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$CeCl_3 \cdot 7H_2O$ Catalyzed C−C and C−N Bond-Forming Cascade Cyclization with Subsequent Side-Chain Functionalization and Rearrangement: A Domino Approach to Pentasubstituted Pyrrole Analogues

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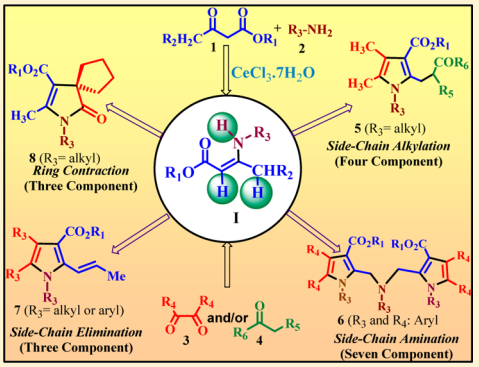
Supporting Information

ABSTRACT: $CeCl_3 \cdot 7H_2O$ is found as an efficient catalyst for new intermolecular domino reactions of three-, four- and seven-component assemblies of common precursors under benign reaction conditions. Generation of enaminioesters from β-keto esters and primary amines, activation of their allylic sp^3 C−H, vinylic sp^2 C−H and N−H bonds, multi C−C and C−N bond-forming cascade cyclization with 1,2-diketones and subsequent side-chain alkylation have been developed to construct functionalized pentasubstituted pyrroles and their chiral analogues. The scope of the domino reaction is successfully explored toward synthesis of highly aryl-substituted pyrroles, pentasubstituted pyrroles bearing C2-olefinic side-chain and spiro-2-pyrrolinones and their chiral analogues via unusual side-chain amination, elimination and ring contraction. The new domino reaction is operationally simple, robust, substrate specific, selective and high yielding.



Substituted pyrrole and pyrrolinone derivatives are highly cited heterocyclic moieties and key skeletons of many natural products including hemoglobin, chlorophylls, vitamin B_{12}, lukianols and tetrapentalones.[1,2] Functionalized pyrroles have found widespread applications as pharmaceuticals (e.g., Lipitor), agrochemicals, flavor additives, antiport agents, organoleptics, synthetic building blocks, and materials for molecular sensors and high-tech devices.[1,3] Recent medicinal research on heterocyclic scaffolds has recognized them as inhibitors for histone deacetylase, monoamine oxidase, FGFR1 and aurora kinase, antimalarial and anticancer agents.[4] The synthesis of a wide variety of such multifunctionalized molecules by a new intermolecular domino reaction is an important addition to the existing robust synthetic approaches in organic chemistry. Domino reactions[5] feature the synthesis of functional molecules by executing all chemical transformations in a single operation. This approach avoids undesirable reaction steps, including the protection, deprotection, and activation of precursors, the isolation and purification of the intermediates, and the use of different catalysts and reaction conditions. This manuscript presents a benign, eco-friendly and practical intermolecular domino reaction that utilizes common precursors and an inexpensive metal catalyst to access multifunctionalized pyrrole analogues involving a new multi C−C and C−N bond-forming cascade cyclization[6] under benign reaction conditions.

The usefulness of the ubiquitous *N*-heterocycles has led to the development of a large number of new methods in recent years, including the Paal−Knorr, Hantzsch, and Schmidt syntheses, cycloaddition, and metal-catalyzed cyclization,[7] using new building blocks and multistep processes.[8] Enamines are important intermediates for organic synthesis[9] and also efficiently used for the synthesis of substituted pyrroles by transition metal-catalyzed C−H activation,[10] and intra- and intermolecular cyclization (eq i, ii, Scheme 1).[11] In this regard, $FeCl_3$-catalyzed four component cyclization reaction of aldehydes, amines, nitroalkenes and 1,3-dicarbonyl compounds to pentasubstituted pyrroles is encouraging.[11b] However, predesigned precursors, stoichiometric amount of unsafe metals as a copromotor and/or high temperature are employed in most of these approaches. Substrate scope of the reaction becomes very limited under the reaction conditions. We have successfully developed a new domino reaction (eq iii) at ambient temperature by direct C−C and C−N bond-forming cascade cyclization involving vinylic sp^2 C−H, allylic sp^3 C−H and a N−H of enaminioesters on use of acetylene-equivalent 1,2-diketone[12] and rare-earth metal catalyst $CeCl_3$[13].

We were unsuccessful in applying various transition and rare-earth metal Lewis acids to the initial multicomponent domino-strategy utilizing common precursor ethyl acetoacetate (**1a**), benzylamine (**2a**), diacetyl (**3a**) and *tert*-butyl acetoacetate (**4a**, entries 1−12, Table 1). To remove the additional preparation of enaminioesters and their purification step, we were also searching for a protocol that could generate enaminioesters in situ from a β-keto ester (**1**) and primary amine (**2**). To our

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Scheme 1. Transition Metal Catalyzed C−H Activated Cyclization vs Rare-Earth Metal Catalyzed Cascade Cyclization

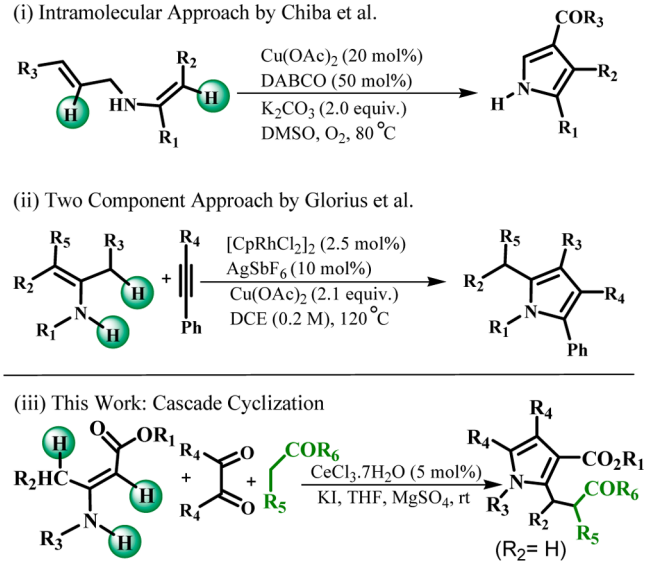


Table 1. Development and Optimization of Intermolecular Domino Reaction to 5a

entry	catalyst[a]	reaction conditions[b]	conversion	yield (%)
1	$VO(acac)_2$	CH_3CN, $MgSO_4$, rt, 36 h		nd[c]
2	$TiCl_4$	CH_3CN, $MgSO_4$, rt, 35 h		nd
3	$Ti(OBu)_4$	CH_3CN, $MgSO_4$, rt, 48 h		nd
4	$ZrCl_4$	CH_3CN, $MgSO_4$, rt, 47 h		nd
5	$FeCl_3$	CH_3CN, $MgSO_4$, rt, 32 h		nd
6	$Cu(OAc)_2$	CH_3CN, $MgSO_4$, rt, 48 h		nd
7	Cu(OTf)	CH_3CN, $MgSO_4$, rt, 42 h		nd
8	$AuCl_3$	CH_3CN, $MgSO_4$, rt, 45 h		nd
9	$Ni(OAc)_2{\cdot}2H_2O$	CH_3CN, $MgSO_4$, rt, 36 h		nd
10	$Pd(OAc)_2$	CH_3CN, $MgSO_4$, rt, 24 h		nd
11	$IrCl_3$	CH_3CN, $MgSO_4$, rt, 45 h		nd
12	$(NH_4)_2Ce(NO_3)_6$	CH_3CN, $MgSO_4$, rt, 45 h		nd
13	$CeCl_3$	MeCN, KI, $MgSO_4$, 48 h	75	45
14	$CeCl_3{\cdot}7H_2O$	MeCN, KI, $MgSO_4$, 48 h	100	79
15	$CeCl_3{\cdot}7H_2O$	MeCN, NaI, $MgSO_4$, 48 h	60	41
16	$CeCl_3{\cdot}7H_2O$	CH_2Cl_2, KI, $MgSO_4$, 48 h	80	64
17	$CeCl_3{\cdot}7H_2O$	THF, KI, $MgSO_4$, 45 h	100	81
18	$CeCl_3{\cdot}7H_2O$	Me_2CO, KI, $MgSO_4$, 48 h	90	73
19	$CeCl_3{\cdot}7H_2O$	THF, KI, $MgSO_4$, 70 °C, 24 h	90	35[d]

[a]Catalyst (5 mol %). [b]KI or NaI (15 mol %). [c]Not detected. [d]Decomposition.

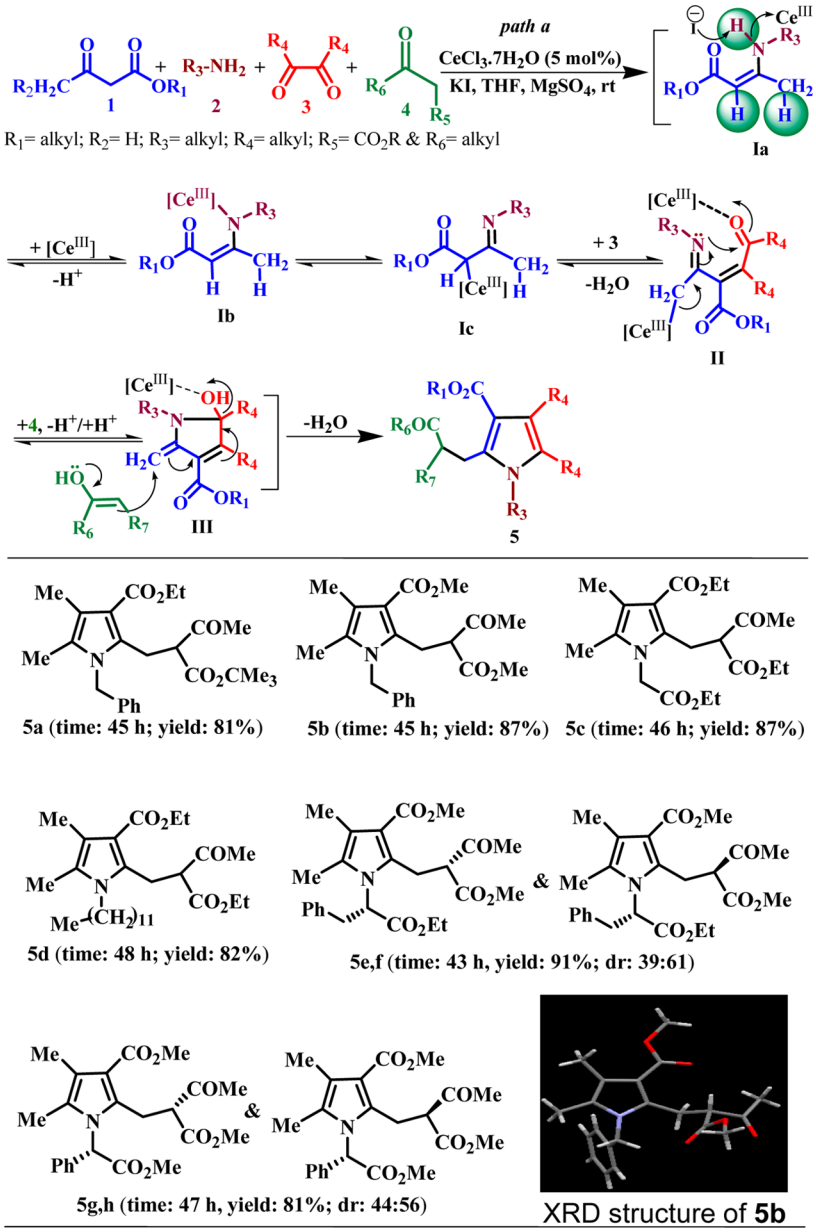
delight, use of environmentally safe and inexpensive metal catalyst $CeCl_3$ (5 mol %) had successfully performed the four-component cascade cyclization reaction with side-chain alkylation to afford pentasubstituted pyrrole **5a** (Scheme 2) in 45% yield (entry 13). Surprisingly, the new domino reaction proceed smoothly to completion under the catalytic influence of hepta-hydrated Cerium(III) chloride ($CeCl_3{\cdot}7H_2O$) and $MgSO_4$ with enhancement of yield up to 79% after purification by silica-gel column chromatography (entry 14). Herein, water molecule-coordinated metal ion might play a vital role during organization of the precursors, their cascade cyclization and/or side-chain alkylation process leading to completion of the reaction. $MgSO_4$ was used as a desiccant to remove water generated during course of the reaction. Despite its suitability for other systems, NaI[13c] was not a good activator for this catalyst to accelerate the reaction convergence (entry 15). THF is a good solvent for the catalytic process (entries 16−18). Our attempt to enhance the reaction convergence by heating (70 °C) was unsuccessful (entry 19). The role of the $CeCl_3{\cdot}7H_2O$ catalyst in promoting generation of enaminioester intermediate was experimentally verified utilizing a *β*-keto ester (**1a**) and a primary amine (**2a**) to afford corresponding enaminioester. We had also verified that the presence of the catalyst was essential for the cascade cyclization with side-chain alkylation reaction among the enaminioester, 1,2-diketone (**3a**) and *tert*-butyl acetoacetate (**4a**) toward construction of **5a**.

This report presents the synthesis of pentasubstituted functionalized pyrroles **5a−d** involving various substrates (**1−4**) under mild reaction conditions and at high yield (81−87%). Chiral pyrroles, an important class of *N*-heterocycles, are usually synthesized by the regioselective transformation of pyrroles via catalytic approaches.[14] Herein, the development of a new domino reaction under benign reaction conditions has improved the substrate scope toward the direct synthesis of valuable chiral pyrroles (**5e−h**; dr: 39:61 and 44:56) utilizing optically pure amino acid derivatives. The structure of the pentasubstituted pyrroles is determined by single crystal X-ray diffraction (XRD) for **5b** and spectral analysis of all new compounds (**5a−h**). Interestingly, the methyl groups at C4 and C5 are not alkylated.

The exact mechanism of the reaction is unknown to us. However, it is expected to proceed through generation of enaminioesters (**Ia**) from a *β*-keto ester (**1**), and primary amine (**2**: R_3 = alkyl), N−H insertion of Ce^{III} with deprotonation using KI (**Ib**), activation of vinylic sp^2 C−H bond of the enaminioester (**Ic**), subsequent C═C bond formation with strongly electrophilic 1,2-diketone (**3**; R_4 = alkyl) and activation of sp^3 C−H to provide intermediate **II**. Putative intermediate **II** undergoes N−C bond-forming cascade cyclization under the influence of the powerful Lewis acid to generate **III**. Simultaneous displacement of the hydroxyl group and side-chain alkylation with compound **4** of the intermediate **III** affords the desired heterocycle **5**. KI may have important role in the deprotonation and protonation process to execute the domino cyclization reaction.

Aryl-substituted pyrroles are commonly synthesized by metal-catalyzed regioselective coupling of bromopyrroles.[15] Pentasubstituted pyrroles bearing a large number of aromatic rings with *π*−*π* stacking and other weak interactions are potential candidates for fabrication of organic nanostructured materials.[13b,16] To achieve the direct synthesis of highly aryl-substituted pyrroles, we had further screened (*path b*, Scheme 3) the domino reaction with a new set of primary amines (**2**: R_3

Scheme 2. Four Component Domino Reaction with Side-Chain Alkylation



= aryl) and 1,2-diketone (**3**: R_4 = aryl). Surprisingly, under the optimized reaction conditions (entry 17, Table 1) novel bis-aminomethyl pyrroles (**6**) bearing a number of aromatic moieties were obtained. Herein, aryl amine was involved in amination reaction to the C2 side-chain of two putative intermediates (**III**) successively with expulsion of hydroxyl groups to result compound **6**. Traces of corresponding side-chain alkylation products (**5**) are also generated in some of the reactions. This reaction is quite substrate specific. Aromatic-ring-substituted 1,2-diketone (**3**) and aromatic amine (**2**) precursors were essential for this reaction to proceed. Various substituted aromatic amines (**2**), diaryl-1,2-diketones (**3**) and 3-ketoesters (**1**) are tolerated in this seven-component domino reaction approach to afford highly substituted aminomethyl pyrroles **6a**–**g** with a high yield (79–92%). The structures are confirmed by X-ray single crystal analyses of compound **6a** and recording spectra (Supporting Information) of all new compounds (**6a**–**g**).

Interestingly, upon the placement of an alkyl group (Et) on the side-chain of β-keto ester [R_1, R_2 = Et, ethyl 3-oxohexanoate (**1d**)] a three-component domino reaction (*path c*, Scheme 4) occurred with primary amines (**2**: R_3 = alkyl) and 1,2-diketones (**3**: R_4 = alkyl or aryl) to afford the pentasubstituted pyrrole **7** bearing a C2-olefinic side-chain. Surprisingly, the sp^3 C_β–H of enamine intermediate underwent an elimination reaction to install a double bond with absolute *trans*-selectivity. Herein, cyclized intermediate **III** is expected to undergo simultaneous removal of C_β–*H* side-chain proton and hydroxyl group under the catalytic conditions. Various achiral and chiral multifunctionalized pyrroles were synthesized by this robust protocol with high yield (76–82%). XRD structure of **7e** is presented in Scheme 4.

Pyrrolinones have found widespread applications as universal peptidomimetics and highly selective inhibitors of VEGF R2/3, HIV-1 integrase, HIF-2 and phosphodiesterase.[2,17] Spirocyclic heterocycles are common in nature and play an important role

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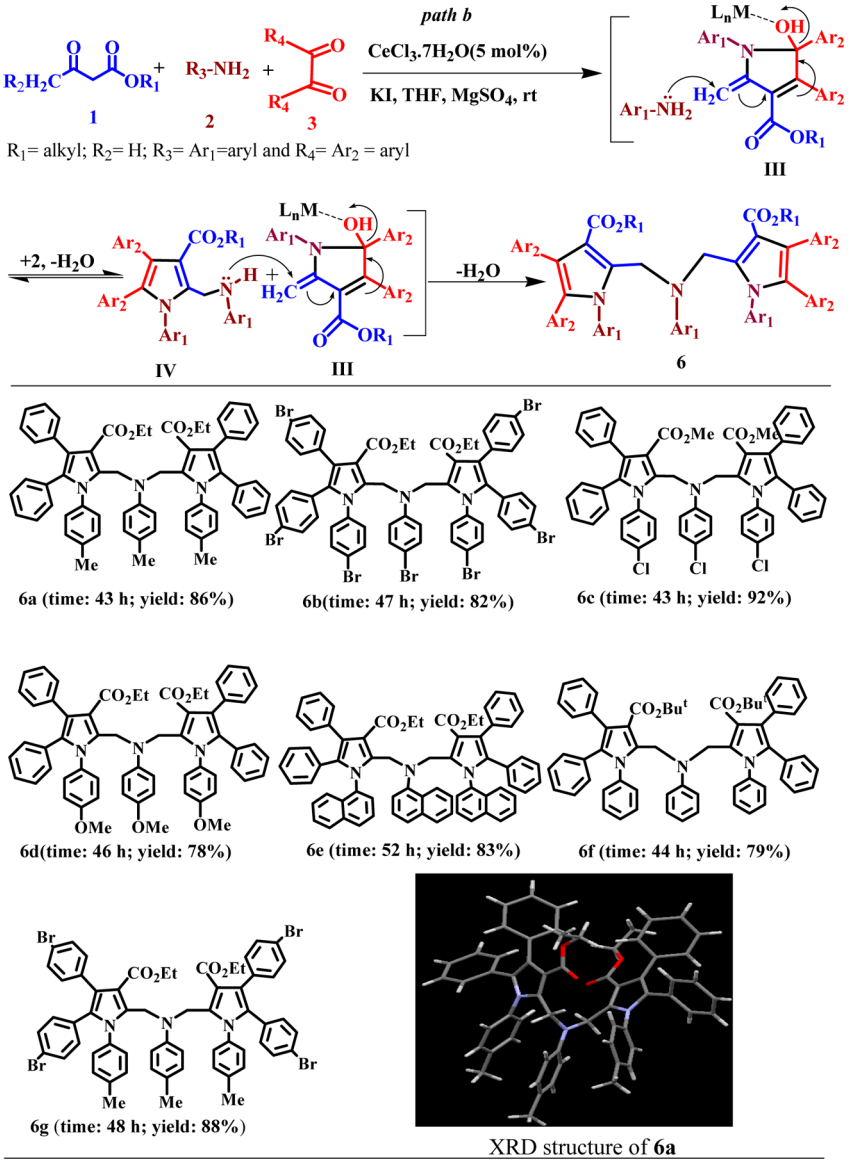
Scheme 3. Three Component Domino Reaction with Side-Chain Amination



in biochemical transformations.[18] To determine the reaction specificity and scope of the new intermolecular domino reaction process, synthesis of pentasubstituted spiro-2-pyrrolinones[19] was successfully investigated (*path d*, Scheme 5). Herein, first one-step synthesis of spiro-2-pyrrolinone (**8**) involving ring contraction was devised under benign reaction conditions in high to excellent yields (74−92%). Herein, the use of cyclic 1,2-diketone [**3**: R_4, R_4 = $(CH_2)_4$] led to formation of corresponding intermediate **II**, which on cascade cyclization produced intermediate **III**. The metal Lewis acid stabilized ionic intermediate involved in migration of the alkyl chain furnished rearranged pentasubstituted spiro-2-pyrrolinones (**8a**−**e**). Interestingly, the domino reaction was unsuccessful when the reaction was carried out using aromatic amines (**2**: R_3 = aryl). The X-ray single crystal structure of the optically pure *N*-heterocycle **8e** is displayed in Scheme 5.

In conclusion, we have devised a new intermolecular domino reaction of easily availabe precursors involving generation of enaminioesters, triple activation of their allylic sp^3 C−H, vinylic sp^2 C−H, and N−H bonds, a multi C−C and C−N bond-forming cascade cyclization with 1,2-diketones and subsequent unusual side-chain alkylation, amination, elimination and ring contraction. We have demonstrated three-, four- and seven-component coupling of *β*-keto esters, primary amines and 1,2-diketones to valuable pentasubstituted pyrroles bearing various functional groups, a large number of aromatic moieties, and *trans*-selective olefin substituent, and spiro-2-pyrrolinones and their chiral analogues. Environmentally benign hepta-hydrated $CeCl_3$ is found as an efficient catalyst for the multistep domino process under mild reaction conditions. Structures of the new and novel *N*-heterocycles are established by means of X-ray single crystal diffraction analyses. Excellent catalytic activity of the inexpensive rare-earth metal salt and synthesis of such a diverse class of highly functionalized pentasubstituted pyrroles by this simple and robust domino reaction are expected to find immense application in organic synthesis, medicinal chemistry and material sciences.

EXPERIMENTAL SECTION

General Procedure A for Synthesis of 5. *β*-Ketoester (**1**, 1.25 mmol), aliphatic amine (**2**, 1.25 mmol), $CeCl_3·7H_2O$ (70 mg, 5 mol %), KI (100 mg, 15 mol %) and anhydrous $MgSO_4$ were taken in dry

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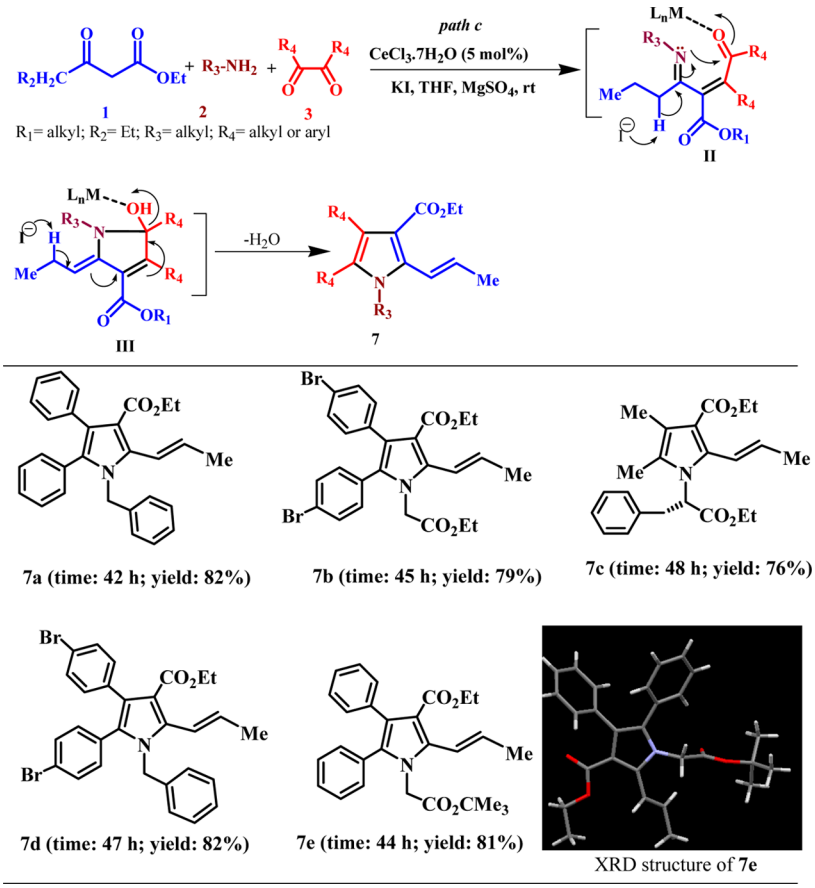
Scheme 4. Three Component Domino Reaction with Side-Chain Elimination



THF (30 mL) and stirred for 24 h at room temperature. 1,2-Diketone (**3**, 1 mmol) and *β*-keto ester (**4**, 1.25 mmol) were added to it and stirred at room temperature for 43−48 h. After removal of the solvent, the reaction mixture was diluted with ethyl acetate (25 mL). The organic layer was washed with water (3 × 10 mL), dried on anhydrous Na_2SO_4 and evaporated under reduced pressure in a rotary evaporator at room temperature. The residue was then subjected to column chromatography over silica gel (60−120 mesh) and eluted with 3% (**5a−c,e−h**) and 5% (**5d**) ethyl acetate in petroleum ether (v/v).

1-Benzyl-2-(2-*tert*-butoxycarbonyl-3-oxo-butyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (5a). 346 mg (81% yield); pale yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.19 (3H, t, J = 7.2 Hz), 1.38 (3H, s), 1.56 (9H, s), 1.98 (3H, s), 2.21 (3H, s), 3.21−3.30 (2H, m), 4.06−4.19 (3H, m), 5.19 (2H, dd, J = 17.4 Hz), 6.82 (2H, d, J = 6.9 Hz), 7.20−7.30 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 9.7, 11.6, 13.9, 23.9, 27.8, 28.5, 30.1, 46.7, 59.0, 61.3, 79.3, 116.3, 125.4, 125.5, 127.1, 128.7, 134.6, 137.8, 165.4, 169.4, 203.8; FT-IR (neat, cm^{-1}) 1178, 1282, 1367, 1682, 1714, 1732, 2978; HR-MS (m/z) for $C_{25}H_{34}NO_5$ (M + H) calculated 428.2437, found 428.2439.

1-Benzyl-2-(2-methoxycarbonyl-3-oxo-butyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid methyl ester (5b). 322 mg (87% yield); pale yellow solid: mp 62−64 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.93 (3H, s), 2.11 (3H, s), 2.15 (3H, s), 3.11−3.18 (1H, dd, J= 7.8 and 14.7 Hz), 3.23−3.28 (1H, dd, J = 6.6 and 14.7 Hz), 3.58 (3H, s), 3.82 (3H, s), 4.09−4.14 (1H, dd, J = 6.6 and 7.8 Hz), 5.08−5.14 (1H, d, J = 17.7 Hz), 5.20−5.26 (1H, d, J= 17.7 Hz), 6.72−6.74 (2H, d, J= 6.9 Hz), 7.14−7.26 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 9.73, 11.47, 24.13, 30.04, 46.8, 50.48, 52.36, 58.98, 111.10, 116.60, 125.40, 125.83, 127.17, 128.78, 135.57, 137.75, 166.41, 169.86, 203.40; FT-IR (KBr, cm^{-1}) 729.7, 782.6, 825.1, 1027.7, 1113.3, 1149.6, 1236.3, 1276.6, 1359.9, 1440.4, 1513.7, 1684.5, 1744.2, 2943.7, 3411.6, 3754.0; HR-MS (m/z) for $C_{21}H_{26}NO_5$ (M + H) calculated 372.1811, found 372.1815.

1-Ethoxycarbonylmethyl-2-(2-ethoxycarbonyl-3-oxo-butyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (5c). 343 mg (87% yield), pale yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13−1.38 (9H, m), 1.95 (3H, s), 2.08 (3H, s), 2.20 (3H, s), 3.09−3.16 (1H, dd, J = 7.5 and 15.0 Hz), 3.21−3.28 (1H, dd, J = 6.6 and 15.0 Hz), 3.99−4.23 (6H, m), 4.63−4.69 (1H, d, J = 18.3 Hz), 4.65−4.81 (1H, d, J = 18.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 9.57, 11.45, 13.87, 14.03, 14.37, 23.86, 30.18, 45.24, 59.05, 59.10, 61.36, 61.54, 111.47, 116.47, 125.54, 135.69, 165.78, 168.67, 169.28; FT-IR (neat, cm^{-1}) 731.2, 787.0, 858.9, 963.9, 1027.2, 1118.7, 1204.6, 1269.6, 1381.1, 1444.4, 1516.3, 1594.6, 1741.8, 2981.3, 3123.9, 3430.8; HR-MS (m/z) for $C_{20}H_{30}NO_7$ (M + H) calculated 396.2022, found 396.2018.

1-Dodecyl-2-(2-ethoxycarbonyl-3-oxo-butyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (5d). 391 mg (82% yield); pale yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.87 (2H, t, J = 7.2 Hz), 1.17−1.34 (26H, m), 1.42−1.55 (2H, m), 2.08 (3H, s), 2.14 (3H, s), 2.21(3H, s), 3.27−3.34 (2H, m), 3.77−3.98 (2H, m), 4.07−4.19 (2H, m), 4.21−4.28 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 9.98, 11.1, 14.4, 14.7, 22.6, 24.1, 26.8, 29.3, 29.5, 29.6, 30.2, 31.3, 31.9, 43.5, 59.0, 61.3, 110.5, 116.3, 124.8, 134.7, 166.0, 169.4, 203.7; FT-IR (neat, cm^{-1}) 1111, 1258, 1444, 1513, 1683, 1716, 1744, 2854, 2926; HR-MS (m/z) for $C_{28}H_{48}NO_5$ (M + H) calculated 478.3532, found 478.3535.

1-(1-Ethoxycarbonyl-2-phenylethyl)-2-(2-methoxycarbonyl-3-oxo-butyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid methyl ester (5e and 5f). dr 39:61; 416 mg (91% yield); pale yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.21 (3H, t, J = 7.2 Hz), 1.99 (3H, s), 2.03 (2H, s), 2.08 (3H, s), 2.12 (3H, s), 2.81−3.03 (2H, m), 3.54 (3H, s), 3.57 (1H, s), 3.65 (3H, s), 3.67−3.71 (2H, m), 4.14−4.21 (1H, m), 6.74−6.78 (2H, m), 7.07−7.10 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 11.29, 13.92, 23.02, 28.96, 31.00, 37.49, 50.27, 52.26, 58.98, 59.36, 61.74, 110.59, 117.97, 124.71, 128.44, 128.93, 129.52, 136.49, 136.96, 166.10, 169.94, 202.51, 203.66; FT-IR (neat, cm^{-1})

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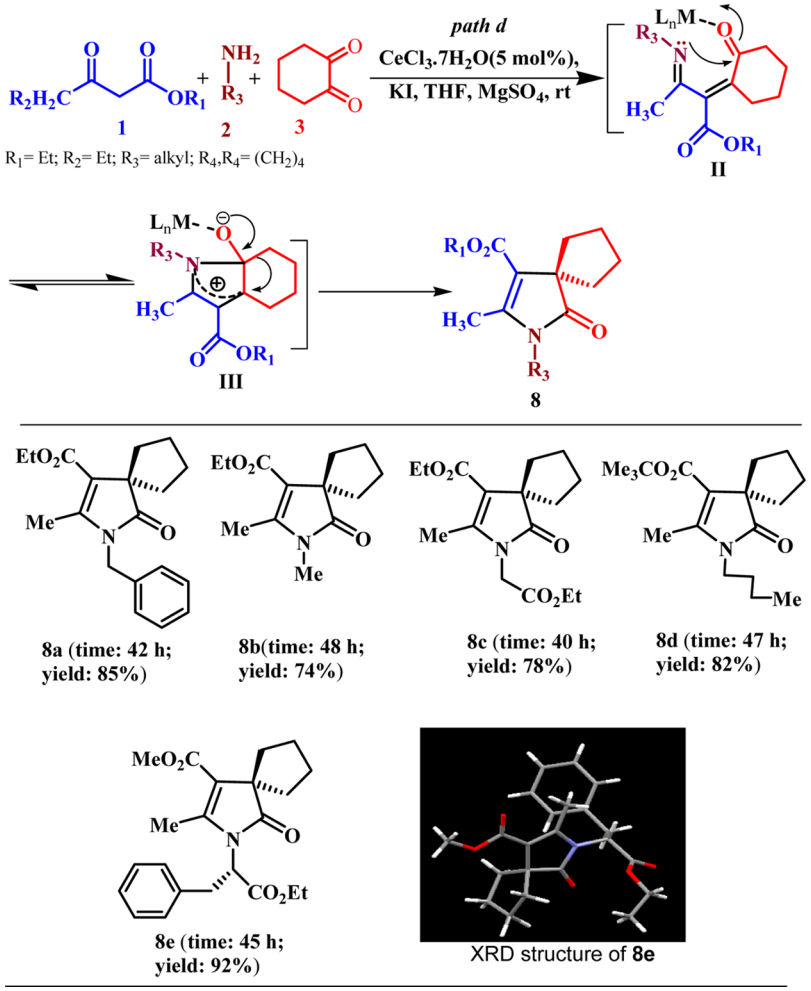
Scheme 5. Three Component Domino Reaction with Ring Contraction



702.4, 753.0, 785.6, 859.3, 1030.4, 1116.5, 1226.0, 1260.8, 1364.7, 1439.9, 1512.9, 1592.0, 1701.7, 1737.4, 2951.3, 3442.8; HR-MS (*m*/*z*) for $C_{25}H_{32}NO_7$ (M + H) calculated 458.2179, found 458.2176.

2-(2-Methoxycarbonyl-3-oxo-butyl)-1-(methoxycarbonyl-phenylmethyl)-4,5-dimethyl-1*H*-pyrrole-3-carboxylic acid methyl ester (5g and 5h). dr 44:56; 348 mg (81% yield); pale yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.15 (3H, s), 2.22 (3H, s), 2.26 (3H, s), 3.38−3.45 (2H, m), 3.55 (1H, s), 3.67 (3H, s), 3.80 (3H, s), 3.89 (3H, s), 4.05−4.13 (2H, m), 6.99−7.03 (2H, m), 7.26−7.35 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 11.35, 11.41, 23.94, 29.37, 30.47, 50.59, 52.47, 52.84, 59.89, 111.77, 117.68, 126.79, 127.10, 127.90, 128.42, 134.96, 136.21, 166.30, 169.44, 170.00, 202.59, 203.42; FT-IR (neat, cm^{-1}) 699.5, 745.5, 790.1, 832.3, 1003.0, 1116.8, 1209.3, 1267.2, 1358.1, 1443.8, 1514.1, 1586.5, 1684.1, 1741.0, 2371.5, 2952.5, 3437.4.; HR-MS (*m*/*z*) for $C_{23}H_{28}NO_7$ (M + H) calculated 430.1866, found 430.1865.

General Procedure B for Synthesis of 6. β-Ketoester (**1**, 1.25 mmol), aromatic amine (**2**, 1.25 mmol), $CeCl_3{\cdot}7H_2O$ (70 mg, 5 mol %), KI (100 mg, 15 mol %) and anhydrous $MgSO_4$ were taken in dry THF (30 mL) and stirred for 24 h at room temperature. Aromatic 1,2-diketone (**3**, 1.0 mmol) and aromatic amine (**2**, 1 mmol) were added to it and stirred at room temperature for 43−52 h. The reaction was monitored by TLC. After evaporation of the solvent, the reaction mixture was diluted with ethyl acetate (25 mL). This organic layer was washed with water (3 × 10 mL) and dried on anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure in a rotary evaporator at room temperature. The residue was then subjected to column chromatography over silica gel (60−120 mesh) and eluted with 2% (**6a**,**f**) 3% (**6b**−**d**,**g**) and 5% (**6e**) ethyl acetate in petroleum ether (v/v).

4′-tolyl-amino-*bis*[(2-methyl)-4,5-diphenyl-1-4′-tolyl-1*H*-pyrrole-3-carboxylic acid ethyl ester] (6a). 383 mg (86% yield); colorless solid: mp 220−221 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.89 (6H, t, *J* = 7.2 Hz), 2.12 (3H, s), 2.18 (6H, s), 3.98 (4H, q, *J* = 7.2 Hz), 4.14 (4H, s), 6.31(2H, d, *J* = 8.4 Hz), 6.64−7.18 (30 H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.7, 20.4, 21.1, 45.4, 59.4, 114.1, 117.0, 123.5, 125.6, 126.4, 127.0, 127.1, 128.0, 128.4, 129.0, 130.7, 131.2, 131.4, 132.8, 135.2, 136.0, 137.6, 145.0, 165.8; FT-IR (KBr, cm^{-1}) 1173, 1276, 1514, 1692, 2978, 3032; HR-MS (*m*/*z*) for $C_{61}H_{56}N_3O_4$ (M + H) calculated 894.4271, found 894.4277.

4′-Bromophenylamino-*bis*[(2-methyl)-4,5-di(4′-bromophenyl)-1-4′-bromophenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester] (6b). 576 mg (82% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.04 (6H, t, *J* = 7.2 Hz), 4.13 (4H, q, *J* = 7.2 Hz), 4.31 (4H, s), 6.42 (2H, d, *J* = 8.7 Hz), 6.65 (4H, d, *J* = 8.4 Hz), 7.03 (6H, dd, *J* = 8.4, 1.8 Hz), 7.16−7.26 (8H, m), 7.35 (4H, d, *J* = 8.4 Hz), 7.47 (4H, d, *J* = 8.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.9, 39.9, 60.2, 114.3, 116.0, 120.7, 121.8; 123.0, 123.9, 129.2, 130.0, 130.5, 131.2, 131.7, 131.9, 132.3, 132.5, 132.6, 133.6, 135.7, 136.5, 145.7, 165.2. FT-IR (neat, cm^{-1}) 1182, 1494, 1694, 2853, 2923, 3382; HR-MS (*m*/*z*) for $C_{58}H_{43}Br_7N_3O_4$ (M + H) calculated 1397.7537, found 1397.7534 (one of the peaks).

4′-Chlorophenylamino-*bis*[(2-methyl)-4,5-diphenyl-1-4′-chlorophenyl-1*H*-pyrrole-3-carboxylic acid methyl ester] (6c). 426 mg (92%, yield); colorless solid: mp 122−124 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.61 (6H, s), 4.31 (4H, s), 6.46 (4H, d, *J* = 8.7 Hz), 6.78 (4H, dd, *J* = 8.1 and 1.8 Hz), 6.97−7.09 (8H, m), 7.18−7.24 (16H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 40.2, 51.1, 113.9, 115.7, 124.6, 126.3, 127.2, 127.7, 129.0, 129.2, 129.8, 130.6, 130.8, 131.0, 133.1, 134.5, 134.7, 135.6, 136.0, 166.2; FT-IR (KBr, cm^{-1}) 1078,

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1174, 1277, 1495, 1694, 2359, 3369; HR-MS (m/z) for $C_{56}H_{43}Cl_3N_3O_4$ (M + H) calculated 926.2319, found 926.2325 (one of the peaks).

4′-Methoxyphenylamino-*bis*[(2-methyl)-4,5-diphenyl-1-4′-methoxyphenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester] (6d). 367 mg (78% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.02 (6H, t, J = 7.2 Hz), 3.74 (6H, s), 3.80 (3H, s), 4.13 (4H, q, J = 7.2 Hz), 4.32 (4H, s), 6.50 (4H, d, J = 9.0 Hz), 6.73 (4H, d, J = 8.7 Hz), 6.80−6.86 (8H, m), 6.92−7.10 (16H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.8, 40.8, 55.4, 55.7, 59.7, 113.4, 113.8, 114.0, 114.6, 115.6, 124.3, 126.0, 126.7, 127.1, 127.5, 129.2, 129.7, 129.9, 130.3, 131.0, 131.3, 132.8, 135.4, 137.4, 142.1, 152.6, 159.2, 163.4, 165.7; FT-IR (neat, cm^{-1}) 698, 828, 1027, 1075, 1176, 1244, 1458, 1510, 1608, 1691, 2847, 2924, 3373; HR-MS (m/z) for $C_{61}H_{56}N_3O_7$ (M + H) calculated 942.4118, found 942.4123.

2′-Naphthylamino-*bis*[(2-methyl)-4,5-di(2′-naphthyl)-1-2′-naphthyl-1*H*-pyrrole-3-carboxylic acid ethyl ester] (6e). 415 mg (83% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.11 (6H, t, J = 6.9 Hz), 4.29 (4H, q, J = 7.2 Hz), 4.42 (2H, d, J = 14.1 Hz), 4.72 (2H, d, J = 14.1 Hz), 6.37 (2H, s), 6.89−7.08 (8H, m), 7.18 (2H, t, J = 7.5 Hz), 7.30−7.68 (23H, m), 7.81 (2H, d, J = 7.5 Hz), 7.92−7.94 (4H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.8, 40.0, 60.0, 113.9, 120.4, 122.6, 124.1, 124.5, 124.6, 124.9, 125.5, 126.1, 126.7, 126.9, 127.2, 127.3, 127.5, 127.6, 127.9, 128.2, 128.3, 129.4, 130.6, 131.0, 131.5, 133.7, 134.1, 134.2, 135.3, 166.1; FT-IR (neat, cm^{-1}) 1275, 1402, 1511, 1610, 1668, 1737, 2927, 3427; HR-MS (m/z) for $C_{70}H_{56}N_3O_4$ (M + H) calculated 1002.4271, found 1002.4270.

Phenylamino-*bis*[(2-methyl)-4,5-diphenyl-1-phenyl-1*H*-pyrrole-3-carboxylic acid *tert*-butyl ester] (6f). 364 mg (79% yield); colorless solid: mp 124−126 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.30 (18H, s), 4.40 (4H, s), 6.46 (4H, d, J = 7.5 Hz), 6.69 (2H, t, J = 7.2 Hz), 6.85 (4H, dd, J = 7.5 and 1.8 Hz), 6.96−7.38 (25H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 27.9, 39.0, 80.2, 113.6, 115.5, 117.6, 124.2, 125.9, 126.7, 127.2, 127.4, 128.3, 128.7, 128.9, 129.0, 130.9, 131.0, 131.2, 132.3, 135.7, 136.5, 137.4, 147.9, 165.0; FT-IR (KBr, cm^{-1}) 695, 752, 1156, 1253, 1290, 1501, 1597, 1679, 2928, 2974, 3383; HR-MS (m/z) for $C_{62}H_{58}N_3O_4$ (M + H) calculated 908.4427, found 908.4429.

4′-Tolylamino-*bis*[(2-methyl)-4,5-di(4′-bromophenyl)-1-4′-tolyl-1*H*-pyrrole-3-carboxylic acid ethyl ester] (6g). 530 mg (88% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.05 (6H, t, J = 7.2 Hz), 2.21 (3H, s), 2.37 (6H, s), 4.13 (4H, q, J = 6.9 Hz), 4.33 (4H, s), 6.39 (2H, d, J = 8.4 Hz), 6.65 (2H, d, J = 8.4 Hz), 6.91 (3H, d, J = 8.1 Hz), 7.04 (3H, d, J = 8.1 Hz), 7.13 (4H, d, J = 8.4 Hz), 7.34 (2H, d, J = 8.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.9, 20.3, 21.1, 39.7, 59.9, 113.4, 114.0, 120.4, 121.3, 123.5, 127.1, 128.2, 129.5, 129.7, 129.9, 130.4, 130.9, 131.4, 132.4, 134.2, 138.0, 145.5, 156.6, 165.1; FT-IR (neat, cm^{-1}) 729, 1181, 1283, 1514, 1683, 3390; HR-MS (m/z) for $C_{61}H_{52}Br_4N_3O_4$ (M + H) calculated 1206.0693, found 1206.0690. (one of the peaks).

General Procedure C for Synthesis of 7. Ethyl 3-oxohexanoate (**1**, 1.25 mmol), aliphatic amine (**2**, 1.25 mmol), $CeCl_3{\cdot}7H_2O$ (70 mg, 5 mol %), KI (100 mg, 15 mol %) and anhydrous $MgSO_4$ were taken in dry THF (30 mL) and stirred for 24 h at room temperature. Aryl-1,2-diketone (**3**, 1 mmol) was added to it and stirred for 72 h at room temperature for completion of the reaction. After evaporation of the solvent, the reaction mixture was diluted with ethyl acetate (25 mL). This organic layer was washed with water (3 × 10 mL) and dried on anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure in a rotary evaporator at room temperature. The residue was then subjected to column chromatography over silica gel (60−120 mesh) and eluted with 1% (**7a**), 3% (**7b**,**d**,**e**) and 5% (**7c**) ethyl acetate−petroleum ether (v/v).

1-Benzyl-4,5-diphenyl-2-propenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (7a). 346 mg (82% yield); colorless solid: mp 92−93 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.12 (3H, t, J = 7.2 Hz), 1.95 (3H, dd, J = 6.6, 1.5 Hz), 4.21 (2H, q, J = 7.2 Hz), 5.22 (2H, s), 6.16−6.28 (1H, m), 6.67 (1H, dd, J = 16.2, 1.5 Hz), 7.02 (2H, d, J = 7.2 Hz), 7.10−7.13 (2H, m), 7.21−7.26 (7H, m), 7.28−7.48 (4H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.7, 19.1, 48.5, 59.5, 112.7, 119.9, 124.5, 125.6, 125.8, 127.0, 127.5, 127.9, 128.5, 130.5, 131.2, 131.5, 132.0, 132.8, 135.4, 138.1, 165.9; FT-IR (KBr, cm^{-1}) 701, 767, 1035, 1159, 1232, 1303, 1406, 1689, 2975; HR-MS (m/z) for $C_{29}H_{28}NO_2$ (M + H) calculated 422.2120, found 422.2120.

4,5-Bis-(4-bromo-phenyl)-1-ethoxycarbonylmethyl-2-propenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (7b). Yield: 454 mg (79% yield); colorless solid; mp 102−104 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.04 (3H, t, J = 7.2 Hz), 1.25 (3H,t, J = 6.9 Hz), 1.94 (3H, dd, J = 1.5 Hz, 6.9 Hz), 4.08 (2H, q, J = 6.9), 4.20 (2H, q, J = 7.2 Hz), 4.49 (2H, s), 5.94−6.06 (1H, m), 6.62 (1H, dd, J = 1.5 Hz, 16.2 Hz), 6.96−7.00 (4H, m), 7.29 (2H, d, J = 8.4 Hz), 7.39 (2H, d, J = 8.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.9, 14.1, 19.1, 47.4, 59.6, 61.8, 112.6, 120.2,120.3, 122.6, 123.5, 129.9, 130.4, 131.7, 131.9, 132.2, 132.6, 133.1, 134.1, 137.0, 165.0, 168; FT-IR (KBr, cm^{-1}) 826, 1012, 1153, 1214, 1300, 1432, 1507, 1704, 1742, 2981; HR-MS (m/z) for $C_{26}H_{26}Br_2NO_4$ (M + H) calculated 574.0230, found 574.0229 (one of the peaks).

1-(1-Ethoxycarbonyl-2-phenyl-ethyl)-4,5-dimethyl-2-propenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (7c). 292 mg (76% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.23−1.33 (6H, m),1.76 (3H, dd, J = 1.5 Hz, 6.6 Hz), 2.03 (3H, s), 2.15 (3H, s), 3.09 (1H, dd, J = 9.6 Hz, 14.1 Hz), 3.53(1H, dd J = 4.8 Hz, 13.8 Hz), 4.16−4.27 (4H, m), 5.12−5.16 (1H, m), 5.43−5.50 (1H, m), 6.05 (1H, dd, J = 1.5 Hz, 15.9 Hz), 6.86−6.89 (2H, m), 7.15−7.19 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 10.6, 11.1, 14.1, 14.3, 18.6, 37.5, 59.0, 61.8, 111.7, 117.6, 121.4, 125.5, 126.8, 128.3, 128.6, 129.9, 132.7, 136.5, 137.0, 166.0, 170.5; FT-IR (neat, cm^{-1}) 964, 1029, 1113, 1248, 1411, 1454, 1497, 1604, 1695, 1739, 2933, 2979; HR-MS (m/z) for $C_{23}H_{30}NO_4$ (M + H) calculated 384.2175, found 384.2174.

1-Benzyl-4,5-bis-(4-bromo-phenyl)-2-propenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (7d). 474 mg (82% yield); colorless solid: mp 126−130 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.05 (3H, t, J = 7.2 Hz), 1.83 (3H, dd, J = 1.5 Hz, J = 6.6 Hz), 4.09 (2H, dd, J = 7.2 Hz, J = 14.4 Hz), 5.06 (2H, s), 6.06−6.11 (1H, m), 6.54 (1H, dd, J = 1.8 Hz, J = 14.4 Hz), 6.79−6.88 (4H, m), 6.97−6.99 (2H, m), 7.24−7.30 (7H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.8, 19.1, 48.6, 59.7, 112.5, 119.8, 120.1, 122.2, 125.7, 127.3, 128.7, 130.2, 130.4, 131.3, 131.6, 132.2, 132.9, 134.3, 136.3, 137.7, 165.5; FT-IR (KBr, cm^{-1}) 1009, 1095, 1146, 1229, 1305, 1493, 1691, 2959; HR-MS (m/z) for $C_{29}H_{25}Br_2NO_2$ (M + H) calculated 578.0332, found 578.0329 (one of the peaks).

1-*tert*-Butoxycarbonylmethyl-4,5-diphenyl-2-propenyl-1*H*-pyrrole-3-carboxylic acid ethyl ester (7e). 361 mg (81% yield); colorless solid: mp 102−106 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.99 (3H, t, J = 7.2 Hz), 1.42 (9H, s), 1.94 (3H, dd, J = 1.8 Hz, 6.6 Hz), 4.05 (2H, q, J = 7.2 Hz), 4.43 (2H, s), 5.99−6.06 (1H, m), 6.68 (1H, dd, J = 1.8 Hz, 16.2 Hz), 7.09−7.17(7H, m), 7.22−7.26 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.8, 19.2, 27.8, 48.2, 59.4, 82.4, 112.5, 120.6, 124.2, 125.7, 127.0, 127.8, 128.2, 130.6, 131.2, 131.4, 132.1, 133.2, 135.5, 136.4, 165.6, 168.0; FT-IR (KBr, cm^{-1}) 963, 1150, 1232, 1307, 1433, 1603, 1695, 1737, 2974; HR-MS (m/z) for $C_{28}H_{32}NO_4$ (M + H) calculated 446.2331, found 446.2328.

General Procedure D for Synthesis of 8. Ethyl 3-oxohexanoate (**1d**, 1.25 mmol), aliphatic amine (**2**, 1.25 mmol), $CeCl_3{\cdot}7H_2O$ (70 mg, 5 mol %), KI (100 mg, 15 mol %) and anhydrous $MgSO_4$ were taken in dry THF (30 mL) and stirred for 24 h at room temperature. 1,2-Cyclohexadione (**3d**, 1 mmol) was added to it and stirred at room temperature for 40−48 h toward completion of the domino reaction. The reaction was monitored by TLC. After evaporation of the solvent, the postreaction mixture was extracted with ethyl acetate (25 mL). This organic layer was washed with water (3 × 10 mL) and dried on anhydrous Na_2SO_4. The solvent was removed under reduced pressure in a rotary evaporator at room temperature. The residue was then subjected to column chromatography over silica gel (60−120 mesh) and eluted with 1% (**8a**), 2% (**8b**,**c**) and 3% (**8d**,**e**) ethyl acetate in petroleum ether (v/v).

2-Benzyl-3-methyl-1-oxo-2-aza-spiro[4.4]non-3-ene-4-carboxylic acid ethyl ester (8a). 266 mg (85% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.10−1.3 (5H, m), 1.68−2.05 (5H, m), 2.25−2.40 (4H, m), 4.12 (2H, q, J = 7.2 Hz), 4.84 (2H, s), 7.06−7.14

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(2H, m), 7.17−7.26 (3H, m); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.8, 14.3, 27.4, 35.9, 43.1, 54.7, 59.4, 113.0, 126.6, 127.5, 128.8, 136.9, 152.5, 164.2, 184.9; FT-IR (neat, cm^{-1}) 700, 734, 951, 1082, 1214, 1309, 1384, 1447, 1619, 1690, 2945; HR-MS (m/z) for $C_{19}H_{24}NO_3$ (M + H) calculated 314.1756, found 314.1757.

2,3-Dimethyl-1-oxo-2-aza-spiro[4.4]non-3-ene-4-carboxylic acid ethyl ester (8b). 176 mg (74% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.23 (3H, t, J = 7.2 Hz), 1.69−1.87 (8H, m), 2.36 (3H, s), 2.98 (3H, s), 4.13 (2H, q, J = 7.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.6, 14.3, 26.2, 27.3, 35.7, 54.7, 59.3, 112.6, 152.6, 164.2, 184.8; FT-IR (neat, cm^{-1}) 801, 1068, 1151, 1210, 1257, 1381, 1449, 1624, 1687, 2927, 3445; HR-MS (m/z) for $C_{13}H_{20}NO_3$ (M + H) calculated 238.1443, found 238.1442.

2-Ethoxycarbonylmethyl-3-methyl-1-oxo-2-aza-spiro[4.4]-non-3-ene-4-carboxylic acid ethyl ester (8c). Yield: 241 mg (78% yield); yellow liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.17−1.35 (6H, m), 1.73−2.01 (6H, m), 2.05−2.10 (2H, m), 2.34 (3H, s), 4.07−4.22 (4H, m), 4.25 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.3, 14.0, 14.3, 14.4, 27.2, 35.6, 40.9, 54.7, 59.4, 61.7, 113.1, 151.2, 164.1, 168.0, 184.5; FT-IR (neat, cm^{-1}) 770, 956, 1088, 1206, 1381, 1624, 1691, 2947; HR-MS (m/z) for $C_{16}H_{24}NO_5$ (M + H) calculated 310.1654, found 310.1657.

2-Butyl-3-methyl-1-oxo-2-aza-spiro[4.4]non-3-ene-4-carboxylic acid *tert*-butyl ester (8d). 252 mg (74% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.92 (3H, t, J = 7.2 Hz), 1.25−1.39 (4H, m), 1.51 −1.54 (10H, m), 1.69−1.76 (3H, m), 1.86−2.06 (4H, m), 2.41 (3H, s), 3.46 (2H, t, J = 7.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.4, 13.6, 19.9, 27.1, 27.7, 28.5, 31.4, 35.4, 39.4, 54.7, 79.9, 113.7, 151.8, 163.7, 184.9; FT-IR (neat, cm^{-1}) 722, 846, 946,1062, 1145, 1255, 1367, 1452, 1617, 1686, 1715, 2937; HR-MS (m/z) for $C_{18}H_{30}NO_3$ (M + H) calculated 308.2226, found 308.2225.

(*S*)-2-(1-Ethoxycarbonyl-2-phenyl-ethyl)-3-methyl-1-oxo-2-aza-spiro[4.4]non-3-ene-4-carboxylic acid ethyl ester (8e). 354 mg (92% yield); colorless solid: mp 158−159 °C; $[\alpha]_D^{25}$ = −170.93° [c 2.25, $CHCl_3$]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.18 (3H, t, J = 7.5 Hz), 1.50−1.54 (2H, m), 1.72−1.88 (6H, m), 1.90 (3H, s), 3.24−3.33 (1H,dd, J = 11.4 and 14.1 Hz), 3.39−3.45 (1H, dd, J = 4.5 and 14.1 Hz), 3.61 (3H, s), 4.08−4.24 (2H, m), 4.40−4.55 (1H, dd), 7.01 (2H, dd, J = 7.5 and 1.5 Hz), 7.02−7.20.; ^{13}C NMR (75 MHz, $CDCl_3$ δ 12.4, 14.1, 27.1, 27.2, 35.0, 35.5, 35.7, 50.5, 54.2, 55.8, 61.8, 112.7, 127.0, 128.6, 129.1, 137.1, 152.2, 164.5, 169.2, 184.3; FT-IR (KBr, cm^{-1}) 1073, 1206, 1264, 1331, 1386, 1441, 1622, 1695, 1745, 2867, 2952; HR-MS (m/z) for $C_{22}H_{28}NO_5$ (M + H) calculated 386.1967, found 386.1969.

Procedure E for Synthesis of Enaminioester. Ethyl acetoacetate (**1a**, 1 mmol), benzylamine (**2a**, 1 mmol), $CeCl_3{\cdot}7H_2O$ (70 mg, 5 mol %), KI (100 mg, 15 mol %) and anhydrous $MgSO_4$ were taken in dry THF (30 mL) and stirred for 24 h at room temperature to complete the reaction. After evaporation of the solvent, the reaction mixture was diluted with ethyl acetate (20 mL). This organic layer was washed with water (3 × 10 mL) and dried on anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure in a rotary evaporator at room temperature. The residue was then subjected to column chromatography over silica gel (60−120 mesh) and eluted with 2% ethyl acetate−petroleum ether (v/v).

3-Benzylaminobut-2-enoic acid ethyl ester. 213 mg (97% yield); yellow liquid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.26 (3H, t, J = 7.2 Hz), 1.91 (3H, s), 4.10 (2H, q, J = 7.2 Hz), 4.42 (2H, d, J = 6.3 Hz), 4.54 (1H, s), 7.25 − 7.36 (5H, m), 8.96 (1H, bs); ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.6, 19.3, 46.7, 58.3, 83.1, 126.7, 127.3, 128.7, 138.7, 161.8, 170.6; FT-IR (KBr, cm^{-1}) 558, 696, 740, 785, 1028, 1064, 1121, 1178, 1242, 1449, 1505, 1610, 1659, 2986, 3298, 3686; HR-MS (m/z) for $C_{13}H_{18}NO_2$ (M + H) calculated 220.1338, found 220.1342.

■ ASSOCIATED CONTENT

Supporting Information

General remarks, NMR spectra and CIF data for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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