (bs, 1H); ¹³C (151 MHz, CDCl₃) δ : 159.38, 150.5, 148.4, 147.7, 137.4, 127.8, 124.0, 123.2, 121.36, 74.2

ppm; IR: $\tilde{\nu}_{max}$ 3112 (w, O–H), 2851 (w), 2702 (w), 1592 (m), 1504 (m, C–O), 1331 (m), 1266 (w), 1046 (m), 774 (s, C–H), 754 (s, C–H), 705 (m, C–H).

Exhibited spectral data are in accordance with previous report [1].

(4-(dimethylamino)phenyl)(pyridin-2-yl)methanol:



A solution of dry THF (20 ml) and 4-bromo-N,N-dimethylaniline (4.2 g, 21 mmol) was slowly added dropwise to the stirred solution of dry THF (15 ml) and magnesium powder (511 mg, 21 mmol) and catalytic amount of crystalline iodine at 70 °C. After initiated the reaction, oil bath was removed and the dropping rate of 2-bromopyridine solution was adjusted to maintain the reaction system refluent. After the dropwise addition, the reaction mixture was stirred another 15 minutes at 25 °C. The reaction mixture was coloured from dark red to black. A solution of THF (10 ml) and 2-pyridinecarboxaldehyde (0,7 equiv1.5 g, 14 mmol) was then added dropwisr at 0 °C. Precipitation of brown solid was observed immediately. The reaction mixture was warmed up and left to stir at r.t. for 3 h. After that the reaction mixture was poured into 150 ml of saturated ammonium chloride solution and extracted to EtOAc (5×30 ml). The combined organic layers were dried over anhydrous Na₂SO₄ and concentrated by distillation under reduced pressure. The residue was subjected to silica column gradient flash chromatography (3:1 hexanes/EtOAc to pure ethylacetate to afford **9** as a pale yellow solid (yield 3.15 g, 98 %).; **9** m.p. 95-98 °C; ¹H NMR (600 MHz. CDCl₃) δ: 8.56 (ddd, J = 4.9 Hz, 1.6 Hz, 1.1 Hz, 1H). 7.60 (t, J = 7.7 Hz, 1.7 Hz, 1H), 7.21 (d, J = 8.7 Hz, 2H), 7.19-7.14 (m, 2H), 6.70 (d, J = 8.8 Hz, 2H), 5.68 (bs, 1H), 5.07 (d, J = 3.2 Hz, 1H), 2.93 (s, 6H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ: 161.7, 150.3, 147.7, 136.6, 131.2, 128.1, 122.1, 121.3, 112.5, 74.8, 40.6 ppm; IR: $\tilde{\nu}_{max}$ 3165 (w, O–H), 3084 (w), 2888 (w), 1611 (m), 1592 (m), 1523 (s), 1359 (m), 1331 (m), 1164 (m), 1024 (m), 803 (m, C-H), 775 (m, C-H), 633 (m, C–H), 553 (s).

Exhibited spectral data are in accordance with previous report [1].

Synthesis of ketones General approach



Solution of an activated (24 h, heated to 120 °C under vacuum) MnO_2 (5 equiv, 3.8 g, 43 mmol) and prepared alcohols (8.6 mmol) in CHCl₃ (70 ml) was stirred 5 h at 80 °C. After reaction proceed (monitored by TLC, eluent mixture: hexanes/EtOAc, 2:1), reaction mixture was cooled down to r.t. and filtered through cellite pad. Cellite phase was washed with CHCl₃ (3×30 ml) and combined organic layers were concentrated by distillation under reduced pressure.

(4-nitrophenyl)(pyridin-2-yl)methanone:



Ketone **10** was isolated as colourless solid (yield 1.95 g, 98 %).;**10** m.p.= 98-101 °C; ¹H NMR (600 MHz, CDCl₃) δ : 8.73 (ddd, J = 4.7 Hz, 1.6 Hz, 0.9 Hz, 1 Hz, 1H), 8.32 (d, J = 8.9 Hz, 2H), 8.25 (d, J = 8.9 Hz, 2H), 8.17 (dt, J = 7.9 Hz, 1.0 Hz, 1H), 7.96 (td, J = 7.7 Hz, 1.7 Hz, 1H), 7.55 (ddd, J = 7.6 Hz, 4.7 Hz, 1.2 Hz, 1H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ : 192.0, 153.7, 149.9, 148.7, 141.5, 137.4, 131.9, 127.1, 124.8, 123.1 ppm; IR: $\tilde{\nu}_{max}$ 3071 (w), 2962 (w), 2888 (w), 1670 (m, C=O), 1513 (s, C–O), 1354 (m), 1308 (s), 1287 (s), 1090 (m), 962 (m), 850 (s), 761 (m), 735 (s).

Exhibited spectral data are in accordance with previous report [2].

(4-(dimethylamino)phenyl)(pyridin-2-yl)methanone:



This compound was synthesized using reported procedure for ketone synthesis. After filtration through cellite pad and concentration under reduced pressure, the residue was subjected to column flash chromatography on silica (hexanes/EtOAc 2:1 to pure EtOAc) to give desired ketone **11** as pale green solid (yield 2.1 g, 62 %).; **11** m.p.= 89-91 °C; ¹H NMR (600 MHz, CDCl₃) δ : 8.69 (dd, J = 4.7 Hz, 0.5 Hz, 1H), 8.06 (d, J = 9.1 Hz, 1H), 7.92 (d, J = 7.8 Hz, 1H), 7.85 (td, J = 7.7 Hz, 1.7 Hz, 1H), 7.42 (ddd, J = 7.5 Hz, 4.8 Hz, 1.2 Hz, 1H), 6.68 (d, J = 9.1 Hz, 1H), 3.07 (s, 6H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ : 191.7, 156.9, 153.5, 148.2, 136.8, 133.4, 125.2, 124.3, 123.7, 110.6, 40.0 ppm; IR: $\tilde{\nu}_{max}$ 3351 (w, C–H), 2921 (w), 1637 (w), 1582 (m, C=O), 1484 (w), 1318 (m), 1153 (m), 1062 (s), 992 (s), 937 (s), 787 (m, C–H), 747 (m, C–H).

Exhibited spectral data are in accordance with previous report [3].

General method for hydrazones synthesis



To a stirred solution of ketone (0,81 mmol) and AcOH (0,5 ml) in EtOH (8 ml) was added phenylhydrazine (0,1 ml) in one portion. The reaction mixture was refluxed 5-18 h (depends on reactivity of ketone).

Hydrazon 1 and 2, isolation procedure:

In the case of hydrazone **5** and **6**, reaction mixture was cooled down to room temperature after 18 h stirring and then concentrated by distillation under reduced pressure. The residue was dissolved in CH_2Cl_2 (30 ml) and washed by H_2O (3×10 ml). In the next step the organic phase was dried over anhydrous Na_2SO_4 and then the solvent was removed by distillation under reduced pressure. The residue was subjected to silica column gradient flash chromatography.

(E)-2-(phenyl(2-phenylhydrazono)methyl)pyridine (1)



Used eluent: (3:1 hexanes/EtOAc); desired hydrazones (*E*)-1 and (*Z*)-1 were obtained as pale yellow and orange solid respectively (overall yield 200 mg, 90 %). (*E*)-1 m.p.= 140-144 °C; ¹H NMR (600 MHz, DMSO-*d*₆) δ : 9.09 (bs, 1H), 8.37 (d, *J* = 4.7 Hz, 1H), 8.15 (d, *J* = 8.1 Hz, 1H), 7.82 (td, *J* = 8.0 Hz, 1.7 Hz, 1H), 7.54 (t, *J* = 7.4 Hz, 2H), 7.48 (t, *J* = 7.4 Hz, 1H), 7.32-7.27 (m, 4H), 7.27-7.20 (m, 3H), 6.84 (t, *J* = 7.2 Hz, 1H) ppm; ¹³C NMR (151 MHz, DMSO-*d*₆) δ : 157.0, 148.7, 145.4, 143.5, 136.7, 133.1, 129.9, 129.3, 129.2, 128.9, 120.6, 120.3, 113.8 ppm; IR: $\tilde{\nu}_{max}$ 3199 (w, N–H), 3048 (w, C–H) 1602 (m, C=N), 1558 (m, C=C), 1426 (s, C=C), 1247 (s, C–N), 1125 (s), 788 (m), 750 (m, C–H), 692 (s, C–H), 560 (m); elemental analysis, calculated for C₁₈H₁₅N₃: C 79.10, H 5.53, N 15.37 %; found C 78.94, H 5.73, N 14.97 %;

(Z)-2-(phenyl(2-phenylhydrazono)methyl)pyridine (1)



(*Z*)-1 m.p.= 84-88 °C; ¹H NMR (600 MHz, DMSO-*d*₆) δ : 12.29 (bs., 1H), 8.85 (d, *J* = 4.8 Hz, 1H), 7.96 (ddd, *J* = 9.0 Hz, 1.2 Hz, 0.6 Hz, 1H), 7.53-7.49 (m, 3H), 7.45-7.41 (m, 2H), 7.40-7.34 (m, 2H), 7.29-7.23 (m, 4H), 6.84 (t, *J* = 6.6 Hz, 1H) ppm; ¹³C (151 MHz, DMSO-*d*₆) δ : 152.7, 148.8, 144.6, 138.6, 138.3, 137.5, 129.1, 128.3, 127.8, 127.7, 124.7, 123.4, 112.0, 113.0 ppm. IR: $\tilde{\nu}_{max}$ 3045 (w), 2917 (w), 2848 (w), 1600 (m), 1565 (m), 1521(s), 1505 (s), 1239 (m), 1125 (m), 1070 (m), 790 (m), 690 (s), 628 (m).

(E)-N,N-dimethyl-4-((2-phenylhydrazineylidene)(pyridin-2-yl)methyl)aniline (2)



Used eluent: (3:1, 2:1 hexanes/EtOAc); desired hydrazones (*E*)-**2** and (*Z*)-**2** were obtained as pale yellow and pale orange solid (overall yield 150 mg, 75 %). (*E*)-**2** m.p.= 135-137 °C ; ¹H NMR (600 MHz, DMSO-*d*₆) δ : 9.04 (bs, 1H), 8.39 (ddd, *J* = 4.8 Hz, 1.8 Hz, 1 Hz, 1H), 8.07 (dt, *J* = 8.1 Hz, 1.1 Hz, 1H), 7.79 (ddd, *J* = 8.1 Hz, 7.5 Hz, 1.9 Hz, 1H), 7.26 (dd, *J* = 8.7 Hz, 1.2 Hz, 1H), 7.24 (ddd, *J* = 7.4 Hz, 4.7 Hz, 1.1 Hz, 1H), 7.21 (dd, *J* = 6.9 Hz, 1.8 Hz, 2H), 7.19 (d, *J* = 8.7 Hz, 1H), 7.14 (d, *J* = 8.8 Hz, 2H), 6.85 (d, *J* = 8.8 Hz, 2H), 6.78 (tt, *J* = 7.1 Hz, 1.2 Hz, 1H), 2.98 (s. 6H) ppm; ¹³C NMR (151 MHz, DMSO-*d*₆) δ : 157.5; 150.6; 148.7; 145.5; 144.2; 136.5; 130.7; 129.3; 122.5; 121.0; 120.0; 119.7; 113.6; 112.6; 40.4 ppm; elemental analysis, calculated for C₂₀H₂₀N₄: C 75.92, H 6.37, N 17.71 %; found C 75.72, H 6.40, N 17.42 %; IR: $\tilde{\nu}_{max}$ 3283 (w, N–H), 3042 (w, C–H), 2891 (w, C–H), 2796 (w, C–H), 1600 (m, C=N), 1519 (m, C=C), 1462 (m, C=C) 1425 (s, C=C), 1245 (s, C–N), 1133 (m), 786 (m), 745 (s, C–H), 692 (s, C–H), 553 (m).

(Z)-N,N-dimethyl-4-((2-phenylhydrazineylidene)(pyridin-2-yl)methyl)aniline (2)



(*Z*)-2 m.p. = 116-118 °C; ¹H NMR (600 MHz. DMSO-*d*₆) δ : 11.67 (bs, 1H), 8.80 (ddd, *J* = 4.9 Hz, 1.7 Hz, 0.9 Hz, 1H), 7.92 (td, *J* = 7.8 Hz, 1.8 Hz, 1H), 7.46 (ddd, *J* = 7.6 Hz, 4.9 Hz, 1.1 Hz, 1H), 7.35 (dt, *J* = 8.0 Hz, 1.1 Hz, 1H), 7.31 (d, *J* = 8.9 Hz, 6H), 7.23-7.29 (m, 2H), 7.16 (dd, *J* = 8.6 Hz, 1.1 Hz, 2H), 6.76 (tt, *J* = 7.1 Hz, 1.3 Hz, 1H), 6.72 (d, *J* = 8.9 Hz, 2H), 2.91 (s, 6H) ppm; ¹³C NMR (151 MHz. DMSO-*d*₆) δ : 153.5, 150.5, 149.3, 145.5, 140.1, 137.9, 129.5, 128.9, 126.7, 125.3, 123.7, 119.8, 113.2, 112.3, 40.4 ppm; IR: $\tilde{\nu}_{max}$ 3131 (w, N–H), 3046 (w, C–H), 3023 (w, C–H), 2805 (w, C–H), 1616 (m, C=N), 1599 (m, C=C), 1518 (m, C=C), 1502 (s, C=C), 1460 (m, C=C), 1119 (s, C–N), 1133 (m), 786 (m), 745 (s, C–H), 692 (s, C–H), 553 (m).

Hydrazone **3**, *isolation procedure:*

After 1 h precipitation occurred. Precipitate was then filtered and washed with cold EtOH. Hydrazon **3** was isolated as mixture of isomers (E/Z ratio 1:2) in overall yield 150 mg (70 %). Isomers were separated by silica flash chromatography (eluent: CH₂Cl₂) to afford isomers in 95 % purity in 79 % yield (mixture of isomers *E* and *Z* in ratio 95:5).

(E)-2-((4-nitrophenyl)(2-phenylhydrazono)methyl)pyridine (3);



(*E*)-**3** m.p. (EtOH) = 184-186°C; ¹H NMR (300 MHz. DMSO-d6) δ : 9.45 (s, 1H), 8.37-8.29 (m, 3H), 8.19 (d, *J*=8.1 Hz, 1H), 7.83 (td, *J*=7.8 Hz, 1.8 Hz, 1H), 7.60 (d, *J*= 8.8 Hz, 2H), 7.35-7.16 (m, 5H), 6.82 (t, *J*= 7.0 Hz, 1H) ppm; ¹H NMR (600 MHz. DMSO-*d*₆) δ : 8.44 (d, *J*=8.6 Hz, 3H), 8.25 (d, *J*=8.1 Hz, 1H), 7.75 (td, *J*= 7.9 Hz, 1.7 Hz, 1H), 7.64 (bs, 1H), 7.59 (d, *J*=8.7 Hz, 2H), 7.29 (d, *J*=8.4 Hz, 7.5 Hz, 2H), 7.18 (dd, *J*= 6.8 Hz, 5.5 Hz, 1H), 7.12 (d, *J*= 7.7 Hz, 2H), 6.94 (t, *J*= 7.3 Hz, 1H) ppm; ¹³C NMR (151 MHz. DMSO-*d*₆) δ : 156.3, 148.8, 147.9, 145.2, 144.6, 141.2,

136.9, 131.8, 129.4, 125.2, 124.3, 122.8, 120.7, 113.9 ppm; elemental analysis calculated for C₁₈H₁₄N₄: C 67.92. H 4.43. N 17.60 %; found C 67.6, H 4.21, N 17.29 %; IR : $\tilde{\nu}_{max}$ 3195 (w, N–H), 3051 (w, C–H), 2927 (w, C–H), 1596 (m, C=N), 1557 (m, C=C), 1510 (s, C=C) 1428 (s, C=C), 1239 (s, C–N), 996 (m), 855 (m), 769 (s, C–H), 699 (s, C–H).

(Z)-2-((4-nitrophenyl)(2-phenylhydrazono)methyl)pyridine (3)



(*Z*)-7 m.p. = 150-152°C; ¹H NMR (600 MHz. DMSO-*d*₆) δ : 11.89 (s, 1H), 8.87 (ddd, *J* = 5.1 Hz, 1.7 Hz, 0.9 Hz, 1H), 8.25 (d, *J* = 8.8 Hz, 2H), 8.01 (td, *J* = 7.8 Hz, 1.4 Hz, 1H), 7.76 (d, *J* = 8.8 Hz, 2H), 7.56 (ddd, *J* = 7.6 Hz, 4.9 Hz, 1.0 Hz, 1H), 7.46 (d, *J* = 7.9 Hz, 1H), 7.36-7.24 (m, 1H), 6.89 (tt, *J* = 6.4 Hz, 1.9 Hz, 1H) ppm; ¹³C NMR (151 MHz. DMSO-*d*₆) δ : 152.0, 149.9, 146.7, 145.4, 141.0, 138.3, 137.2, 129.6, 128.5, 124.3, 124.1, 121.3, 120.2, 114.0 ppm; IR : $\tilde{\nu}_{max}$ 3100 (w, N–H), 3024 (w, C–H), 2820 (w, C–H), 1586 (m, C=N), 1564 (m, C=C), 1506 (s, C=C) 1336 (s, C=C), 1240 (m, C–N), 1147 (s), 1107 (m), 855 (s, C–H), 713 (s, C–H).

1.1 Alternative Synthetic Procedure

Phenylhydrazine (0,1 ml) was added in one portion to a solution of ketone (0,81 mmol) and AcOH (0,5 ml) in EtOH (2.5 ml; 5 ml for synthesis of hydrazone **3**) in active ultrasonic bath (25 W; 50 Hz) at room temperature. The reaction mixture was than exposed to ultrasound waves for another 10-25 min (depends on reactivity of ketone; precipitation occurred after 5-10 min). Temperature of the bath was maintained not to exceed 25 °C. Sonification at room temperature thus leads to precipitation of the thermodynamically less stable *E* isomer. Precipitate was then filtered and washed with cold EtOH. Hydrazones (*E*)-**1**, (*E*)-**2** and (*E*)-**3** were isolated as pure *E* isomers in 50 %, 26 % and 55 % yields respectively.



Figure S1. ¹H NMR spectrum of 6 in CDCl₃ at 298.15 K.



Figure S2. ¹³C NMR spectrum of 6 in CDCl₃ at 298.15 K.



Figure S3. ¹H NMR spectrum of 9 in CDCl₃ at 298.15 K.



Figure S4. ¹³C NMR spectrum of 9 in CDCl₃ at 298.15 K.



Figure S5. ¹H NMR spectrum of 10 in CDCl₃ at 298.15 K.





Figure S6. ¹³C NMR spectrum of 10 in CDCl₃ at 298.15 K.



Figure S7. ¹H NMR spectrum of 11 in CDCl₃ at 298.15 K.



Figure S8. ¹³C NMR spectrum of 11 in CDCl₃ at 298.15 K.



Figure S9. ¹H NMR spectrum of (E)-1 in DMSO- d_6 at 298.15 K.





Figure S10. ¹³C NMR spectrum of (*E*)-1 in DMSO-*d*₆ at 298.15 K.



Figure S11. ¹H NMR spectrum of (Z)-1 in DMSO- d_6 at 298.15 K.



160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 f1 (ppm)

Figure S12. ¹³C NMR spectrum of (*Z*)-1 in DMSO-*d*₆ at 298.15 K.



Figure S13. ¹H NMR spectrum of (*E*)-2 in DMSO-*d*₆ at 298.15 K.



Figure S14. ¹³C NMR spectrum of (*E*)-2 in DMSO- d_6 at 298.15 K. Unmarked signals belong to Z isomer.



Figure S15. ¹H NMR spectrum of (Z)-2 in DMSO- d_6 at 298.15 K.



Figure S16. ¹³C NMR spectrum of (Z)-2 in DMSO- d_6 at 298.15 K. Unmarked signals belong to E isomer.



Figure S17. ¹H NMR spectrum of mixture of (*Z*)-**3** and (*E*)-**3** (2:1) in DMSO-*d*₆ at 298.15 K.



Figure S18. ¹³C NMR spectrum of mixture of (*Z*)-**3** and (*E*)-**3** (2:1) in DMSO-*d*₆ at 298.15 K.



Figure S19. ¹H NMR spectrum of (*E*)-3 in DMSO- d_6 at 298.15 K.



Figure S20. ¹H NMR spectrum of (*Z*)-**3** in DMSO-*d*₆ at 298.15 K.



Figure S21. ¹H NMR spectrum of (*E*)-**3** in CDCl₃ at 298.15 K.

2 Photochemical Study

Electronic absorption spectra were obtained on an Agilent 8453 diode array spectrophotometer (Hewlett Packard, USA). The solvents used were NMR-spectroscopy (DMSO- d_6 , benzene- d_6 , toluene- d_8 , CDCl₃; Eurisotop, France) and HPLC or UV-spectroscopy grade (benzene, for spectrophotometry, TCI, Japan; DMSO and DMF, Acros Organics, UK; toluene, MeOH and MeCN, LiChrosolv[®], Merck, Germany) and were used without further purification. Solution fluorescence was measured in a 1 cm cuvette with FSP 920 (Edinburgh Instruments, UK) spectrofluorimeter in a right-angle arrangement. The fluorescent quantum yield (Φ_F) of the compounds studied in solution was determined by equations (1) and (2) using an integrating sphere (Edinburgh Instruments):

$$\Phi_F^X = \frac{L_{Sam}}{E_{Ref} - E_{Sam}} (\%) \tag{1}$$

corrected to re-absorption by:

$$\Phi_F = \frac{\Phi_F^2}{1 - a + a\Phi_F^X/100} \,(\%) \tag{2}$$

where L_{Sam} is the area under the detected spectrum in the part of the spectrum where sample emission occurs, E_{Ref} is area under the reflection part of the detected spectrum using the pure solvent as reference material (diffuse reflectance), E_{Sam} is area under the reflection part of the detected spectrum after absorption by the sample and *a* is the reabsorbed area. Transient absorption spectra were measured on a Flash photolysis LP980-Spectrometer (Edinburgh Instruments; $\lambda_{exc} = 355 \text{ nm} - \text{Nd/YAG}$ laser).

All quantitative photochemical measurements were performed at 25°C in the dark, with either UV-glass window 340 nm or epoxy-encased 405 nm LED diodes (LED341W and LED405E; Thorlabs; Figs. SXA and SXB) as light sources with optical power of P=0.33 mW and P=10 mW, respectively. Photochemical measurements were performed using the apparatus described elsewhere (Fig.7 in reference [4]) without ultrasonic horn H and lens L1 and using a Thorlabs PM16-140 - USB Power Meter (Integrating Sphere Sensor, FC Fiber Adapter, Si, 350 - 1100 nm, 500 mW Max) or an Ocean Optics HR4000CG-UV-NIR spectrophotometer (for the wavelength of 341 nm) for initial and transmitted light intensity determination. The light sources were three 340 nm or four 405 nm LED diodes Thorlabs with overall incident photon flux $I_0=1.32\pm0.02\times10^{-6}$ mol s⁻¹ dm⁻³ and $I_0=4.2\pm0.2\times10^{-5}$ mol s⁻¹ dm⁻³, respectively. The actual concentration of the corresponding isomer in freshly prepared air-saturated solutions during irradiation in a 1 cm quartz fluorescence cuvette were measured spectrophotometrically (based on previously determined extinction coefficients of pure isomers) in right-angle arrangement (Agilent 8453; no interference with the irradiation LED light beam was observed). The photostationary state composition was determined from UV-Vis spectrum.



Fig. SXA. Typical spectral intensity distribution of used 340 nm LED diode with UV-glass window (LED341W; Thorlabs).



Fig. SXB. Typical spectral and radial intensity distribution of used 405 nm epoxy-encased LED diode (LED405E; Thorlabs).

Ultrafast UV-Vis kinetic measurements were measured on a Thermo Scientific Evolution Array UV-Visible Spectrophotometer (Thermo Fisher Scientific, USA). Irradiation of solution was carried out using 100W UV LED module (ProLight Opto, Taiwan; 33.2mm(L) x 35mm(W); Figs. SXC and SXD) and homemade cuvette holder (allowing simultaneous absorbance measurement and perpendicular irradiation of solution) in a right-angle arrangement.



Fig. SXC. Relative spectral power distribution of used 100W UV LED module (ProLight Opto, Taiwan; 33.2mm(L) x 35mm(W)).



Fig. SXD. Typical representative spatial radiation pattern of used 100W UV LED module (ProLight Opto, Taiwan; 33.2mm(L) x 35mm(W)).

2.1 Photoisomerization Quantum Yields

Determination of photochemical quantum yields

The *E*-to-*Z* photoisomerization quantum yields (Φ_{E-Z}) of the pyridyl hydrazones **1–3** were determined by equation (S1) at low *E*-to-*Z* conversion (to eliminate the effect of *Z*-to-*E* photoisomerization) [5]:

$$\phi_{E-Z} = \frac{\int_{0}^{t} dc}{\int_{0}^{t} I_{a} dt} = \frac{\Delta c}{\int_{0}^{t} I_{a} dt}$$
(S1)

where: Δc is the concentration change in *E*-isomer, I_a is light intensity absorbed by the *E*-isomer at the irradiation wavelength λ using a monochromatic light source, and *t* is the irradiation time. Because extinction coefficients of both isomers are known and their absorption maxima are sufficiently separated, the concentration change Δc can be easily determined spectrophotometrically.

Similarly, the *Z*-to-*E* photoisomerization quantum yield (Φ_{Z-E}) of the pyridyl hydrazones **1–3** was determined by equation (S2) at low *Z*-to-*E* photoconversion (to eliminate the effect of *E*-to-*Z* photoisomerization):

$$\phi_{Z-E} = \frac{\int_{c_0}^{c_t} dc}{\int_{0}^{t} I_a dt} = \frac{\Delta c}{\int_{0}^{t} I_a dt}$$
(S2)

where: Δc is the concentration change in Z-isomer, I_a is light intensity absorbed by the Z-isomer at the irradiation wavelength λ using a monochromatic light source, and t is the irradiation time. The concentration change Δc was determined spectrophotometrically.

The absorbed light intensity I_a during the mutual *E*-to-*Z* and *Z*-to-*E* isomerization at the corresponding irradiation wavelengths λ was determined using a Thorlabs PM16-140 - USB Power Meter (Integrating Sphere Sensor, FC Fiber Adapter, Si, 350 - 1100 nm, 500 mW Max) or an Ocean Optics HR4000CG-UV-NIR spectrophotometer (for the wavelength of 341 nm) by Eq. (S3):

$$I_{a\lambda} = I_{0\lambda} - I_{T\lambda} \tag{S3}$$

The incident light intensity $I_{0 \ 340}$ at 340 nm was determined by ferrioxalate (FE) actinometry (Fig. SXEA), according to Eq. (S4) [6] under the total light absorption conditions:

$$I_{0 340} = I_{a, FE 340} = \left(\frac{dA_{FE 390}}{dt}\right) \frac{1}{\Phi_{FE 340} \cdot \varepsilon_{FE 390} \cdot l},$$
 (S4)

where: $I_{a,FE340}$ is ferrioxalate actinometer absorbed light intensity (photon flux in mol s⁻¹ dm⁻³), $A_{FE 390}$ is ferrioxalate absorbance at 390, $\varepsilon_{FE 390}$ is ferrioxalate molar extinction coefficient at 390 nm, $\Phi_{FE 340}$ is quantum yield of ferrioxalate photochemical conversion at 340 nm and *l* is the path length. Ferrioxalate absorbance at 340 nm was controlled by the Ocean Optics HR4000CG-UV-NIR spectrophotometer.

The incident light intensity $I_{0 \ 405}$ at 405 nm was determined by ferrioxalate (FE) actinometry (Fig. SXEB), according to Eq. (S5) [6]:

$$I_{0\,405} = \frac{I_{a, FE\,405}}{1 - 10^{-A_{FE}\,405}} = \frac{\left(\frac{dA_{FE\,390}}{dt}\right)\frac{1}{\varPhi_{FE\,405} \cdot \varepsilon_{FE\,390} \cdot t}}{1 - 10^{-A_{FE}\,405}}$$
(S5)

,

where: $I_{a,FE465}$ is ferrioxalate actinometer absorbed light intensity (photon flux in mol s⁻¹ dm⁻³), $A_{FE 390}$ is ferrioxalate absorbance at 390 nm, $A_{FE 405}$ is ferrioxalate absorbance at 405 using the 405 nm Thorlabs LED light source, ε_{FE390} is ferrioxalate molar extinction coefficient at 390 nm, Φ_{FE405} is quantum yield of ferrioxalate photochemical conversion at 405 nm and *l* is the path length. Ferrioxalate absorbance at 405 nm (A_{FE405}) was measured by the Thorlabs PM16-140 - USB Power Meter.



Fig. SXE. Decrease in absorbance of ferrioxalate (FE) actinometer solution at 390 nm in 0.05 mol dm⁻³ H_2SO_4 during irradiation with light of 340 (A) and 405 (B) nm wavelength, respectively (three LED341W and four LED405E diodes Thorlabs with individual optical power of *P*=0.33 mW and *P*=10 mW, respectively).

Determined $I_{0 340}=1.32\pm0.02\times10^{-6}$ mol s⁻¹ dm⁻³ and $I_{0 405}=4.2\pm0.2\times10^{-5}$ mol s⁻¹ dm⁻³ are in good agreement with the theoretical values of $I_{0 340}=0.8\times10^{-6}$ mol s⁻¹ dm⁻³ and $I_{0 405}=3.9\times10^{-5}$ mol s⁻¹ dm⁻³, respectively, calculated from the manufacturer's incident optical power input of 0.99 mW (three LED diodes Thorlabs LED341W) and 40 mW (four epoxy-encased LED diodes Thorlabs LED405E) to cuvette volume of 3.5 mL.

2.2 Calculated UV-Vis Spectra

Table S1. Calculated and experimentally determined $\Delta \lambda_A$ values (difference between absorption maximum of *E* and corresponding *Z* isomer) of the studied benzoylpyridine hydrazones **1**, **2** and **3** (TD-cam-B3LYP/6-311+G(2d,p)//cam-B3LYP/6-31+G(2d,p) level; benzene).

Hydrazone	$\Delta \lambda_{ m A \ Exp}$	$\Delta \lambda_{ m A \ Calc}$
Trydrazone	[nm]	[nm]
1	(354-324)= 30	(387-348)= 39
2	(364-326)= 38	(400-353)= 47
3	(360-316) = 44	(405-338) = 67



Figure S22. Calculated and experimentally determined $\Delta \lambda_A$ values (difference between absorption maximum of *E* and corresponding *Z* isomer) of the studied benzoylpyridine hydrazones **1**, **2** and **3** (TD-cam-B3LYP/6-311+G(2d,p)//cam-B3LYP/6-31+G(2d,p) level; benzene).



Figure S23. UV-Vis absorption spectra in of hydrazone 1 in benzene.



Figure S24. UV-Vis absorption spectra in of hydrazone 2 in benzene.



Figure S25. UV-Vis absorption spectra in of hydrazone 3 in benzene.

2.3 Photochromic Behaviour



Figure S26. UV-Vis absorption spectra of (*E*)-1 and (*Z*)-1 (5×10^{-5} M) with their PSS states in benzene. PSS₃₄₁ _{nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 45 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 30 min.



Figure S27. UV-Vis absorption spectra of (*E*)-1 and (*Z*)-1 (5×10^{-5} M) with their PSS states in CH₃CN. PSS₃₄₁ _{nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 80 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 70 min.



Figure S28. UV-Vis absorption spectra of (*E*)-1 and (*Z*)-1 (5×10^{-5} M) with their PSS states in DMF. PSS_{341 nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 50 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 40 min.



Figure S29. UV-Vis absorption spectra of (*E*)-1 and (*Z*)-1 (5×10^{-5} M) with their PSS states in MeOH. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 1 hod. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 20 min.



Figure S30. UV-Vis absorption spectra of (*E*)-2 and (*Z*)-2 (5×10^{-5} M) with their PSS states in benzene. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 20 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 1 h.



Figure S31. UV-Vis absorption spectra of (*E*)-**2** and (*Z*)-**2** (5×10^{-5} M) with their PSS states in CH₃CN. PSS₃₄₁ _{nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 30 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 30 min.



Figure S32. UV-Vis absorption spectra of (*E*)-**2** and (*Z*)-**2** (5×10^{-5} M) with their PSS states in DMF. PSS_{341 nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 20 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 15 min.



Figure S33. UV-Vis absorption spectra of (*E*)-**2** and (*Z*)-**2** (5×10^{-5} M) with their PSS states in MeOH. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 20 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 15 min.



Figure S34. UV-Vis absorption spectra of (*E*)-**3** and (*Z*)-**3** (5×10^{-5} M) with their PSS states in benzene. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 30 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 10 min.



Figure S35. UV-Vis absorption spectra of (*E*)-**3** and (*Z*)-**3** (5×10^{-5} M) with their PSS states in CH₃CN. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 1 h. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 16 min.



Figure S36. UV-Vis absorption spectra of (*E*)-**3** and (*Z*)-**3** (5×10^{-5} M) with their PSS states in DMF. PSS_{341 nm} UV-Vis spectrum was obtained upon 341 nm light irradiation for 45 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 12 min.



Figure S37. UV-Vis absorption spectra of (*E*)-**3** and (*Z*)-**3** (1.5×10^{-5} M) with their PSS states in MeOH. PSS₃₄₁ nm UV-Vis spectrum was obtained upon 341 nm light irradiation for 35 min. PSS_{405 nm} UV-Vis spectrum was obtained upon 405 nm light irradiation for 15 min.



Scheme S1. Rotor and stator parts of the studied benzoylpyridine hydrazones 1, 2 and 3.

2.4 Nanosecond Flash Photolysis



Figure S38. Transient absorption spectrum of (*E*)-**2** in benzene (A), transient absorption spectrum of (*Z*)-**2** in benzene (B) ($\lambda_{exc} = 355$ nm; 1 cm cuvette; T = 298.15 K).



Figure S39. Transient absorption spectrum of (*E*)-**3** in benzene (A) and transient absorption spectrum of (*Z*)-**3** in benzene (B) ($\lambda_{exc} = 355$ nm; 1 cm cuvette; T = 298.15 K).
2.5 Infrared Spectroscopy

The IR spectra were recorded using a Thermo Nicolet Magna IR-560 FT-IR (DTGS detector, 128 scans). The evolution of the peaks is built measuring the absorbance of the band in respect to the baseline.



Figure S40. Evolution of two IR bands (1254 cm⁻¹ and 3335 cm⁻¹) for (*E*)-1 in a n-hexane solution at different illumination times (0, 2, 5, 15, 23 and 28 minutes) at 311 nm.



Figure S41. Normalised intensity of the two IR bands (1254 cm⁻¹ and 3335 cm⁻¹) for (*E*)-1 in a n-hexane solution at different illumination times (0, 2, 5, 15, 23 and 28 minutes) at 311 nm. The starting point is pure (*E*)-1.



Figure S42. IR spectra in the 1000 - 1600 cm⁻¹ spectral region of (*E*)-1 and (*Z*)-1 recorded on a ZnSe substrate.

2.6 Photoswitching Cycles



Figure S43. Photoswitching Cycles during Altered Irradiation of the Hydrazone 1 Photochromic System with Light of 341 nm and 405 nm Wavelength in Benzene (T = 298.15 K).



Figure S44. Photoswitching Cycles during Altered Irradiation of the Hydrazone **2** Photochromic System with Light of 341 nm and 405 nm Wavelength in Benzene (T = 298.15 K).



Figure S45. Photo of photoswitching cycles of **3** in benzene snapped directly from the Agilent 8453 UV-Vis spectrophotometer software.

3 Thermal Kinetics Study



Scheme S2. Scheme of heat (thermally) induced *E*-to-*Z* isomerization of studied benzoylpyridine hydrazones with highlighted protons those intensities were compared.

Activation parameters for the thermal isomerization of the benzoylpyridine hydrazones (*E*)-5, (*E*)-6 and (*E*)-7 were determined from an Arrhenius (the logarithm of a reaction rate constant plotted against inverse temperature) or an Eyring plot (the Eyring–Polanyi equation) at three different temperatures (due to time-consuming experiments). At a given temperature, the rate constant at two other measured temperatures was calculated to obtain the corresponding activation energy (or Gibbs free energy). The arithmetical average of three activation energy (or Gibbs free energy) values obtained from three data sets at three different temperatures gave reasonable activation energy (or Gibbs free energy) value that nicely agrees with experimentally observed half-lives for the *E*-to-*Z* isomerization of the less stable *E*-isomers.

Corresponding rate constants for thermally initiated *E*-to-*Z* isomerization (k_1) and back thermal *Z*-to-*E* isomerization (k_2) were determined from non-linear fitting of equilibrium kinetics between two isomers, according to Eq. (S6) [7]:

$$E \stackrel{k_1}{\rightleftharpoons} Z_{k_2}$$

$$y = \left(S_0 / (k_1 + k_2)\right) \left(k_2 + k_1 \exp - (k_1 + k_2)t\right).$$
(S6)

where: S_0 is the *E* isomer concentration in % and *t* is the time. The *E* isomer concentration was determined using UV-Vis (extinction coefficients of pure isomers were known) or ¹H NMR spectroscopy (based on relative concentration estimated from integral intensity of pyridine hydrogen of both isomers in ¹H NMR experiments – Scheme S2; red protons). In the case of pyridine hydrogen signal overlap (only for (*E*)-**2** in toluene-*d*₈), the relative concentration of the isomers was determined from integral intensity of the most acidic NH hydrogens (Scheme S2; blue protons).



Figure S46. Thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 at 343.15 K. The plot is the decreasing concentration of (E)-1 as a function of time.



Figure S47. Thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 at 348.15 K. The plot is the decreasing concentration of (E)-1 as a function of time.



Figure S48. Thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 at 353.15 K. The plot is the decreasing concentration of (E)-1 as a function of time.



Figure S49. Thermal isomerization of (Z)-1 \rightarrow (E)-1 in DMSO- d_6 at 353.15 K. The plot is the decreasing concentration of (Z)-1 as a function of time.



Figure S50. Arrhenius plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 (343.15 K).



Figure S51. Eyring plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 (343.15 K).



Figure S52. Arrhenius plot of the thermal isomerization of (*E*)-1 \rightarrow (*Z*)-1 in DMSO-*d*₆(348.15 K).



Figure S53. Eyring plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 (348.15 K).



Figure S54. Arrhenius plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 (353.15 K).



Figure S55. Eyring plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in DMSO- d_6 (353.15 K).



Figure S56. Arrhenius plot of the thermal isomerization of (Z)-1 \rightarrow (E)-1 in DMSO- d_6 for k_2 constant (353.15 K).



Figure S57. Eyring plot of the thermal isomerization of (*Z*)-1 \rightarrow (*E*)-1 in DMSO-*d*₆ for *k*₂ constant (353.15 K).



Figure S58. Thermal isomerization of (E)-1 \rightarrow (Z)-1 in toluene- d_8 at 353.15 K. The plot is the decreasing concentration of (E)-1 as a function of time.



Figure S59. Thermal isomerization of (Z)-1 \rightarrow (E)-1 in toluene- d_8 at 353.15 K. The plot is the decreasing concentration of (Z)-1 as a function of time.



Figure S60. Arrhenius plot of the thermal isomerization of (E)-1 \rightarrow (Z)-1 in toluene- d_8 (353.15 K).



Figure S61. Eyring plot of the thermal isomerization of (Z)-1 $\rightarrow (E)$ -1 in toluene- d_8 (353.15 K).



Figure S62. Arrhenius plot of the thermal isomerization of (*Z*)-1 \rightarrow (*E*)-1 in toluene-*d*₈ for *k*₂ constant (353.15 K).



Figure S63. Eyring plot of the thermal isomerization of (*Z*)-1 \rightarrow (*E*)-1 in toluene-*d*₈ for *k*₂ constant (353.15 K).



Figure S64. Thermal isomerization of (E)-2 \rightarrow (Z)-2 in DMSO- d_6 at 353.15 K. The plot is the decreasing concentration of (E)-2 as a function of time.



Figure S65. Thermal isomerization of (E)-2 \rightarrow (Z)-2 in toluene- d_8 at 353.15 K. The plot is the decreasing concentration of (E)-2 as a function of time.



Figure S66. Arrhenius plot of the thermal isomerization of (E)-2 \rightarrow (Z)-2 in DMSO- d_6 at 353.15 K.



Figure S67. Eyring plot of the thermal isomerization of (E)-2 \rightarrow (Z)-2 in DMSO- d_6 at 353.15 K.



Figure S68. Arrhenius plot of the thermal isomerization of (E)-2 \rightarrow (Z)-2 in toluene- d_8 at 353.15 K.



Figure S69. Eyring plot of the thermal isomerization of (E)-2 \rightarrow (Z)-2 in toluene- d_8 at 353.15 K.



Figure S70. Thermal isomerization of (E)-**3** \rightarrow (Z)-**3** in toluene- d_8 at 353.15 K. The plot is the decreasing concentration of (E)-**3** as a function of time.



Figure S71. Arrhenius plot of the thermal isomerization of (E)-**3** \rightarrow (Z)-**3** in toluene- d_{8} at 353.15 K.



Figure S72. Eyring plot of the thermal isomerization of (E)-**3** \rightarrow (Z)-**3** in toluene- d_8 at 353.15 K.

3.1 Thermal Kinetics Monitored by UV-Vis Spectroscopy

(related to **Table 4** in the main text)



Figure S73. Thermal isomerization of (*E*)-3 \rightarrow (*Z*)-3 (5×10⁻⁵ M) in DMSO at 333.15 K.



Figure S74. Thermal isomerization of (*E*)-3 \rightarrow (*Z*)-3 (1×10⁻⁴ M) in DMSO at 333.15 K.



Figure S75. Thermal isomerization of (*E*)-3 \rightarrow (*Z*)-3 (2×10⁻⁴ M) in DMSO at 333.15 K.



Figure S76. Thermal isomerization of (*E*)-3 \rightarrow (*Z*)-3 (3×10⁻⁴ M) in DMSO at 333.15 K.



Figure S77. Thermal isomerization of (*E*)-3 \rightarrow (*Z*)-3 (4×10⁻⁴ M) in DMSO at 333.15 K.



Figure S78. Thermal isomerization rate constant dependence on concentration of hydrazone (*E*)-3 in DMSO.



Figure S79. Activation energy dependence on concentration of (*E*)-3 in DMSO.



Figure S80. Dependence of activation Gibbs energy on concentration of (*E*)-3 in DMSO.



Figure S81. Thermal isomerization of (E)-3 \rightarrow (Z)-3 $(5 \times 10^{-5} \text{ M})$ in DMF at 353.15 K.



Figure S82. Thermal isomerization of (E)-3 \rightarrow (Z)-3 $(4 \times 10^{-4} \text{ M})$ in DMF at 353.15 K.



Figure S83. Thermal isomerization of (E)-3 \rightarrow (Z)-3 $(5 \times 10^{-5} \text{ M})$ in MeOH at 313.15 K.



Figure S84. Thermal isomerization of (E)-3 \rightarrow (Z)-3 $(2 \times 10^{-4} \text{ M})$ in MeOH at 313.15 K.

3.2 Transition State Geometry



Figure S85. Calculated geometries of transition state (TS) for mutual *E*-to-*Z* (*Z*-to-*E*) thermal isomerization of benzoylpyridine hydrazone 1 in vacuum at the cam-B3LYP/6-31+G(2d,p) level.



Figure S86. Calculated geometries of transition state (TS) for mutual *E*-to-*Z* (*Z*-to-*E*) thermal isomerization of benzoylpyridine hydrazone **2** in vacuum at the cam-B3LYP/6-31+G(2d,p) level.



Figure S87. Calculated geometries of transition state (TS) for mutual *E*-to-*Z* (*Z*-to-*E*) thermal isomerization of benzoylpyridine hydrazone **3** in vacuum at the cam-B3LYP/6-31+G(2d,p) level.

3.3 Thermodynamic Parameters of Thermal Isomerization

Compd	Т	Ratio of Isomers (Z:E)	K	$\Delta_{\rm r}G^0$ [kcal mol ⁻¹]
		DMSO- d_6		
(<i>E</i>)-1	343.15	66:34	1.94	-0.45
	348.15	69:31	2.23	-0.55
	353.15	71:29	2.45	-0.63
(Z)-1	353.15	70:30	0.43	0.59
		Toluene- d_8		
(<i>E</i>)-1	353.15	87:13	6.69	-1.33
(Z) -1	353.15	85:15	0.18	1.21
(E) -2	353.15	66:34	1.94	-0.46
(E) -3	353.15	92:8	11.50	-1.71

Table S2. Equilibrium constant (*K*) and Reaction Gibbs free energy ($\Delta_r G^0$) determined from the ratio of *E* and *Z* isomer in solution at equilibrium.

3.4 Acid-base Switching



Figure S88. UV-Vis spectrum of (Z)-1 in DMSO after addition of CF₃COOH (12 µl to 3 ml) at 298.15 K.



Figure S89. UV-Vis spectrum of (Z)-3 in DMSO after addition of CF_3COOH (12 µl to 3 ml) at 298.15 K.



Figure S90. UV-Vis spectra of (*E*)-1, (*Z*)-1, (*E*)-1H⁺ (24 µl to 3 ml) in DMSO at 298.15 K.



Figure S91. UV-Vis spectra of (*E*)-3, (*Z*)-3, (*E*)-3H⁺ (24 µl to 3 ml) in toluene at 298.15 K.



Figure S92. UV-Vis spectra of (*E*)-1, (*Z*)-1, (*E*)-1H⁺ (24 µl to 3 ml) in toluene at 298.15 K.



Figure S93. ¹H NOESY spectrum of (*E*)-1 in DMSO-*d*₆ after addition of excess of CF₃COOH at 298.15 K.



Figure S94. UV-Vis spectrum of (*E*)-**3** in DMSO after addition of CF₃COOH (12 μ l to 3 ml) at 298.15 K. The mixture was than threated by Et₃N (12 μ l and 24 μ l, respectively, to 3 ml) to restore *E* form of hydrazone.



Figure S95. UV-Vis spectrum of (*E*)-1 in DMSO after addition of CF₃COOH (24 μ l to 3 ml) at 298.15 K. The mixture was than threated by Et₃N (24 μ l to 3 ml) to restore *E* form of hydrazone.



Figure S96. UV-Vis spectrum of (*E*)-1 in toluene after addition of Et_3N (24 µl to 3 ml) at 298.15 K.



Figure S97. UV-Vis spectrum of (*E*)-**3** in toluene after addition of Et_3N (24 µl to 3 ml) at 298.15 K.



Figure S98. UV-Vis spectrum of (*E*)-1 in DMSO after addition of Et_3N (24 µl to 3 ml) at 298.15 K.



Figure S99. UV-Vis spectrum of (*E*)-**3** in DMSO after addition of Et_3N (12 µl and 24 µl, respectively, to 3 ml) at 298.15 K.



Figure S100. Array of 1H NMR of benzoylpyridine hydrazone (*E*)-1 in DMSO-*d*₆ at 353.15 K.



Figure S101. Array of 1H NMR of benzoylpyridine hydrazone (*E*)-2 in DMSO-*d*₆ at 353.15 K.


Scheme S3. Proposed mechanism of gradual proton signal appearance in ¹H NMR spectra of (*E*)-1 and (*E*)-2 at approximately 10 ppm (corresponding to hydrazone -C=N-N-H hydrogen of E-H⁺ form) with increasing time during the thermal isomerization of the (*E*)-1 and (*E*)-2 isomers in highly polar DMSO-*d*₆.

3.5 pK_a Constant Determination

Experimental pK_a values were obtained through pH-spectrophotometric titrations in a DMF:buffer solution mixture (9:1 v/v; Figures S102-S104).

GENERAL PROCEDURE:

Benzoylpyridine hydrazones were dissolved in DMF (to obtain 1×10^{-4} mol dm⁻³ overall hydrazone concentrations) at 298.15 K. A buffer solution (Britton-Robinson, universal buffer solution I, 0.3 mL) with adjusted pH was then added to 2.7 mL of hydrazone solution. The pH of buffer solutions was measured with Laboratory pH Meter WTW inoLab 720.

Britton-Robinson buffer solution consists of a mixture of 0.04 M H_3BO_3 , 0.04 M H_3PO_4 and 0.04 M AcOH (M = mol dm⁻³ = mol L⁻¹). Desired pH was adjusted by titration with 0.2 M NaOH.

Table S3. The pK_a values of the studied benzoylpyridine hydrazone *E* isomers (*E*)-1, (*E*)-2 and (*E*)-3.

Hydrazone	pK _a
(E) -1	11.63 ± 0.15
(E)- 2	> 12.00 ^a
(E) -3	9.36 ± 0.02

^a – the exact value of pK_a cannot be determined by sigmoidal fitting in this case due to large fitting error.



Figure S102. Evolution of absorbance at 350 nm and 470 nm for benzoylpyridine hydrazone 1 in DMF:buffer solution mixture (9/1 v/v; T = 298.15 K).



Figure S103. Evolution of absorbance at 300 nm and 480 nm for benzoylpyridine hydrazone **2** in DMF:buffer solution mixture (9/1 v/v; T = 298.15 K). Unfortunately, the exact value of pK_a cannot be determined by sigmoidal fitting in this case due to large fitting error.



Figure S104. Evolution of absorbance at 350 nm and 410 nm for benzoylpyridine hydrazone **3** in DMF:buffer solution mixture (9/1 v/v; T = 298.15 K).

3.6 Mechanism of Thermally Initiated *E-Z* Isomerization of 3 in DMSO



Scheme S4. One of the possible isomerization mechanisms of (E)-3 in highly polar DMSO based on association of the (E)-3 molecules.



Figure S105. ¹H NMR spectra of benzoylpyridine hydrazone **3** in DMSO- d_6 after trifluoroacetic acid (CF₃COOH; excess) and tetrabutylammonium hydroxide (TBA⁺OH⁻, excess) addition (T = 298.15 K).



Figure S106. Time-dependent Concentration Changes of the Benzoylpyridine Hydrazone (*E*)-**3** during its Thermal *E*-to-Z Isomerization in MeCN- d_3 at Different Initial *E* isomer concentration (*T* = 333.15 K).

3.7 Addition of Et₃N



In DMSO

Figure S107. UV-Vis kinetic measurement of the (E)-**3** + Et₃N photochromic system in DMSO during and after the 400 nm excitation (100W UV LED module ProLight Opto; T = 298.15 K); (A) 10 µL addition of Et₃N to 3 mL of (E)-**3** solution, (B) 130 µL addition of Et₃N to 3 mL of (E)-**3** solution.



Figure S108. UV-Vis spectra benzoylpyridine hydrazone **3** in DMF:buffer solution mixture (9/1 v/v; T = 298.15 K).

In DMF



Figure S109. UV-Vis kinetic measurement of the (E)-**3** + Et₃N photochromic system in DMF during and after the 400 nm excitation (100W UV LED module ProLight Opto; T = 298.15 K); (A) 20 µL addition of Et₃N to 3 mL of (*E*)-**3** solution, (B) 500 µL addition of Et₃N to 3 mL of (*E*)-**3** solution.

In MeCN



Figure S110. UV-Vis kinetic measurement of the (E)-**3** + Et₃N photochromic system in MeCN during and after the 400 nm excitation (100W UV LED module ProLight Opto; T = 298.15 K); (A) 80 µL addition of Et₃N to 3 mL of (*E*)-**3** solution, (B) 500 µL addition of Et₃N to 3 mL of (*E*)-**3** solution.

In MeOH



Figure S111. UV-Vis kinetic measurement of the (E)-**3** + Et₃N photochromic system in MeOH during and after the 400 nm excitation (100W UV LED module ProLight Opto; T = 298.15 K); (A) 20 µL addition of Et₃N to 3 mL of (E)-**3** solution, (B) 500 µL addition of Et₃N to 3 mL of (E)-**3** solution.

4 Quantum-chemical Calculations

The relative stabilities of benzoyl-pyridine hydrazones **1-3** were investigated using quantum-chemical calculations at the cam-B3LYP/6-31+G(2d,p) in vacuum. Stationary points were characterized as minima by computation of harmonic vibrational frequencies. All calculations were performed by Gaussian 16 program package [8].

Computational details

Cartesian coordinates and electronic (E) and free (G) energies (atomic units).

Hydrazone 1

	(E)-1 isomer				(Z)-1 isome	r	
С	1.8614580	-1.1895860	-0.0183000	С	-1.2529600	1.3664180	0.0282380
С	3.1901830	-0.8188350	-0.2430970	С	-2.5722030	1.6681070	0.3971770
С	4.1715910	-1.7984000	-0.2626560	С	-2.9744450	2.9883060	0.4686580
С	3.8056450	-3.1185090	-0.0557780	С	-2.0623860	3.9938890	0.1709630
С	2.4588160	-3.3904960	0.1631680	С	-0.7747430	3.6161810	-0.1679480
н	3.4476070	0.2199440	-0.4059170	Н	-3.2624650	0.8702240	0.6332500
н	5.2077020	-1.5295370	-0.4392750	Н	-3.9911550	3.2320150	0.7578400
н	4.5350550	-3.9198700	-0.0596190	Н	-2.3357330	5.0413600	0.2094950
н	2.1280820	-4.4124420	0.3338950	Н	-0.0203570	4.3647120	-0.3947220
Ν	-0.4292920	-0.5688810	-0.0155600	Ν	0.4550810	-0.4225900	-0.0360060
Ν	1.5114410	-2.4647860	0.1850820	Ν	-0.3740910	2.3489670	-0.2347740
Ν	-1.4263530	0.3103040	0.0071630	Ν	1.4703610	0.4244840	-0.0439990
н	-1.2300070	1.3041240	0.0444560	Н	1.2619810	1.4167630	-0.1515110
С	0.7891780	-0.1643560	-0.0065020	С	-0.7795780	-0.0347300	-0.0298520
С	1.1539530	1.2851230	0.0113820	С	-1.7710620	-1.1483850	-0.0365820
С	1.0390000	2.0589620	-1.1445260	С	-2.8199620	-1.1812720	-0.9572330
С	1.5860670	1.8938170	1.1901660	С	-1.6331110	-2.2125700	0.8546420
С	1.3591340	3.4116040	-1.1247360	С	-3.7082500	-2.2485300	-0.9850030
н	0.7036620	1.5928650	-2.0656980	Н	-2.9319690	-0.3726150	-1.6722310
С	1.9043180	3.2461930	1.2115510	С	-2.5214830	-3.2795660	0.8302800
н	1.6754210	1.2998920	2.0939780	Н	-0.8156040	-2.1962630	1.5663140
С	1.7925320	4.0074240	0.0537050	С	-3.5639560	-3.3009260	-0.0885940
н	1.2710470	3.9993030	-2.0321170	Н	-4.5105970	-2.2610930	-1.7150800
н	2.2401470	3.7058370	2.1348130	Н	-2.3992270	-4.0965790	1.5334720
н	2.0427560	5.0626220	0.0699240	Н	-4.2583790	-4.1338790	-0.1083210
С	-2.7540520	-0.1107020	0.0090740	С	2.7814430	-0.0440280	-0.0393070
С	-3.7604440	0.8562420	0.0370680	С	3.8164530	0.8932090	-0.0727010
С	-3.0938290	-1.4634680	-0.0176460	С	3.0861390	-1.4050310	0.0007180
С	-5.0932900	0.4732240	0.0388790	С	5.1377290	0.4734900	-0.0673650
н	-3.4956400	1.9094870	0.0586670	Н	3.5791040	1.9522850	-0.1014760
С	-4.4320430	-1.8297890	-0.0157950	С	4.4132570	-1.8099400	0.0059050
Е	-858.755043 H	artree			E	-858.762760 Hartree	
G	-858.511813 H	artree			G	-858.516774 Hartree	

Hydrazone **2**

	(E)-2 isomer				(<i>Z</i>)-2 isomer		
С	0.3635820	2.5106220	-0.0411180	С	0.4815680	2.0601460	0.0596290
С	-0.8273630	3.1819020	-0.3339050	С	-0.5395220	2.9346020	0.4603720
С	-0.8336720	4.5679170	-0.3629020	С	-0.2792740	4.2884460	0.5560410
С	0.3429140	5.2499260	-0.0960490	С	0.9918690	4.7596160	0.2494040
С	1.4767100	4.4966870	0.1901320	С	1.9499860	3.8323440	-0.1218740
Н	-1.7296400	2.6214840	-0.5425440	Н	-1.5179860	2.5434170	0.7017040
Н	-1.7476420	5.1053320	-0.5933110	Н	-1.0610570	4.9717090	0.8704490
н	0.3890500	6.3325960	-0.1038810	Н	1.2388170	5.8128810	0.3056630
н	2.4202280	4.9909070	0.4106950	Н	2.9630030	4.1478900	-0.3569210
Ν	1.5547680	0.4631910	-0.0315020	Ν	1.1527720	-0.3174470	-0.0534260
Ν	1.4966200	3.1720530	0.2216820	Ν	1.7131410	2.5259800	-0.2113280
Ν	1.6449630	-0.8645190	0.0023250	Ν	2.4489470	-0.0397930	-0.0480050
н	0.8039020	-1.4260700	0.0742220	Н	2.7280370	0.9354810	-0.1443740
С	0.4002160	1.0264720	-0.0217680	С	0.2413410	0.6007700	-0.0270390
С	-0.8775200	0.2566790	-0.0022610	С	-1.1560800	0.0884300	-0.0327300
С	-1.3114670	-0.4550900	-1.1202240	С	-2.1172700	0.5643660	-0.9227890
С	-1.6806310	0.2103390	1.1364570	С	-1.5415510	-0.9370100	0.8282230
С	-2.4919370	-1.1816260	-1.1099030	С	-3.4021980	0.0464200	-0.9584920
н	-0.7180170	-0.4318590	-2.0293820	Н	-1.8587430	1.3539790	-1.6216400
С	-2.8619280	-0.5123280	1.1665540	С	-2.8216600	-1.4655690	0.8094850
н	-1.3790510	0.7592500	2.0231920	Н	-0.8158450	-1.3300700	1.5317070
С	-3.2952650	-1.2413440	0.0434700	С	-3.7876420	-0.9952130	-0.0968710
н	-2.7844190	-1.7031570	-2.0108030	Н	-4.1015130	0.4529790	-1.6761920
н	-3.4464400	-0.5074670	2.0762030	н	-3.0634470	-2.2533730	1.5097180
С	2.8826080	-1.4989030	0.0261710	С	3.3885070	-1.0647180	-0.0642600
С	2.9179130	-2.8936200	0.0879140	С	4.7424750	-0.7202330	-0.0905250
С	4.0775010	-0.7788780	-0.0146930	С	3.0229810	-2.4117850	-0.0512780
С	4.1341790	-3.5594110	0.1090690	С	5.7143780	-1.7085750	-0.1048400
н	1.9883120	-3.4545820	0.1206300	Н	5.0278080	0.3273470	-0.0983310
С	5.2857050	-1.4604190	0.0063840	С	4.0072320	-3.3896520	-0.0652450
н	4.0399490	0.3015310	-0.0587080	Н	1.9736340	-2.6737550	-0.0360030
С	5.3286340	-2.8494080	0.0677920	С	5.3560780	-3.0521310	-0.0917620
н	4.1453770	-4.6432180	0.1582440	Н	6.7611950	-1.4239910	-0.1257710
Н	6.2096580	-0.8921530	-0.0247350	Н	3.7116380	-4.4338300	-0.0569010
Е	-992.662338 Hatree			Е	-992.668555 Hartree		
G	-992.351264 Hartree			G	-992.355014 Hartree		

Hydrazone **3**

	(E)-3 isomer			(Z)-3 isomer				
С	0.1253460	2.4895990	-0.0378520	С	0.3530520	2.0703030	0.0563360	
С	-1.0921650	3.0997440	-0.3502560	С	-0.6577290	2.9456730	0.4776110	
С	-1.1688810	4.4843990	-0.3677730	С	-0.3996940	4.3021760	0.5426670	
С	-0.0340170	5.2218920	-0.0723290	С	0.8590470	4.7717590	0.1882090	
С	1.1320010	4.5255320	0.2294610	С	1.8098320	3.8421020	-0.1963450	
н	-1.9629390	2.5007760	-0.5856950	н	-1.6269200	2.5599370	0.7624180	
н	-2.1041620	4.9764620	-0.6123670	н	-1.1732470	4.9875260	0.8718530	
н	-0.0433680	6.3053630	-0.0705710	н	1.1032050	5.8265470	0.2196530	
н	2.0446990	5.0648120	0.4715140	н	2.8142860	4.1567280	-0.4656430	
Ν	1.4242520	0.5013790	-0.0335020	Ν	1.0484870	-0.3047190	-0.0130620	
Ν	1.2182150	3.2034130	0.2517840	Ν	1.5745070	2.5337890	-0.2582180	
Ν	1.6008460	-0.8131670	-0.0057530	Ν	2.3338230	-0.0217220	-0.0504190	
н	0.8066540	-1.4397000	0.0579010	н	2.6020170	0.9550050	-0.1740230	
С	0.2458000	1.0105580	-0.0280570	С	0.1289990	0.6087350	0.0028370	
С	-0.9924960	0.1744880	-0.0135910	С	-1.2555370	0.0641670	0.0037560	
С	-1.3633290	-0.5610020	-1.1419140	С	-2.2408580	0.5773430	-0.8454220	
С	-1.7817650	0.0984860	1.1358100	С	-1.5775760	-1.0204380	0.8243140	
С	-2.5029750	-1.3518060	-1.1317600	С	-3.5126520	0.0299430	-0.8770930	
н	-0.7574300	-0.5037760	-2.0398230	н	-2.0049390	1.4018550	-1.5084610	
С	-2.9223200	-0.6892200	1.1631630	С	-2.8449100	-1.5773150	0.8070780	
н	-1.4993900	0.6653930	2.0159810	н	-0.8166420	-1.4260570	1.4794660	
С	-3.2632180	-1.4015300	0.0248250	С	-3.7977240	-1.0401050	-0.0442320	
н	-2.8085840	-1.9211480	-1.9992630	н	-4.2779940	0.4114710	-1.5393360	
н	-3.5446420	-0.7591460	2.0451520	н	-3.1057400	-2.4125400	1.4429900	
С	2.8832800	-1.3648280	0.0176610	С	3.2869850	-1.0407610	-0.0596090	
С	3.0084140	-2.7531890	0.0688510	С	4.6336600	-0.6780810	-0.1134250	
С	4.0242270	-0.5642570	-0.0126870	С	2.9351090	-2.3891600	-0.0145130	
С	4.2665840	-3.3365170	0.0901090	С	5.6172740	-1.6551730	-0.1229020	
н	2.1186620	-3.3759020	0.0932080	н	4.9055640	0.3724810	-0.1459340	
С	5.2755410	-1.1634010	0.0088260	С	3.9303120	-3.3560060	-0.0237840	
н	3.9150860	0.5115840	-0.0489110	н	1.8896780	-2.6645160	0.0210930	
С	5.4097770	-2.5467280	0.0597340	С	5.2737750	-3.0015080	-0.0774960	
н	4.3505670	-4.4172190	0.1308170	Н	6.6601500	-1.3597040	-0.1652920	
Н	6.1595780	-0.5348410	-0.0138100	н	3.6481370	-4.4031000	0.0095210	
Е	-1063.211414	Hartree			E	-1063.222163 Hartr	ee	
G	-1062.969093 Hartree				G	-1062.977285 Hartr	ee	

5 References

- [1] Catel, D.; Payen, O.; Chevallier, F.; Mongin, F.; Gros, P. C. *Tetrahedron* **2012**, *68*, 4018-4028.
- [2] Wittenberg, R.; Srogl, J.; Egi, M.; Liebeskind, L. S. Org. Lett., 2003, 5, 3033–3035.
- [3] Wang, X.; Wang, D. Z. *Tetrahedron* **2011**, *67*, 3406-3411.
- [4] A. Gáplovský, Š. Toma and J. Donovalová, J. Photochem. Photobiol. A Chem., 2007, 191, 162–166.
- [5] P. Klán and J. Wirz, *Photochemistry of organic compounds : from concepts to practice*, Wiley, 2009, p 114.
- [6] T. Lehóczki, É. Józsa and K. Ősz, J. Photochem. Photobiol. A Chem., 2013, 251, 63–68.
- [7] Atkins, P. and de Paula, J. Atkins' Physical Chemistry. 10th Edition, Oxford University Press., Oxford, 2014, p147-148.
- [8] Gaussian 16, Revision A.03, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, G. A. Petersson, H. Nakatsuji, X. Li, M. Caricato, A. V. Marenich, J. Bloino, B. G. Janesko, R. Gomperts, B. Mennucci, H. P. Hratchian, J. V. Ortiz, A. F. Izmaylov, J. L. Sonnenberg, D. Williams-Young, F. Ding, F. Lipparini, F. Egidi, J. Goings, B. Peng, A. Petrone, T. Henderson, D. Ranasinghe, V. G. Zakrzewski, J. Gao, N. Rega, G. Zheng, W. Liang, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, K. Throssell, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. J. Bearpark, J. J. Heyd, E. N. Brothers, K. N. Kudin, V. N. Staroverov, T. A. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. P. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, J. M. Millam, M. Klene, C. Adamo, R. Cammi, J. W. Ochterski, R. L. Martin, K. Morokuma, O. Farkas, J. B. Foresman, and D. J. Fox, Gaussian, Inc., Wallingford CT, 2016.