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Tin(IV) chloride mediated (3 + 2) annulation of *trans*-2-aroyl-3-styrylcyclopropane-1,1-dicarboxylates with nitriles: diastereoselective access to 5-vinyl-1-pyrroline derivatives†

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A tin(IV) chloride promoted (3 + 2) annulation of *trans*-2-aroyl-3-styrylcyclopropane-1,1-dicarboxylates with nitriles is reported. The transformation involves the Lewis acid assisted formation of 1,5-dipolar intermediates from the cyclopropane dicarboxylates and nitriles followed by cyclization. The reactions proceed in a highly diastereoselective manner and afford 5-vinyl-1-pyrroline derivatives in 60–88% yields.

Introduction

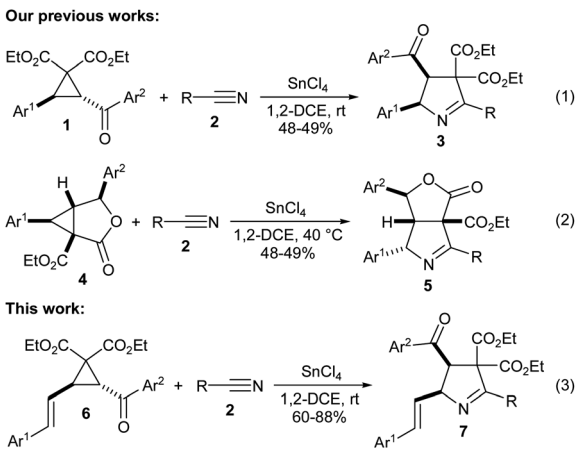
The annulation (formal cycloaddition) reactions of donor–acceptor (D–A) cyclopropanes are one of the efficient tools for the construction of various carbocyclic and heterocyclic compounds.[1] The merits of the methodology include excellent stereoselectivity, atom economy and formation of products in good yields with diverse functionality. Due to their merits, few of the methods have been employed as key steps in the total synthesis of various biologically important natural products.[2]

1-Pyrrolines are an important class of heterocyclic compounds as the core is present in a notable number of natural products and biologically relevant compounds.[3] They also serve as versatile synthetic intermediates for the access of pharmaceutically important compounds.[4] So numerous approaches have been developed for the synthesis of 1-pyrrolines.[5] The (3 + 2) annulation of D–A cyclopropanes with nitriles is a versatile strategy for the stereoselective synthesis of 1-pyrrolines.[6]

Few years back, we reported that aroyl substituted D–A cyclopropanes **1** undergo $SnCl_4$-promoted (3 + 2) annulation with nitriles **2** to give 1-pyrrolines **3** diastereoselectively (Scheme 1, eqn (1)).[7] Recently, we reported a similar approach for the access of γ-butyrolactone-fused 1-pyrrolines **5** from γ-butyrolactone-fused D–A cyclopropanes **4** (Scheme 1, eqn (2)).[8] Meanwhile, we have also synthesized and explored the synthetic potential of a similar class of aroyl substituted D–A cyclopropanes having aryl vinyl donor group, namely, *trans*-2-aroyl-3-styrylcyclopropane-1,1-dicarboxylates **6**.[9] Naturally, we became interested in exploring the (3 + 2) annulation of **6** with various nitriles with a view to obtain vinyl-substituted 1-pyrroline derivatives **7** (Scheme 1, eqn (3)). It is interesting to note that the vinyl pyrroline core is present in alkaloids isolated from the venom of the myrmicine ant *Megalomyrmex foreli* of Costa Rica.[10]

Results and discussion

To identify optimal reaction conditions for the (3 + 2) annulation of *trans*-2-aroyl-3-styrylcycyopropane-1,1-dicarboxylates with nitriles, we selected cyclopropane **6a** and benzonitrile (**2a**) as model substrates and reacted under the optimized conditions previously reported for similar D–A cyclopropanes **1** (Table 1, entry 1).[7] Accordingly, when 1 equiv. of **6a** was treated with 5 equiv. of **2a** in the presence of 1 equiv. of $SnCl_4$ in 1,2-dichloroethane (1,2-DCE) at room temperature for 12 h, the



Scheme 1 Comparison of the present work with our previous works.

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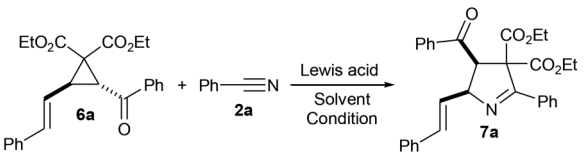
† Electronic supplementary information (ESI) available: Copies of ^1H and ^{13}C NMR spectra of all products and X-ray structural information of **8**. CCDC 2048692. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/d1ra01194d

Table 1 Optimization of the reaction conditions for the [3 + 2] annulation[a]



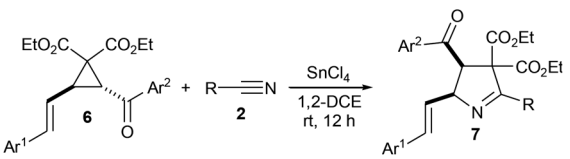
Entry	Reagents (equiv.) and conditions[a]	Yield of 7a[b] (%)
1	$SnCl_4$ (1.0), 1,2-DCE, rt, 12 h [using **2a** (5 equiv.)]	86
2	$SnCl_4$ (1.0), 1,2-DCE, rt, 12 h	86
3	$SnCl_4$ (0.2), 1,2-DCE, rt, 12 h	10
4	$SnCl_4$ (0.5), 1,2-DCE, rt, 12 h	58
5	$SnCl_4$ (1.5), 1,2-DCE, rt, 12 h	65
6	$SnCl_4$ (2.0), 1,2-DCE, rt, 12 h	62
7	$SnCl_4$ (1.0), 1,2-DCE, 0 °C, 12 h	55
8	$SnCl_4$ (1.0), 1,2-DCE, 60 °C, 12 h	46
9	$SnCl_4$ (1.0), CH_2Cl_2, rt, 12 h	30
10	$SnCl_4$ (1.0), $MeNO_2$, rt, 12 h	10
11	$SnCl_4$ (1.0), PhMe, rt, 12 h	30
12	$SnCl_4$ (1.0), THF, rt, 24 h	NR[c]
13	$SnCl_4 \cdot 5H_2O$ (1.0), 1,2-DCE, rt, 12 h	c.m.[d]
14	$SnCl_2$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
15	$AlCl_3$ (1.0), 1,2-DCE, rt, 12 h	70
16	$TiCl_4$ (1.0), 1,2-DCE, rt, 12 h	Trace
17	$BF_3 \cdot Et_2O$ (1.0), 1,2-DCE, rt, 12 h	—[e]
18	$InCl_3$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
19	$In(OTf)_3$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
20	$Cu(OTf)_2$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
21	$Sc(OTf)_3$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
22	$Yb(OTf)_3$ (1.0), 1,2-DCE, rt, 24 h	NR[c]
23	*p*-TsOH (1.0), 1,2-DCE, rt, 24 h	NR[c]

[a] The reaction was conducted with **1a** (1 equiv.), **2a** (2.5 equiv.), Lewis acid (*n* equiv.) and solvent (3 mL). [b] Isolated yield. [c] No reaction. [d] Complicated mixture of products. [e] **6a** underwent fragmentation to give cinnamaldehyde and phenacyl malonate.[9a]

expected vinyl 1-pyrroline product was produced in 86% yield (entry 1). Normally, an excess amount of nitrile (2.5 to 5 equiv.) was used in cyclopropane-nitrile annulations for achieving better yields.[6] In the present case, we observed that the use of 2.5 equiv. of **2a** was enough to obtain the same yield (entry 2). So, in the subsequent experiments, we used only 2.5 equiv. of **2a**. Next, we reduced the amount of $SnCl_4$ to 0.2 or 0.5 equiv., but the yield of **7a** was also decreased to 10 and 58%, respectively (entries 3 and 4). When the amount of $SnCl_4$ was increased to 1.5 or 2 equiv., again the yield of **6a** was decreased owing to the formation of more impurities (entries 5 and 6). The yield of **7a** also decreased when the reaction was carried out at 0 °C or 60 °C (entries 7 and 8). Switching the solvent to dichloromethane, nitromethane or toluene also gave only a lower yield of **7a** while the reaction did not take place in THF (entries 9–12). We also investigated the suitability of other tin sources for the transformation. When $SnCl_4 \cdot 5H_2O$ was used, the reaction gave a complicated mixture of products (entry 13) while the reaction did not take place with $SnCl_2$ (entry 14). We also tested other Lewis acids for the transformation. The use of $AlCl_3$ reduced the yield of **7a** to 70% while $TiCl_4$ gave only trace amount of **7a** (entries 15 and 16). Upon using $BF_3 \cdot OEt_2$, the cyclopropane **6a** did not react with **2a**; instead, it underwent fragmentation to give cinnamaldehyde and phenacyl malonate (entry 17).[9a] When other Lewis acids such as $InCl_3$, $In(OTf)_3$, $Cu(OTf)_2$, $Sc(OTf)_3$ and $Yb(OTf)_3$ were used, the transformation did not take place (entries 18–22). Also, the reaction did not work when a Bronsted acid, *viz.*, *p*-TSOH was used (entry 23). So we chose treating 1 equiv. of **6a** with 2.5 equiv. of **2a** in the presence of 1 equiv. of $SnCl_4$ in 1,2-DCE at room temperature as optimal condition for the formation of **7a** in a better yield.

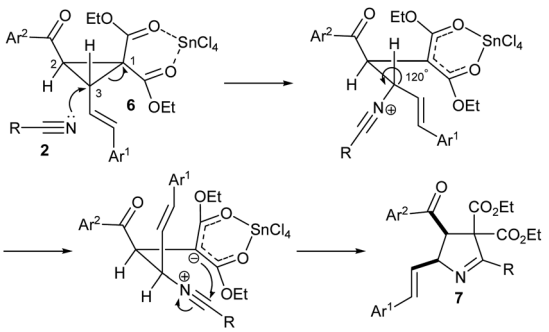
Next, we examined the scope of the transformation for various vinyl D–A cyclopropanes and ntriles and the results are summarized in Table 2. Initially, we tested the reactions of cyclopropane **6a** with aromatic nitriles **2a–d** having electron donating and electron withdrawing substituents on the aryl ring (entries 1–4). Except for the reaction in entry 4, in which the expected product was not detected, all other reactions afforded the corresponding 5-vinyl-1-pyrroline derivatives **7a–c** in 66–75% yields. When **6a** was reacted with nitriles **2e** and **2f** having bulky 1-naphthyl and heteroaromatic 2-thienyl rings, vinyl 1-pyrrolines **7d** and **7e** were formed in 76 and 80% yields, respectively (entries 5 and 6). We also reacted cyclopropane **6a** with an aliphatic nitrile, *viz.*, acetonitrile (**2g**) and obtained the corresponding 1-pyrroline derivative **7f** in 88% yield (entry 7). Next, we reacted cyclopropanes **6b–g** having different aromatic rings as Ar^1 or Ar^2 with benzonitrile (**2a**) and obtained the

Table 2 Scope of the reaction

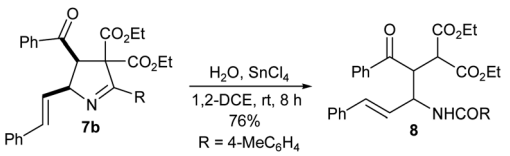


Entry	Ar^1, Ar^2	R	Yield of 7[a] (%)
1	Ph, Ph (**6a**)	Ph (**2a**)	86 (**7a**)
2	Ph, Ph (**6a**)	4-MeC_6H_4 (**2b**)	75 (**7b**)
3	Ph, Ph (**6a**)	4-$MeOC_6H_4$ (**2c**)	66 (**7c**)
4	Ph, Ph (**6a**)	4-$O_2NC_6H_4$ (**2d**)	n.d.[b]
5	Ph, Ph (**6a**)	1-Naphthyl (**2e**)	76 (**7d**)
6	Ph, Ph (**6a**)	2-Thienyl (**2f**)	80 (**7e**)
7	Ph, Ph (**6a**)	Me (**2g**)	88 (**7f**)
8	4-$MeOC_6H_4$, Ph (**6b**)	Ph (**2a**)	78 (**7g**)
9	2-Naphthyl, Ph (**6c**)	Ph (**2a**)	76 (**7h**)
10	2-Thienyl, Ph (**6d**)	Ph (**2a**)	72 (**7i**)
11	Ph, 4-MeC_6H_4 (**6e**)	Ph (**2a**)	69 (**7j**)
12	Ph, 4-$MeOC_6H_4$ (**6f**)	Ph (**2a**)	63 (**7k**)
13	Ph, 4-$O_2NC_6H_4$ (**6g**)	Ph (**2a**)	68 (**7l**)
14	4-MeC_6H_4, Ph (**6h**)	4-MeC_6H_4 (**2b**)	78 (**7m**)
15	4-MeC_6H_4, Ph (**6h**)	4-BrC_6H_4 (**2h**)	60 (**7n**)
16	4-MeC_6H_4, Ph (**6h**)	Me (**2g**)	80 (**7o**)
17	4-$O_2NC_6H_4$, Ph (**6i**)	2-Thienyl (**2f**)	65 (**7p**)
18	4-MeC_6H_4, 4-MeC_6H_4 (**6j**)	Me (**2g**)	86 (**7q**)

[a] Isolated yield. [b] Not detected.



Scheme 2 Mechanism for the formation of vinyl 1-pyrrolines 7.



Scheme 3 Synthetic application of a vinyl 1-pyrroline.

respective 1-pyrrolines **7g–l** in 63–78% yields (entries 8–13). Finally, we reacted various substrates having different Ar^1, Ar^2 or R groups and obtained the corresponding 1-pyrrolines **7m–q** in 60–86% yields (entries 14–18).

We propose a mechanism depicted in Scheme 2 for the formation of vinyl 1-pyrrolines **7** from D–A cyclopropanes **6** and nitriles **2** based on earlier reports.[7,8,11] Accordingly, the Lewis acid ($SnCl_4$) complexes with malonate unit of **6**, which facilitates the nucleophilic attack of **2** on **6** at the carbon (C-3) attached to vinyl unit. In the resulting 1,5-dipolar intermediate, the groups attached to C-3 undergo 120° rotation which brings the nitrile carbon and the malonate carbanion in close proximity for cyclization. It may be noted that the rotation also brings Ar^1 and Ar^2 groups to a *cis*-position. So the product 1-pyrroline **7** is formed in a diastereoselective manner.

The vinyl 1-pyrroline products synthesized in the present study could serve as potential synthetic precursors for other compounds. To prove the point, we treated vinyl 1-pyrroline **7b** with water in the presence of 1 equiv. of $SnCl_4$ in 1,2-DCE for 8 h. It underwent nucleophilic addition of water followed by ring-opening to furnish the multifunctional malonate **8** in 76% yield (Scheme 3; the structure of **8** was confirmed by X-ray analysis[12]).

Conclusions

In summary, we have developed a convenient method for the generation of vinyl 1-pyrroline derivatives from *trans*-2-aroyl-3-styrylcyclopropane-1,1-dicarboxylates and nitriles. The method involves a [3 + 2] annulation between the reactants and affords the products in good yields with excellent diastereoselectivity. The products could serve as potential precursors for other compounds as exemplified by the formation of a multifunctional malonate from one of the products.

Experimental section

General procedure for the synthesis of vinyl 1-pyrrolines 7

To a solution of 2-aroyl-3-styrylcyclopropane-1,1-dicarboxylate **6** (1.0 mmol) and nitrile **2** (2.5 mmol) in 1,2-dichloroethane (3 mL) was added $SnCl_4$ (1.0 mmol, 0.261 g) and the reaction mixture was stirred at room temperature. After completion of the reaction (12 h), the reaction mixture was quenched with water and extracted with dichloromethane. The organic layer was washed with brine (2 × 10 mL), dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography using EtOAc/hexane (1 : 9) to afford vinyl 1-pyrroline **7**.

Diethyl 4-benzoyl-2-phenyl-5-styryl-4,5-dihydropyrrole-3,3-dicarboxylate (7a)

Yellow oily liquid. Yield: 427 mg (86%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91 (d, J = 8.0 Hz, 4H), 7.62–7.38 (m, 10H), 7.14–7.02 (m, 3H), 6.37 (q, J = 16.0 Hz, 1H), 5.50 (t, J = 6.6 Hz, 1H), 5.01, (d, J = 6.0 Hz, 1H), 4.31–4.24 (m, 2H), 4.00–3.94 (m, 2H), 1.21 (t, J = 7.2 Hz, 3H), 1.01 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (400 MHz, $CDCl_3$): δ 196.5, 167.8, 166.0, 161.0, 147.8, 137.5, 136.8, 133.8, 133.7, 132.7, 132.5, 130.9, 130.0, 129.0, 128.8, 128.6, 128.3, 127.8, 127.7, 127.4, 124.5, 75.0, 74.7, 63.3, 62.4, 59.7, 13.8, 13.5 ppm. HRMS (ESI-TOF) m/z: $[M + MeOH + H]^+$ calcd for $C_{32}H_{34}NO_6$, 528.2375; found: 528.2380.

Diethyl 4-benzoyl-5-styryl-2-*p*-tolyl-4,5-dihydropyrrole-3,3-dicarboxylate (7b)

Light yellow liquid. Yield: 382 mg (75%). ^{1}H NMR (400 MHz,$CDCl_3$): δ 7.84–7.80 (m, 4H), 7.30–7.11 (m, 11H), 6.49 (d, J = 16.0 Hz, 1H), 6.15–6.09 (m, 1H), 5.48–5.44 (m, 1H), 5.25 (d, J = 8.8 Hz, 1H), 4.36–4.20 (m, 4H), 2.43 (s, 3H), 1.22 (t, J = 7.2 Hz, 3H), 1.17 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (400 MHz, $CDCl_3$): δ 195.5, 168.3, 168.2, 167.7, 144.2, 140.7, 136.8, 135.0, 132.1, 131.1, 129.9, 129.0, 128.53, 128.49, 128.3, 127.5, 126.6, 126.6, 75.0, 73.3, 62.6, 62.1, 59.1, 21.7, 13.8, 13.7 ppm. MS (ESI-TOF): m/z 544.19 $[M + Cl]^-$. Anal. calcd for $C_{32}H_{31}NO_5$: C 75.42, H 6.13, N 2.75; found: C 75.78, H 6.25, N 2.68.

Diethyl 4-benzoyl-2-(4-methoxyphenyl)-5-styryl-4,5-dihydropyrrole-3,3-dicarboxylate (7c)

Pale yellow liquid. Yield: 347 mg (66%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91 (d, J = 7.2 Hz, 2H), 7.73 (d, J = 8.8 Hz, 2H), 7.50–7.13 (m, 8H), 6.80 (d, J = 9.2 Hz, 2H), 6.61 (d, J 15.6 Hz, 1H), 6.27 (q, J = 16.0 Hz, 1H), 5.38 (t, J = 7.0 Hz, 1H), 4.81 (d, J = 7.6 Hz, 1H), 4.11–3.91 (m, 4H), 3.75 (s, 3H), 1.03 (t, J = 7.2 Hz, 3H), 0.95 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.3, 168.9, 167.4, 159.4, 142.3, 142.1, 136.4, 133.4, 130.6, 129.6, 128.6, 126.2, 113.7, 76.7, 71.5, 64.4, 62.1, 60.5, 55.3, 13.74, 13.70 ppm. MS (ESI-TOF): m/z 524.21 $[M - H]^-$. Anal. calcd for $C_{32}H_{31}NO_6$: C 73.13, H 5.94, N 2.66; found: C 73.35, H 5.85, N 2.72.

Diethyl 4-benzoyl-2-naphthalen-1-yl-5-styryl-4,5-dihydro-pyrrole-3,3-dicarboxylate (7d)

Yellow oily liquid. Yield: 414 mg (76%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.09 (d, J = 8.4 Hz, 1H), 7.90–7.76 (m, 4H), 7.49–7.36 (m, 3H), 7.17–7.00 (m, 5H), 6.51 (d, J = 15.6 Hz, 1H), 5.85 (s, 1H), 5.00 (d, J = 8.4 Hz, 1H), 4.82 (t, J = 7.6 Hz, 1H), 3.97–3.25 (m, 4H), 1.19 (t, J = 7.2 Hz, 3H), 0.80 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.7, 172.14, 172.09, 167.5, 144.3, 143.7, 138.5, 136.5, 133.4, 129.7, 128.58, 128.57, 128.43, 128.40, 128.1, 127.7, 114.8, 114.3, 81.9, 72.6, 72.58, 63.0, 61.4, 60.0, 13.8, 13.4, ppm. MS (ESI-TOF): m/z 566.18 $[M + Na–2H]^-$. Anal. calcd for $C_{35}H_{31}NO_5$: C 77.04, H 5.73, N 2.57; found: C 77.28, H 5.67, N 2.69.

Diethyl 4-benzoyl-5-styryl-2-thiophen-2-yl-4,5-dihydro-pyrrole-3,3-dicarboxylate (7e)

Brown oily liquid. Yield: 401 mg (80%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 7.2 Hz, 2H), 7.92–7.36 (m, 11H), 7.14–7.02 (m, 1H), 6.40–6.34 (m, 1H), 5.50 (t, J = 6.8 Hz, 1H), 5.01 (d, J = 6.0 Hz, 1H), 4.31–4.24 (m, 2H), 3.97 (q, J = 7.2 Hz, 2H), 1.21 (t, J = 7.2 Hz, 3H), 1.01 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 198.0, 168.3, 167.8, 150.2, 142.0, 141.1, 135.6, 134.0, 129.6, 128.5, 128.3, 126.7, 126.5, 125.9, 124.89, 124.86, 124.0, 82.7, 81.5, 69.7, 62.5, 62.0, 57.9, 13.8, 13.5 ppm. MS (ESI-TOF): m/z 502.18 $[M + H]^+$. Anal. calcd for $C_{29}H_{27}NO_5S$: C 69.44, H 5.43, N 2.79; found: C 69.76, H 5.55, N 2.88.

Diethyl 4-benzoyl-2-methyl-5-styryl-4,5-dihydropyrrole-3,3-dicarboxylate (7f)

Yellow oily liquid. Yield: 381 mg (88%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, J = 7.6 Hz, 2H), 7.45–7.06 (m, 8H), 6.93–6.91 (m, 2H), 6.42 (d, J = 16.0 Hz, 1H), 5.79 (q, J = 15.6 Hz, 1H), 5.19 (t, J = 9.2 Hz, 1H), 5.08 (d, J = 7.2 Hz, 1H), 4.25–4.04 (m, 4H), 2.43 (s, 3H), 1.24 (t, J = 7.2 Hz, 3H), 1.01 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (400 MHz, $CDCl_3$): δ 197.8, 166.9, 166.7, 137.6, 136.6, 133.3, 133.2, 128.8, 128.7, 128.6, 128.5, 128.2, 127.5, 126.5, 126.5, 75.1, 74.1, 62.9, 61.8, 56.9, 18.9, 14.0, 13.7 ppm. MS (ESI-TOF): m/z 512.27 $[M + DMSO + H]^+$. Anal. calcd for $C_{26}H_{27}NO_5$: C 72.04, H 6.28, N 3.23; found: C 72.33, H 6.40, N 3.36.

Diethyl 4-benzoyl-5-[2-(4-methoxyphenyl)-vinyl]-2-phenyl-4,5-dihydropyrrole-3,3-dicarboxylate (7g)

Yellow oily liquid. Yield: 410 mg (78%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.99 (d, J = 7.2 Hz, 2H), 7.60–7.26 (m, 11H), 6.95 (d, J = 8.8 Hz, 1H), 6.62 (d, J = 15.2 Hz, 1H), 6.27 (q, J = 16.0 Hz, 1H), 5.19 (t, J = 7.6 Hz, 1H), 4.75 (q, J = 8.8 Hz, 1H), 4.30–4.16 (m, 4H), 3.86 (s, 3H), 1.27 (t, J = 7.2 Hz, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.3, 170.7, 168.2, 158.9, 145.3, 142.7, 137.7, 132.6, 131.5, 129.9, 129.4, 128.6, 128.4, 113.5, 72.2, 61.8, 61.2, 55.3, 51.0, 40.0, 13.9, 13.7 ppm. HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{32}H_{31}NO_6$, 526.2224; found: 526.2235.

Diethyl 4-benzoyl-5-(2-naphthalen-2-yl-vinyl)-2-phenyl-4,5-dihydropyrrole-3,3-dicarboxylate (7h)

Pale yellow liquid. Yield: 414 mg (76%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81–7.60 (m, 11H), 7.49–7.43 (m, 6H), 6.34 (q, J = 7.2 Hz, 1H), 6.15 (q, J = 5.6 Hz, 1H), 5.47 (t, J = 4.4 Hz, 1H), 4.36–4.20 (m, 4H), 3.46 (q, J = 14.8 Hz, 1H), 3.20 (q, J = 11.2 Hz, 1H), 1.31 (t, J = 8.4 Hz, 3H), 0.58 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 194.0, 173.1, 169.5, 166.8, 153.0, 134.6, 134.0, 131.9, 129.2, 129.1, 129.0, 128.8, 128.6, 128.1, 126.9, 126.4, 126.0, 124.6, 81.6, 62.8, 51.8, 50.8, 14.1, 14.0 ppm. MS (ESI-TOF): m/z 577.23 $[M + MeOH]^+$. Anal. calcd for $C_{35}H_{31}NO_5$: C 77.04, H 5.73, N 2.57; found: C 77.15, H 5.88, N 2.69.

Diethyl 4-benzoyl-2-phenyl-5-(2-thiophen-2-yl-vinyl)-4,5-dihydropyrrole-3,3-dicarboxylate (7i)

Yellow oily liquid. Yield: 361 mg (72%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.29 (d, J = 8.8 Hz, 3H), 8.05 (d, J = 8.4 Hz, 3H), 7.27–7.19 (m, 8H), 6.56 (d, J = 2.4 Hz, 1H), 5.03–5.01 (m, 1H), 4.27 (q, J = 7.2 Hz, 2H), 3.75–3.70 (m, 2H), 3.57–3.52 (m, 1H), 1.25 (t, J = 7.2 Hz, 3H), 0.77 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.0, 171.8, 167.5, 150.5, 144.8, 143.8, 141.3, 138.0, 130.5, 128.5, 128.4, 127.9, 123.8, 82.0, 72.7, 63.2, 61.7, 60.0, 13.8, 13.4. ppm. HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{29}H_{27}NO_5S$, 502.1683; found: 502.1676.

Diethyl 4-(4-methylbenzoyl)-2-phenyl-5-styryl-4,5-dihydro-pyrrole-3,3-dicarboxylate (7j)

Pale yellow liquid. Yield: 351 mg (69%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.06 (d, J = 7.2 Hz, 2H), 7.58–7.26 (m, 11H), 6.66–6.57 (m, 2H), 6.21 (q, J = 16.0 Hz, 1H), 4.86 (q, J = 10.0 Hz, 1H), 4.24–4.09 (m, 4H), 2.40 (s, 3H), 1.26 (t, J = 7.2 Hz, 3H), 1.18 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.4, 171.7, 167.6, 144.0, 143.8, 139.8, 134.8, 132.0, 131.0, 129.9, 128.9, 128.6, 128.4, 127.7, 119.2, 109.2, 81.6, 72.3, 62.9, 61.5, 59.9, 21.8, 13.8, 13.5 ppm. MS (ESI-TOF): m/z 542.16 $[M + MeOH + H]^+$. Anal. calcd for $C_{32}H_{31}NO_5$: C 75.42, H 6.13, N 2.75; found: C 75.59, H 6.22, N 2.70.

Diethyl 4-(4-methoxybenzoyl)-2-phenyl-5-styryl-4,5-dihydro-pyrrole-3,3-dicarboxylate (7k)

Yellow oily liquid. Yield: 331 mg (63%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.95 (d, J = 7.2 Hz, 2H), 7.94–7.37 (m, 5H), 6.89 (d, J = 8.8 Hz, 2H), 6.52 (d, J = 12.0 Hz, 1H), 5.43 (q, J = 8.0 Hz, 1H), 4.24–3.95 (m, 5H), 3.81 (s, 3H), 1.11 (t, J = 7.2 Hz, 3H), 1.03 (t, J = 7.0 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 198.7, 170.0, 169.5, 158.0, 136.4, 135.8, 133.5, 131.3, 130.2, 129.1, 128.6, 113.4, 69.1, 61.4, 61.2, 60.4, 56.0, 55.3, 13.7, 13.4 ppm. HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{32}H_{31}NO_6$, 526.2224; found: 526.2202.

Diethyl-4-(4-nitro-benzoyl)-2-phenyl-5-styryl-4,5-dihydro-pyrrole-3,3-dicarboxylate (7l)

Brown oily liquid. Yield: 367 mg (68%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.94 (d, J = 7.6 Hz, 2H), 7.51–7.46 (m, 9H), 6.54 (d, J = 16.0 Hz, 1H), 6.44 (d, J = 7.2 Hz, 1H), 5.00 (d, J = 8.0 Hz, 1H), 4.83 (d, J = 7.6 Hz, 1H), 3.96–3.2 (m, 4H), 0.77 (t, J = 7.2 Hz, 3H), 0.63 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 199.1, 168.7, 168.0, 137.3, 136.9, 136.1, 134.0, 133.8, 130.2, 128.9, 128.7, 128.6, 128.5, 128.7, 128.6, 128.5, 128.1, 127.9, 127.3,

126.9, 126.3, 85.3, 88.0, 70.3, 61.9, 61.5, 57.5, 13.33, 13.25 ppm. MS (ESI-TOF): m/z 579.35 $[M + K]^+$. Anal. calcd for $C_{31}H_{28}N_2O_7$: C 68.88, H 5.22, N 5.18; found: C 68.79, H 5.31, N 5.30.

Diethyl 4-(4-methylbenzoyl)-2-(1-methylene-pent-2-enyl)-5-styryl-4,5-dihydropyrrole-3,3-dicarboxylate (7m)

Yellow oily liquid. Yield: 408 mg (78%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.72–7.68 (m, 4H), 7.46–7.00 (m, 9H), 6.37 (d, J = 15.6 Hz, 1H), 6.00 (d, J = 7.2 Hz, 1H), 5.34 (t, J = 8.4 Hz, 1H), 5.13 (d, J = 8.4 Hz, 1H), 4.19–4.11 (m, 4H), 2.32 (s, 3H), 2.30 (s, 3H), 1.10 (t, J = 7.2 Hz, 3H), 1.05 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 195.6, 168.3, 168.1, 167.7, 144.2, 140.6, 136.8, 135.0, 133.8, 132.1, 131.0, 129.9, 129.4, 129.0, 128.51, 128.49, 128.3, 127.5, 129.7, 126.6, 75.0, 73.3, 62.6, 62.1, 59.1, 21.7, 21.5, 13.8, 13.7 ppm. HRMS (ESI-TOF) m/z: $[M + NH_4]^+$ calcd for $C_{33}H_{33}NO_5$, 541.2697; found: 541.2700.

Diethyl 4-benzoyl-2-(4-bromophenyl)-5-(2-*p*-tolyl-vinyl)-4,5-dihydropyrrole-3,3-dicarboxylate (7n)

Brown liquid. Yield: 355 mg (60%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84 (d, J = 8.4 Hz, 2H), 7.44–7.15 (m, 15H), 6.49–6.48 (m, 1H), 4.24–4.09 (m, 3H), 2.31 (s, 3H), 1.18 (t, J = 7.2 Hz, 3H), 0.76 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.8, 168.3, 166.5, 166.4, 143.8, 140.8, 137.2, 136.6, 133.6, 132.0, 129.9, 128.7, 128.6, 128.5, 126.6, 119.2, 109.2, 75.0, 74.7, 62.9, 62.4, 60.3, 21.8, 13.7, 13.6 ppm. HRMS (ESI-TOF) m/z: $[M + NH_4]^+$ calcd for $C_{32}H_{30}BrNO_5$, 605.1646; found: 605.1646.

Diethyl 4-benzoyl-2-methyl-5-(2-*p*-tolyl-vinyl)-4,5-dihydro-pyrrole-3,3-dicarboxylate (7o)

Pale yellow liquid. Yield: 358 mg (80%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.76 (d, J = 8.0 Hz, 2H), 7.30–6.99 (m, 7H), 6.49 (d, J = 15.2 Hz, 1H), 5.86 (q, J = 15.2 Hz, 1H), 5.22–5.10 (m, 2H), 4.32–4.10 (m, 4H), 2.49 (s, 3H), 2.36 (s, 3H), 1.31 (t, J = 7.2 Hz, 3H), 1.08 (t, J = 7.0 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.2, 166.9, 166.8, 144.1, 136.7, 135.7, 135.2, 133.2, 129.3, 128.6, 128.2, 127.4, 126.7, 126.5, 75.1, 74.2, 62.8, 61.7, 56.8, 21.6, 18.8, 14.0, 13.7 ppm. MS (ESI-TOF): m/z 465.12 $[M + NH_4]^+$. Anal. calcd for $C_{27}H_{29}NO_5$: C 72.46, H 6.53, N 3.13; found: C 72.33, H 6.64, N 3.27.

Diethyl 4-benzoyl-5-[2-(4-nitrophenyl)-vinyl]-2-thiophen-2-yl-4,5-dihydropyrrole-3,3-dicarboxylate (7p)

Yellow oily liquid. Yield: 354 mg (65%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 7.2 Hz, 2H), 7.62–7.38 (m, 5H), 7.14–7.02 (m, 1H), 6.40–6.34 (m, 1H), 5.51– (t, J = 6.8 Hz, 1H), 5.01 (d, J = 6.0 Hz, 1H), 4.31–4.24 (m, 2H), 3.97 (q, J = 7.2 Hz, 2H), 1.21 (t, J = 7.2 Hz, 3H), 1.01 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.5, 167.8, 166.3, 161.0, 147.8, 137.47, 136.8, 133.75, 133.67, 133.14, 132.67, 132.5, 130.8, 129.0, 128.8, 128.6, 128.3, 127.8, 127.7, 127.4, 124.5, 75.0, 74.7, 63.3, 62.4, 59.7, 13.8, 13.5 ppm. HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{29}H_{26}N_2O_7S$, 547.1533; found: 547.1537.

Diethyl 2-methyl-4-(4-methyl-benzoyl)-5-(2-*p*-tolyl-vinyl)-4,5-dihydropyrrole-3,3-dicarboxylate (7q)

Pale yellow liquid. Yield: 396 mg (86%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 (d, J = 8.0 Hz, 2H), 7.00 (d, J = 8.0 Hz, 3H), 6.90 (d, J = 8.0 Hz, 3H), 6.79 (d, J = 7.6 Hz, 2H), 5.57 (d, J = 6.0 Hz, 1H), 5.34 (d, J = 8.0 Hz, 1H), 4.33–4.02 (m, 4H), 2.58 (s, 3H), 2.31 (s, 3H), 2.12 (s, 3H), 1.33 (t, J = 7.2 Hz, 3H), 0.99 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 198.3, 169.5, 166.9, 166.7, 143.2, 136.7, 135.4, 134.5, 128.6, 128.3, 128.2, 128.0, 75.7, 75.6, 62.9, 61.5, 57.8, 21.6, 21.0, 18.8, 14.0, 13.6 ppm. MS (ESI-TOF): m/z 494.28 $[M + MeOH + H]^+$. Anal. calcd for $C_{28}H_{31}NO_5$: C 72.86, H 6.77, N 3.03; found: C 72.92, H 6.87, N 3.11.

Synthesis of diethyl 2-[2-benzoylamino-1-(4-methylbenzoyl)-4-phenyl-but-3-enyl]malonate (8)

To a solution of vinyl 1-pyrroline **7b** (1.0 mmol, 510 mg) in 1,2-dichloroethane (5 mL) was added $SnCl_4$ (1.0 mmol, 260 mg). After 15 min, water (1.0 mmol, 18 μL) was added and the reaction mixture was allowed to stir at room temperture for 8 h. After completion of the reaction, the reaction mixture was extracted with dichloromethane. The organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography using EtOAc/hexane (1 : 9) to give **8**. Pale yellow liquid. Yield: 400 mg (76%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (d, J = 8.4 Hz, 2H), 7.44–7.37 (m, 5H), 7.22–7.15 (m, 8H), 6.49 (d, J = 1.6 Hz, 1H), 5.02 (s, J = 1H), 4.24–(m, 3H), 3.74–3.54 (m, 3H), 2.31 (s, 3H), 1.18 (t, J = 7.2 Hz, 3H), 0.76 (t, J = 7.2 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.4, 171.7, 167.6, 144.0, 143.8, 139.8, 134.8, 132.0, 131.0, 129.9, 128.9, 128.6, 128.4, 127.7, 119.2, 109.2, 72.3, 62.9, 61.5, 59.9, 21.8, 13.8, 13.5 ppm. HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{32}H_{33}NO_6$, 528.2381; found: 528.2376.

Conflicts of interest

There are no conflicts to declare.

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12 CCDC 2048692 for compound **8**. See the ESI† for details.