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Organocatalytic asymmetric domino Michael/O-alkylation reaction for the construction of succinimide substituted 3(2*H*)-furanones catalyzed by quinine†

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A new organocatalytic asymmetric domino Michael/O-alkylation reaction of maleimides with γ-halogenated-β-ketoesters catalyzed by simple, cheap, and commercially available quinine is described. The substrates are also commercially available. A variety of new chiral succinimide substituted 3(2*H*)-furanones were obtained in high yields (up to 94%) and good enantioselectivities (up to 94% ee). The absolute configuration of the new compound **4f** was determined by single-crystal X-ray analysis and the proposed reaction pathway is also shown.

3(2*H*)-Furanones are core structural motifs that are widely present in many natural products and medicinally important agents.[1] 3(2*H*)-Furanone derivatives exhibit a wide range of biological activities such as antiulcer,[2] antitumor,[3] antiallergic,[4] antiproliferactive,[5] selective MAO-B inhibitory[6] and selective COX-2 inhibitory[7] activities. A variety of approaches toward the synthesis of achiral 3(2*H*)-furanones have been established, including metal-free processes[8] as well as transition-metal-catalyzed cyclizations.[9] However, protocols to construct chiral 3(2*H*)-furanone derivatives have been less studied. Marson and coworkers reported Sharpless's asymmetric dihydroxylation followed by a cyclization sequence of enynones to synthesize chiral 3(2*H*)-furanones.[10] Jing and coworkers reported asymmetric Michael addition of simple 3(2*H*)-furanones to α,β-unsaturated ketones catalyzed by a cinchona-based tertiary–primary diamine catalyst[11] or α,β-unsaturated aldehydes catalyzed by diphenylprolinol silyl ether[12] to construct complex chiral 3(2*H*)-furanones. These reactions require harsh reaction conditions or specific substrates and complex chiral catalysts. Recently, γ-halogenated-β-ketoesters, which are commercially available, are used to construct chiral 3(2*H*)-furanones with imines[13] and chain nitroalkenes[14] *via* domino reactions.[15] This synthetic strategy is efficient and mild. However, these reactions also need complex chiral catalysts such as tertiary amine squaramide,[13a] tertiary amine thiourea[13b,14a] and 6′-demethyl quinine catalysts.[14b] Moreover, the substrate scope is relatively limited. For the significance of chiral 3(2*H*)-furanones, it is strongly useful and desirable to discover other appropriate electrophiles such as cyclic alkenes to react with γ-halogenated-β-ketoesters catalyzed by simple, cheap, commercially available catalysts to construct diverse chiral substituted 3(2*H*)-furanones.

Maleimides, which are also commercially available, are an important class of cyclic alkenes. They have been extensively applied in asymmetric organocatalysis to construct chiral succinimide derivatives, which are core structural units found in natural products and clinical drug candidates.[16] To date, there has been no report of asymmetric reaction of γ-halogenated-β-ketoesters with maleimides, which could afford a new class of chiral products combining biologically significant succinimides with 3(2*H*)-furanones. These fused chiral products might show higher or new biological activities. Recently, we reported the same transformation in racemic version catalyzed by Et_3N.[17] As a part of our continuing interests in the construction of more complex and novel drug candidates,[18] herein, we wish to report the first asymmetric domino Michael/O-alkylation reaction of γ-halogenated-β-ketoesters with maleimides catalyzed by simple, cheap, commercially available cinchona alkaloids to access a new range of chiral succinimide substituted 3(2*H*)-furanones (Fig. 1). Córdova and coworkers reported asymmetric domino Michael/α-alkylation reaction of γ-halogenated-β-ketoesters with α,β-unsaturated aldehydes to afford cyclopentanone products.[19] This report shows variable chemical reactivities of γ-halogenated-β-ketoesters with activated alkenes. Our preliminary studies involved maleimide **1a** and ethyl 4-bromo-acetoacetate **2a** as substrates, these were allowed to react in the presence of 20 mol% cinchonine with 100 mol% Na_2CO_3 in CH_2Cl_2 at room temperature. The reaction worked

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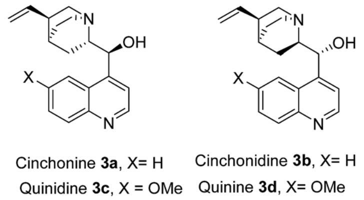
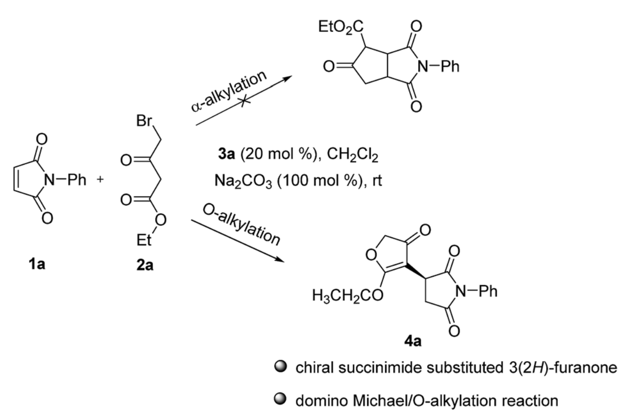


Fig. 1 Screened catalysts.

well and gave succinimide substituted 3(2*H*)-furanone **4a** in 85% yield and 68% ee *via* domino Michael/O-alkylation process not Michael/α-alkylation process (Scheme 1).

To evaluate the reactivity of this catalytic system, the reaction of *N*-phenyl maleimide **1a** with ethyl 4-bromo-acetoacetate **2a** was used as a model reaction, and four kinds of natural cinchona alkaloid catalysts were investigated in CH_2Cl_2 at room temperature (Table 1, entries 1–4). All catalysts gave good yields, quinine afforded best enantioselectivity than other catalysts and was chosen as the most suitable catalyst for further optimazation (Table 1, entry 4). Then an array of base additives were screened (Table 1, entries 4–6). Organic base Et_3N afforded good yield but poor enantioselectivity (Table 1, entry 5). Weak inorganic base $NaHCO_3$ decreased the reaction rate, afforded poor yield after reaction for 24 h (Table 1, entry 6). Inorganic base Na_2CO_3 afforded good yield and moderate enantioselectivity after reaction for 10 h. In terms of yields and enantioselectivities, Na_2CO_3 was chosen as the most suitable base additive for further optimization (Table 1, entry 4). Afterward, a series of solvents were evaluated (Table 1, entries 7–13). Halohydrocarbon solvents afforded good yield and moderate enantioselectivity (Table 1, entry 7). THF and toluene gave lower yields and enantioselectivities (Table 1, entries 9 and 10). Et_2O gave poor yield (Table 1, entry 8) and *n*-hexane gave trace product (Table 1, entry 13), the possible reason might be the poor solubility of the raw materials and catalyst in these solvents. Polar solvents such as EtOAc and acetonitrile gave good yields and poor enantioselectivities (Table 1, entries 11 and 12). A survey of solvents revealed that $CHCl_3$ was the most suitable solvent (Table 1, entry 7).

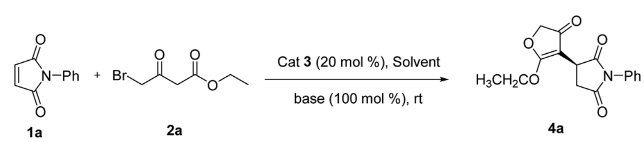


Scheme 1 Asymmetric domino Michael/O-alkylation reaction.

To further optimize the reaction conditions, reaction temperature was investigated (Table 2, entries 1–4). Decreasing reaction temperature increased enantioselectivities but slowed down the reaction rate. After reaction for 24 h, good yield could still be obtained at 0 °C (Table 2, entry 2), but further lowering the reaction temperature, the yields decreased obviously (Table 2, entries 3 and 4). 0 °C was the optimal reaction temperature. Then we examined the effect of catalyst loadings. Decreasing catalyst loadings to 10 mol% still gave good yield and enantioselectivity (Table 2, entry 5). We next examined the effect of molar ratio, increasing or lowering the molar ratio slightly influenced the yields and slightly decreased the enantioselectivities (Table 2, entries 6 and 7). The substrate concentration was also examined. It was found that increasing or lowering the substrate concentration slightly decreased the yields and enantioselectivities (Table 2, entries 8 and 9). Consequently, the following reaction conditions were recommended: 10 mol% quinine, 1 equivalent of Na_2CO_3 with 0.2 M of substrate concentration in $CHCl_3$ at 0 °C.

Under the optimal reaction conditions, the generality of this protocol was studied (Table 3). Firstly, a wide range of *N*-aromatic and aliphatic maleimides **1a–m** were studied (Table 3, entries 1–13). All gave good yields and moderate to good enantioselectivities (80–94% yield, 68–94% ee). *N*-phenyl maleimides with strong electron-withdrawing nitro group **1g** and **1i** gave slightly lower yields and enantioselectivities (Table 3, entries 7 and 9). For *N*-aliphatic maleimides, good yields and enantioselectivities could still be obtained (Table 3, entries 11–13) and *N*-benzyl maleimide gave best enantioselectivity (91% yield, 94% ee, Table 3, entry 13). In addition, methyl 4-chloroacetoacetate **2b** and ethyl 4-bromoacetoacetate **2c** were

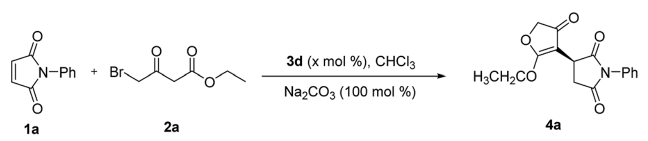
Table 1 Optimization of reaction conditions[a]



Entry	Cat.	Base	Solvent	Time (h)	Yield[b] (%)	ee[c] (%)
1	**3a**	Na_2CO_3	CH_2Cl_2	10	85	68[d]
2	**3b**	Na_2CO_3	CH_2Cl_2	10	83	64
3	**3c**	Na_2CO_3	CH_2Cl_2	10	86	68[d]
4	**3d**	Na_2CO_3	CH_2Cl_2	10	88	71
5	**3d**	Et_3N	CH_2Cl_2	2	92	49
6	**3d**	$NaHCO_3$	CH_2Cl_2	24	49	74
7	**3d**	Na_2CO_3	$CHCl_3$	10	90	75
8	**3d**	Na_2CO_3	Et_2O	10	68	52
9	**3d**	Na_2CO_3	THF	10	82	47
10	**3d**	Na_2CO_3	Toluene	10	80	68
11	**3d**	Na_2CO_3	EtOAc	10	84	19
12	**3d**	Na_2CO_3	CH_3CN	10	89	12
13	**3d**	Na_2CO_3	*n*-Hexane	10	Trace	nd

[a] Unless otherwise noted, reactions were conducted with 0.2 mmol **1a**, 0.2 mmol **2a**, 20 mol% catalyst **3**, 100 mol% base, in 1.0 mL solvent at rt. [b] Isolated yields. [c] Determined by chiral HPLC analysis. [d] Contrary configuration.

Table 2 Optimization of reaction conditions[a]



Entry	Temp (°C)	x	Time (h)	Yield[b] (%)	ee[c] (%)
1	25	20	10	90	75
2	0	20	24	91	83
3	−10	20	24	72	84
4	−20	20	24	67	85
5	0	10	24	89	83
6[d]	0	10	24	87	82
7[e]	0	10	24	92	80
8[f]	0	10	24	88	79
9[g]	0	10	24	86	82

[a] Unless otherwise noted, reactions were conducted with 0.2 mmol **1a**, 0.2 mmol **2a**, catalyst **3d**, 100 mol% Na_2CO_3, in 1.0 mL $CHCl_3$. [b] Isolated yields. [c] Determined by chiral HPLC analysis. [d] 1.5 equivs **1a** was used. [e] 1.5 equivs **2a** was used. [f] 0.5 mL $CHCl_3$ was used. [g] 2.0 mL $CHCl_3$ was used.

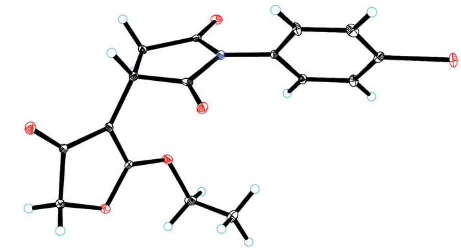
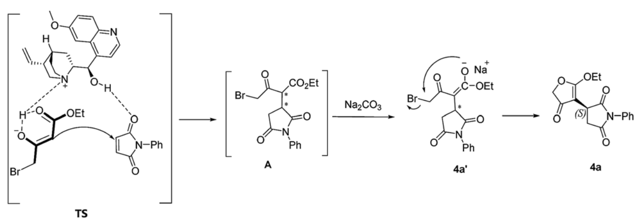


Fig. 2 X-ray crystal structure of product **4f**.

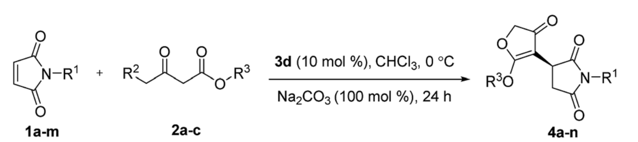


Scheme 2 Proposed mechanism.

also tested, both provided good yields and enantioselectivities (Table 3, entries 14 and 15). The absolute configuration was determined by an X-ray analysis of the single crystal of **4f**, which was assigned as (S) (Fig. 2).[20]

Based on the experimental results and the observed configuration of **4f**, a plausible mechanism is proposed in Scheme 2.[18a] The tertiary amine group of quinine catalyst activates 4-bromoacetoacetate in its enol form and the hydroxyl moiety activates maleimide through hydrogen bonding, thus the enolate would attack the maleimide from Re face *via* transition state TS (Scheme 2). Through the dual activation of quinine catalyst, Michael reaction is realized and generates intermediary Michael adduct **A**. Then in the presence of Na_2CO_3, intermediary Michael adducts **A** forms enolate ion **4a′**, which undergoes an intramolecular O-alkylation process to form the product **4a** with (*S*)-configuration.

Table 3 Scope of substrates[a]



Entry	1/R[1]	2/R[2], R[3]	4	Yield[b] (%)	ee[c] (%)
1	**1a**/C_6H_5	**2a**/Br, Et	**4a**	89	83
2	**1b**/4-$CH_3C_6H_4$	**2a**/Br, Et	**4b**	93	83
3	**1c**/4-$CH_3OC_6H_4$	**2a**/Br, Et	**4c**	90	87
4	**1d**/4-FC_6H_4	**2a**/Br, Et	**4d**	87	80
5	**1e**/4-ClC_6H_4	**2a**/Br, Et	**4e**	92	84
6	**1f**/4-BrC_6H_4	**2a**/Br, Et	**4f**	88	83
7	**1g**/4-$NO_2C_6H_4$	**2a**/Br, Et	**4g**	84	77
8	**1h**/3-FC_6H_4	**2a**/Br, Et	**4h**	87	79
9	**1i**/3-$NO_2C_6H_4$	**2a**/Br, Et	**4i**	82	68
10	**1j**/2-MeC_6H_4	**2a**/Br, Et	**4j**	80	83
11	**1k**/CH_3	**2a**/Br, Et	**4k**	94	72
12	**1l**/Cyclohexyl	**2a**/Br, Et	**4l**	85	89
13	**1m**/Bn	**2a**/Br, Et	**4m**	91	94
14	**1a**/C_6H_5	**2b**/Cl, Me	**4n**	86	78
15	**1a**/C_6H_5	**2c**/Cl, Et	**4a**	83	80

[a] Unless otherwise noted, reactions were conducted with 0.2 mmol **1a**, 0.2 mmol **2a**, 10 mol% catalyst **3d**, 100 mol% Na_2CO_3, in 1.0 mL $CHCl_3$ at 0 °C. [b] Isolated yields. [c] Determined by chiral HPLC analysis.

Conclusions

In summary, we have developed a new organocatalytic asymmetric domino Michael/O-alkylation reaction of maleimides with γ-halogenated-β-ketoesters catalyzed by simple, cheap, and commercially available quinine. The substrates are also commercially available. A wide range of new chiral succinimide substituted 3(2*H*)-furanones were smoothly obtained in high yields (up to 94%) and good enantioselectivities (up to 94% ee). Further, expansion of these new succinimide substituted 3(2*H*)-furanones to access products with known biological activities or new biologically significant molecules and testing their pharmacological activities are ongoing in our laboratory.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

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