OL | Organic Letters

Cite This: Org. Lett. XXXX, XXX, XXX−XXX

Letter

pubs.acs.org/OrgLett

Phosphine-Mediated MBH-Type/Umpolung Addition Domino Sequence: Divergent Construction of Coumarins

Zhi-Xiong Deng,[†,∥] Yu Zheng,[†,∥] Zhen-Zhen Xie,[†] Yue-Heng Gao,[†] Jun-An Xiao,[§] Si-Qi Xie,[†] Hao-Yue Xiang,*[,†] Xiao-Qing Chen,*[,†,‡] and Hua Yang*[,†,‡]

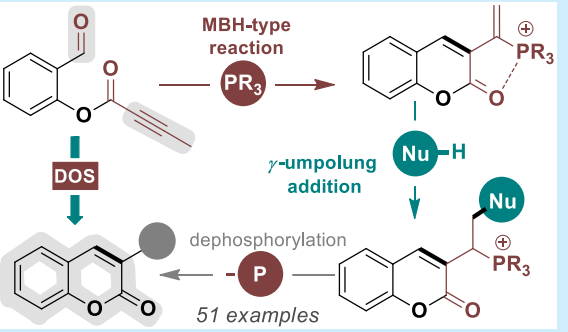
[†]College of Chemistry and Chemical Engineering, Central South University, Changsha 410083, P. R. China

[‡]Key Laboratory of Hunan Province for Water Environment and Agriculture Product Safety, Central South University, Changsha 410083, P. R. China

[§]Guangxi Key Laboratory of Natural Polymer Chemistry and Physics, Nanning Normal University, Nanning 530001, P. R. China

Supporting Information

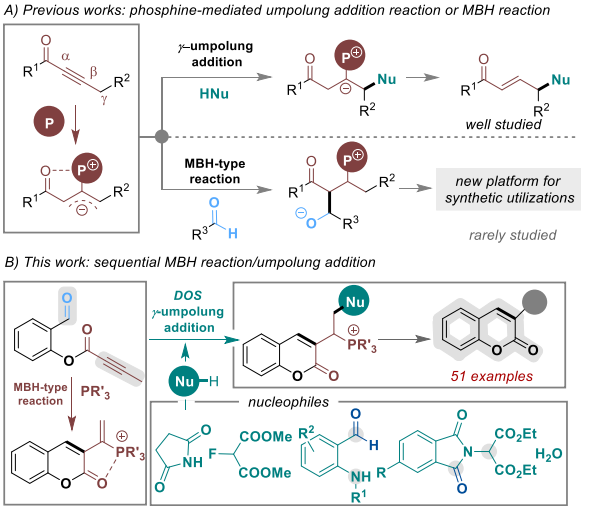
ABSTRACT: We herein report a phosphine-mediated domino process of MBH-type reaction/umpolung γ-addition through the rational integration of the privileged reactivities of alkynoate. Simply by manipulating the nucleophilic reagent, the developed protocol offers a facile, diversity-oriented construction of a wide range of three-substituted coumarins.



The past decades have witnessed the blossom of phosphine-mediated transformations, many of which are playing vital roles in carbon−carbon (C−C) bond-forming events.[1] Recently, because of their unique synthetic potentials and reactivity, activated alkynes have been proven to be suitable substrates for a range of phosphine-mediated reactions.[2] Mechanistically, these phosphine-mediated transformations mainly depend on the formation of key zwitterionic intermediates, which can be generated through the 1,4-addition of phosphine to activated alkynes (Scheme 1A).[3] Prominently, when a suitable nucleophile is available, a process known as the umpolung γ-addition reaction may readily occur.[4] Alternatively, being one of the earliest disclosed phosphine-catalyzed reactions, the Morita−Baylis−Hillman (MBH) reaction could serve as an effective synthetic platform for the construction of C−C bonds as well.[5] Nevertheless, as stated in Kataoka's report,[6] a longstanding challenge is still waiting to be addressed for the mechanistically difficult MBH-type reaction of the activated alkynes. In 2018, Ramasastry's group[7] unveiled an unprecedented case for the MBH-type reaction of α,β-ynones, providing access to a variety of heteroarenes. Obviously, the success of this strategy will expand the dimension of phosphine chemistry.

Inspired by these advances, we rationalized that the preinstallation of an electrophilic moiety at the suitable position of alkynoate might facilitate the intramolecular MBH-type reaction to generate the corresponding zwitterionic intermediate, which could be trapped by external nucleophiles to effect an umpolung γ-addition. Following this rationale, we designed a sequential MBH reaction/umpolung addition process by installing the alkynoate moiety into salicylaldehyde substrates, leading to the rapid construction of structurally diverse three-substituted coumarins by readily varying nucleophiles (Scheme 1B).

Scheme 1. Synthetic Profiles of Phosphine-Mediated Reactions of Alkynoates and the Rationale of This Work



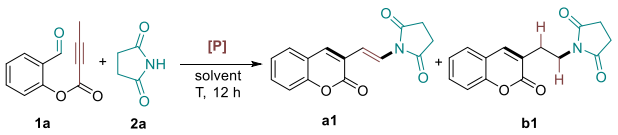
Received: November 26, 2019

DOI: 10.1021/acs.orglett.9b04248
Org. Lett. XXXX, XXX, XXX−XXX

Coumarin and its derivatives, as privileged scaffolds, are widely encountered in natural and synthetic compounds with a wide range of pharmacological properties.[8] Although impressive advances in the construction of coumarins have been encouragingly achieved,[9] the diversity-oriented synthesis (DOS) of this class of significant heterocycles is always an everlasting goal being pursued by synthetic and medicinal chemists. In this work, by manipulating the nucleophilic reagents, the newly developed protocol offers a facile, diversity-oriented construction of a wide range of three-substituted coumarins, which would surely enrich the library of coumarins.

Initially, alkynoate **1a** and 2,5-pyrrolidinedione **2a** were used as the substrates to test our hypothesis (Table 1). It was found that the reaction proceeded smoothly in the presence of $MePPh_2$ (50 mol %) and 4 Å MS in anhydrous $PhCH_3$ at 80 °C, along with AcOH/AcONa as a buffer solution.[4] Interestingly, both the corresponding product **a1** and its reduced analogue **b1** were isolated in 44 and 15% yields, respectively (entry 1). Next, various phosphines were then investigated to modulate the product formation (entries 2−5). It was found that $P(p\text{-Tol})_3$ favored the generation of product **a1**. The effect of reaction temperature was then investigated but with no improved yield (entries 6 and 7). Afterward, the solvent effect was also evaluated (entries 8−10), and anhydrous CH_3CN was finally proven to be the optimal solvent for the formation of **a1** (entry 8). Next, we would like to manipulate the chemoselectivity, allowing the selective formation of the reduced product **b1**. A literature survey disclosed that the presence of water is beneficial for the phosphine-involved reductive reactions.[3a] Thus 10 equiv of water and a stoichiometric amount of phosphine were then used. Similarly, the effects of phosphine, temperature, and solvent were investigated (entries 11−20). $P(p\text{-FPh})_3$ and $PhCH_3$ gave the best results, whereas the formation of **a1** was almost completely sequestered (entry 16). It is worth mentioning that, to a certain extent, the pH value of the reaction media has an impact on the chemical yields of **a1** and **b1** (entries 21 and 22). Gratifyingly, the practicality and scalability of this protocol were successfully demonstrated by performing the reaction for **a1** on a 1 mmol scale under the standard reaction conditions to give a similar result without any loss of efficiency (entry 23).

Table 1. Optimization of Reaction Conditions[a]



entry	solvent	[P]	T (°C)	yield (%) (**a1**/**b1**)[b]
1[c]	$PhCH_3$	$MePPh_2$	80	44/15
2[c]	$PhCH_3$	$P(n\text{-Bu})_3$	80	−/−
3[c]	$PhCH_3$	$P(p\text{-Tol})_3$	80	48/trace
4[c]	$PhCH_3$	$P(p\text{-FPh})_3$	80	20/30
5[c]	$PhCH_3$	PPh_3	80	30/10
6[c]	$PhCH_3$	$P(p\text{-Tol})_3$	100	47/6
7[c]	$PhCH_3$	$P(p\text{-Tol})_3$	50	42/10
8[c]	**CH_3CN**	**$P(p\text{-Tol})_3$**	**80**	**60/trace**
9[c]	THF	$P(p\text{-Tol})_3$	80	44/trace
10[c]	IPA	$P(p\text{-Tol})_3$	80	12/11
11[d]	$PhCH_3$	$MePPh_2$	80	15/50
12[d]	$PhCH_3$	PPh_3	80	8/50
13[d]	$PhCH_3$	$P(n\text{-Bu})_3$	80	9/−
14[d]	$PhCH_3$	$P(p\text{-FPh})_3$	80	trace/80
15[d]	$PhCH_3$	$P(p\text{-Tol})_3$	80	40/20
16[d]	**$PhCH_3$**	**$P(p\text{-FPh})_3$**	**50**	**trace/84**
17[d]	$PhCH_3$	$P(p\text{-FPh})_3$	20	10/38
18[d]	CH_3CN	$P(p\text{-FPh})_3$	50	12/52
19[d]	THF	$P(p\text{-FPh})_3$	50	trace/78
20[d]	IPA	$P(p\text{-FPh})_3$	50	13/35
21[e]	CH_3CN	$P(p\text{-Tol})_3$	80	51/trace
22[f]	$PhCH_3$	$P(p\text{-FPh})_3$	50	trace/70
23[c,g]	CH_3CN	$P(p\text{-Tol})_3$	80	61/trace

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.4 mmol), phosphine (0.1 mmol), and solvent (2 mL), 12 h. [b]Isolated yields. [c]Anhydrous solvent with 4 Å MS (100 mg), AcOH/AcONa (0.1 mmol/0.1 mmol), and 0.1 mmol of phosphine was used. [d]10 equiv of H_2O, AcOH/AcONa (0.1 mmol/0.1 mmol), and 0.24 mmol of phosphine were used. [e]Anhydrous solvent with 4 Å MS (100 mg) and 0.1 mmol of phosphine was used. [f]10 equiv of H_2O and 0.24 mmol of phosphine were used. [g]Performed on 1 mmol scale for **1a**.

We were pleased to observe the diversified reactivities of this designed domino sequence, which prompted us to extensively evaluate the scope of alkynoates **1** as well as nucleophiles **2**, including C-, N-, and O-centered nucleophiles (Scheme 2). First, by using **2a** as the nucleophile, the substitution patterns on alkynoate **1** were investigated, and moderate to good yields were generally achieved in these transformations (**a1**−**10** and **b1**−**10**), whereas the yields for the series of products **b** were slightly better than those for the corresponding products **a**. Subsequently, further efforts were devoted to exploiting the diversity of the nucleophile. Encouragingly, dimethyl fluoromalonate **2b**, as a C-centered nucleophile, was also compatible with this phosphine-mediated reaction system, although with lower yields (**c1**−**4**). Furthermore, aiming to expand the dimension of the structural complexity of coumarins, other nucleophiles bearing a nucleophilic site and electrophilic site simultaneously (**2c**−**f**) were also taken into consideration. We envisaged that employing *o*-aminobenzaldehyde by introducing a carbonyl group at the ortho position of aniline would allow us to design a new domino process, MBH reaction/umpolung γ-addition/Witting reaction, delivering difficultly accessible heterocycles. By slightly modifying the reaction system, a wide range of novel coumarins possessing significant dihydroquinoline (**d1**−**11**) were rapidly installed, in which good yields were generally achieved and diverse functional groups were well tolerated. Interestingly, phthalimidomalonate, bearing a C-centered nucleophilic site and electrophilic site simultaneously, was also conducive to this MBH reaction/umpolung γ-addition/Witting reaction sequence, successfully delivering novel pyrroloisoindolinone-attached coumarins (**e1**−**3**). To investigate whether the transformation could be directly trapped by water, the reaction was conducted without adding any extra nucleophile. Interestingly, the desired products 3-vinyl coumarins **f1**−**9** were obtained in good yield. Ultimately, the structures of this series of compounds were unequivocally confirmed by X-ray crystallographic analysis (**a1**, **c1**, and **d6**).

Whereas this attractive domino sequence offers a facile pathway for rapidly enriching the library of coumarins, we questioned whether the strategy could be extended to *N*-(2-formylphenyl)-2-butynamide, thus generating quinolinones. Significantly, *N*-(2-formylphenyl)-2-butynamide **3** was also proven to be suitable for these transformations, giving the corresponding quinolinones (**g1**−**4**) by simply modulating the

DOI: 10.1021/acs.orglett.9b04248
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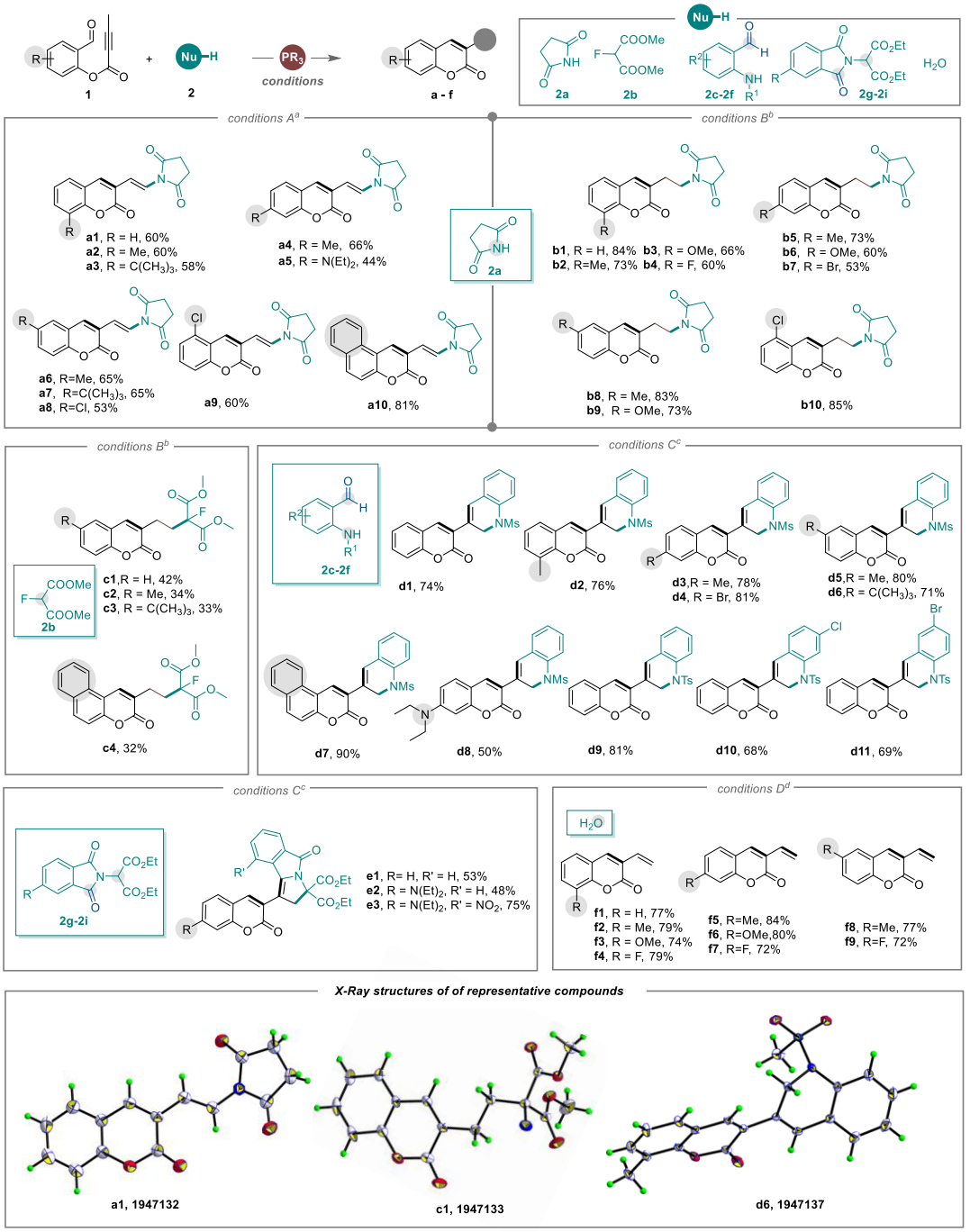
Scheme 2. Diversity-Oriented Studies on the Scope of Alkynoates 1 and Nucleophiles 2



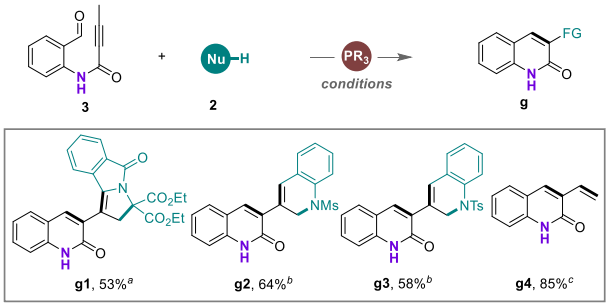
[a]Conditions A: **1** (0.3 mmol), **2a** (0.6 mmol), P(*p*-Tol)$_3$ (0.15 mmol), AcOH/AcONa (0.15 mmol/0.15 mmol) and 4 Å MS (150 mg) in anhydrous CH_3CN (2 mL), 80 °C, 12 h, isolated yields. [b]Conditions B: **1** (0.3 mmol), **2a** or **2b** (0.6 mmol), P(*p*-FPh)$_3$ (0.36 mmol), AcOH/AcONa (0.15 mmol/0.15 mmol), and H_2O (3 mmol) in $PhCH_3$ (2 mL), 50 °C, 12 h, isolated yields. [c]Conditions C: **1** (0.4 mmol), **2c**-**2g** (0.2 mmol), $MePPh_2$ (0.24 mmol) and 4 Å MS (100 mg) in anhydrous CH_3CN (2 mL), 50 °C, 12 h, isolated yields. [d]Conditions D: **1** (0.3 mmol), P(*p*-Tol)$_3$ (0.36 mmol) AcOH/AcONa (0.15 mmol/0.15 mmol) in $PhCH_3$ (2 mL), 30 °C, 12 h, isolated yields.

nucleophiles under the corresponding conditions (Scheme 3). These results further demonstrate the diversity-oriented feature of this designed reaction sequence.

To gain mechanistic insights into the reaction pathways, a series of monitoring experiments by ^{31}P NMR spectroscopy and labeling experiments were carried out (Figure 1; see the Supporting Information for details). $MePPh_2$ and $MePPh_2$=O show characteristic peaks at −27 and 31 ppm, respectively. Interestingly, while mixing **1a** with $MePPh_2$, three distinct peaks around 31, 29, and 18 ppm were observed after 6 h. Upon mixing **1a** and **2a** with $MePPh_2$, only the characteristic peak for $MePPh_2$=O at 31 ppm was observed after 6 h. These results suggest that phosphine was actively involved with the formation of the intermediates (29 and 18 ppm) (Figure 1A). Meanwhile, the reaction mixture was also examined in situ by HRMS. Encouragingly, the initial MBH-type adduct ylide **I**,

DOI: 10.1021/acs.orglett.9b04248
Org. Lett. XXXX, XXX, XXX−XXX

Scheme 3. Extension of the Designed Domino Sequence to the Synthesis of Quinolinones



[a]Conditions: **3** (0.4 mmol), **2c** or **2d** or **2g** (0.2 mmol), $MePPh_2$ (0.1 mmol), and 4 Å MS (100 mg) in anhydrous CH_3CN (2 mL), 50 °C, 12 h, isolated yield. [b]Conditions: **3** (0.3 mmol), P(*p*-Tol)$_3$ (0.36 mmol), AcOH/AcONa (0.15 mmol/0.15 mmol) in $PhCH_3$ (2 mL), 30 °C, 12 h, isolated yield. [c]Conditions: **3** (0.3 mmol), P(*p*-Tol)$_3$ (0.36 mmol), AcOH/AcONa (0.15 mmol/0.15 mmol) in $PhCH_3$ (2 mL), 30 °C, 12 h, isolated yield.

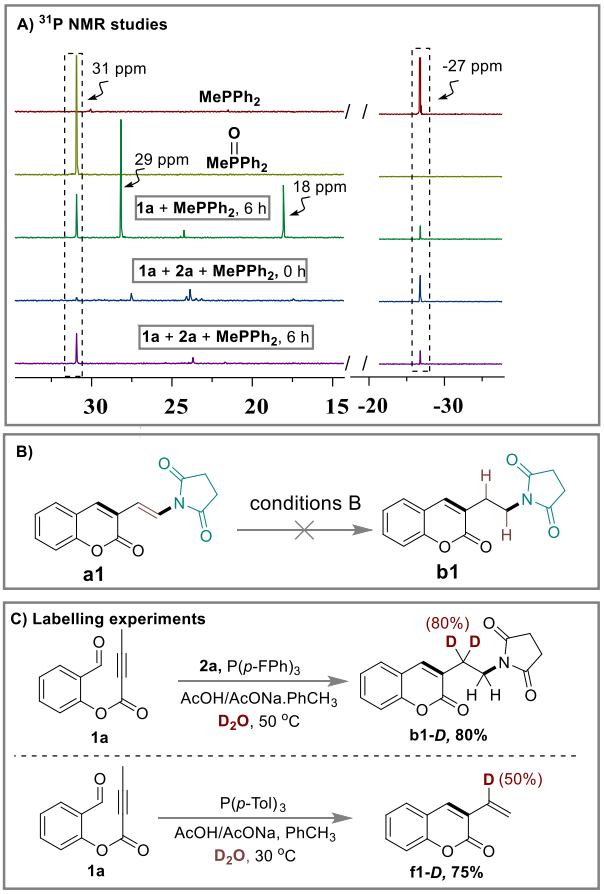
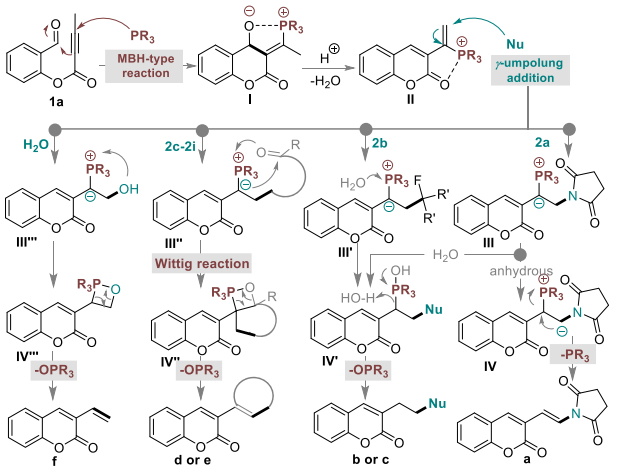


Figure 1. ^{31}P NMR, ESI-MS studies, and labeling experiments.

the dehydration intermediate **II**, and the γ-addition intermediate **III** were able to be detected in the mixture of **1a** with $MePPh_2$, respectively. To verify whether **a1** is the precursor of **b1**, **a1** was subjected to the reaction conditions B. It was found that compound **b1** was unable to be obtained under these conditions (Figure 1B). As a consequence, we speculated that the reductant for this transformation was the phosphine. Moreover, by adding D_2O to the reaction system, the corresponding deuterated products **b1**-**D** and **f1**-**D** were able to be detected, indicating that water served as the major proton source during the process (Figure 1C).

On the basis of previous reports[3a,10] and our control experiments, we propose a plausible mechanism for this phosphine-mediated domino process (Scheme 4). Initially, a

Scheme 4. Proposed Mechanism



conjugate addition of PR_3 to alkynoate **1a**, followed by an intramolecular nucleophilic attack to the aldehyde moiety (MBH-type reaction) were underwent to generate the ylide intermediate **I**. The subsequent protonation and dehydration of ylide **I** delivered the phosphonium **II**. The phosphonium **II** is susceptible to the attacks by various nucleophiles, leading to ylide intermediates. Finally, dephosphorylation of intermediates gave diverse coumarins via divergent pathways: (1) Under anhydrous conditions **A**, the direct elimination of phosphine of **III** would be favored, giving the conjugate coumarin analogue **a**. (2) In the presence of excess water, intermediate **III** was prone to being attacked by water rather than undergoing an elimination process. Further releasing the corresponding phosphine oxide of the intermediates **IV′** ultimately furnished the corresponding products **b**. (3) The placement of a carbonyl group juxtaposed with respect to a nucleophile would promote an intramolecular cyclization to generate the corresponding products **d** and **e**. (4) In the absence of any extra nucleophile, the intermediate **II** would be directly attacked by water to furnish the corresponding intermediate **III‴**, which would further deliver the final products **f**. As we can see, the structural features and the reaction conditions would significantly affect the late-stage pathways, facilitating the diversity-oriented synthesis of coumarin scaffolds.

In summary, we herein present a phosphine-mediated domino process to assemble a wide range of coumarins with high structural diversity, in which the MBH-type reaction, umpolung γ-addition, and Witting reaction are rationally integrated. This phosphine-mediated transformation demonstrates high tolerance for the nucleophilic partners with diversified structural features. As a result, a wide range of coumarins with novel skeletons were rapidly assembled. Moreover, intriguing mechanistic details governing these processes were also elucidated. We believe that this work will inspire the extensive exploitation of the phosphine-mediated transformations in designing efficient pathways to access synthetically challenging heterocycles.

DOI: 10.1021/acs.orglett.9b04248
Org. Lett. XXXX, XXX, XXX−XXX

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.orglett.9b04248.

Experimental procedures and spectral data for all new compounds (PDF)

Accession Codes

CCDC 1947132−1947133, 1947135, and 1947137 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: xianghaoyue@csu.edu.cn (H.-Y.X.).
*E-mail: xqchen@csu.edu.cn (X.-Q.C.).
*E-mail: hyangchem@csu.edu.cn (H.Y.)

ORCID

Hao-Yue Xiang: 0000-0002-7404-4247
Xiao-Qing Chen: 0000-0002-8768-8965
Hua Yang: 0000-0002-5518-5255

Author Contributions

‖Z.X.D. and Y.Z. contributed equally.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We gratefully acknowledge the financial support from the National Natural Science Foundation of China (21576296, 21776318, 21676302, and 81703365), Central South University, and Guangxi Teachers Education University.

■ REFERENCES

(1) (a) Lu, X.-Y; Zhang, C.-M; Xu, Z.-R. Reactions of Electron-Deficient Alkynes and Allenes under Phosphine Catalysis. *Acc. Chem. Res.* **2001**, *34*, 535−544. (b) Ye, L.-W.; Zhou, J.; Tang, Y. Phosphine-Triggered Synthesis of Functionalized Cyclic Compounds. *Chem. Soc. Rev.* **2008**, *37*, 1140−1152. (c) Guo, H.-C; Fan, Y.-C.; Sun, Z.-H; Wu, Y.; Kwon, O. Phosphine Organocatalysis. *Chem. Rev.* **2018**, *118*, 10049−10293.

(2) (a) Kuroda, H.; Tomita, I.; Endo, T. Novel Phosphine-Catalyzed Zipper Cyclization of Aliphatic Diyne-Dione and Yue-Dione Systems. *Org. Lett.* **2003**, *5*, 129−131. (b) Najera, C.; Sydnes, L. K.; Yus, M. Conjugated Ynones in Organic Synthesis. *Chem. Rev.* **2019**, *119*, 11110−11244. (c) Meng, L.-G.; Cai, P.; Guo, Q.; Xue, X. Cycloaddition of Alkynyl Ketones with N-Tosylimines Catalyzed by Bu_3P and DMAP: Synthesis of Highly Functionalized Pyrrolidines and Azetidines. *J. Org. Chem.* **2008**, *73*, 8491−8496. (d) Deng, Z.-X.; Xie, Z.-Z.; Zheng, Y.; Xiao, J.-A.; Wang, R.-J.; Xiang, H.-Y.; Yang, H. Intramolecular Hydrogen-Bonding-Assisted Phosphine-Catalysed [3 + 2] Cyclisation of Ynones with O-hydroxy/Amino Benzaldehydes. *Org. Biomol. Chem.* **2019**, *17*, 2187−2191.

(3) (a) Xia, Y.-Z; Liang, Y.; Chen, Y.; Wang, M.; Jiao, L.; Huang, F.; Liu, S.; Li, Y.; Yu, Z.-X. An Unexpected Role of a Trace Amount of Water in Catalyzing Proton Transfer in Phosphine-Catalyzed (3 + 2) Cycloaddition of Allenoates and Alkenes. *J. Am. Chem. Soc.* **2007**, *129*, 3470−3471. (b) Nair, V.; Menon, R. S.; Sreekanth, A. R.; Abhilash, N.; Biju, A. T. Engaging Zwitterions in Carbon-Carbon and Carbon-Nitrogen Bond-Forming Reactions: A Promising Synthetic Strategy. *Acc. Chem. Res.* **2006**, *39*, 520−530.

(4) Trost, B. M.; Li, C.-J. Novel "Umpolung" in C-C Bond Formation Catalyzed by Triphenylphosphine. *J. Am. Chem. Soc.* **1994**, *116*, 3167−3168.

(5) (a) Basavaiah, D.; Venkateswara Rao, K.; Jannapu Reddy, R. J. The Baylis-Hillman Reaction: A Novel Source of Attraction, Opportunities, and Challenges in Synthetic Chemistry. *Chem. Soc. Rev.* **2007**, *36*, 1581−1588. (b) Shi, Y.-L.; Shi, M. Aza-Baylis-Hillman Reactions and Their Synthetic Applications. *Eur. J. Org. Chem.* **2007**, *2007*, 2905−2916.

(6) Kataoka, T.; Kinoshita, H.; Kinoshita, S.; Iwamura, T.; Watanabe, S.-I. A Convenient Synthesis of α-Halomethylene Aldols or β-Halo−(hydroxyalkyl) Acrylates using The Chalcogeno-Baylis-Hillman Reaction. *Angew. Chem., Int. Ed.* **2000**, *39*, 2358−2360.

(7) Mondal, A.; Hazra, R.; Grover, J.; Raghu, M.; Ramasastry, S. S. V. Organophosphine-Catalyzed Intramolecular Hydroacylation of Activated Alkynes. *ACS Catal.* **2018**, *8*, 2748−2753.

(8) (a) Robert, S.; Bertolla, C.; Masereel, B.; Dogné, J. M.; Pochet, M. Novel 3-Carboxamide-Coumarins as Potent and Selective FXIIa Inhibitors. *J. Med. Chem.* **2008**, *51*, 3077−3080. (b) Maresca, A.; Temperini, C.; Pochet, L.; Masereel, B.; Scozzafava, A.; Supuran, C. T. Deciphering the Mechanism of Carbonic Anhydrase Inhibition with Coumarins and Thiocoumarins. *J. Med. Chem.* **2010**, *53*, 335−344. (c) Cao, D.-X; Liu, Z.-Q; Verwilst, P.; Koo, S.; Jangjili, P.; Kim, J. S.; Lin, W. Coumarin-Based Small-Molecule Fluorescent Chemosensors. *Chem. Rev.* **2019**, *119*, 10403−10519.

(9) (a) Pratap, R.; Ram, V. J. Natural and Synthetic Chromenes, Fused Chromenes, and Versatility of Dihydrobenzo[h]Chromenes in Organic Synthesis. *Chem. Rev.* **2014**, *114*, 10476−10526. (b) Zheng, D.; Yu, J.; Wu, J. Generation of Sulfonyl Radicals from Aryldiazonium Tetrafluoroborates and Sulfur Dioxide: The Synthesis of 3-Sulfonated Coumarins. *Angew. Chem., Int. Ed.* **2016**, *55*, 11925−11929. (c) Zhu, F.; Li, Y.; Wang, Z.; Wu, X.-F. Iridium-Catalyzed Carbonylative Synthesis of Chromenones from Simple Phenols and Internal Alkynes at Atmospheric Pressure. *Angew. Chem., Int. Ed.* **2016**, *55*, 14151−14154.

(10) (a) Lorton, C.; Voituriez, A. Phosphine-Promoted Synthesis of 9H-Pyrrolo[1,2-a]Indole Derivatives Via an γ-Umpolung Addition/Intramolecular Wittig Reaction. *J. Org. Chem.* **2018**, *83*, 5801−5806. (b) Huang, Z.-S; Chen, Q.-Q; Yang, X.-Q; Liu, Y.; Zhang, L.; Lu, T.; Zhou, Q.-F. Phosphine-Mediated Domino Reactions of Phthalimido-malonates with Allenoates or But-2-Ynoate: Facile Entry into Highly Functionalized Pyrroloisoindolinone Derivatives. *Org. Chem. Front.* **2017**, *4*, 967−971. (c) Zhang, K.; Cai, L.-C; Yang, Z.-Y; Houk, K. N.; Kwon, O. Bridged [2.2.1] Bicyclic Phosphine Oxide Facilitates Catalytic γ-Umpolung Addition-Wittig Olefination. *Chem. Sci.* **2018**, *9*, 1867−1872. (d) Schweizer, Z. Z.; Smucker, L. D.; Votral, R. J. Reactions of Phosphorus Compounds. VII. A General Chain-Extension Reaction. *J. Org. Chem.* **1966**, *31*, 467−471.

DOI: 10.1021/acs.orglett.9b04248
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