PPh_3-catalyzed unexpected α-addition reaction of 1-(*o*-hydroxyaryl)-1,3-diketones to terminal alkynoates: a straightforward synthesis of multifunctional vinylesters†

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PPh_3-catalyzed α-addition reactions of 1-(*o*-hydroxyaryl)-1,3-diketones to terminal alkynoates involving carbon–carbon bond cleavage to give multifunctional vinylesters are described.

Vinylesters are important intermediates in organic synthesis. They have served as key building blocks in the preparation of nitrogen-containing molecules and used as monomers in polymerization.[1,2] Moreover, they have also been used as valuable synthetic intermediates in total synthesis[3] and as versatile building blocks for many functionalized molecules.[4] Recently, the carbon–carbon bond-forming reaction, using electron-deficient alkynes as a source of carbon nucleophiles, has been a useful method in organic synthesis.[5] Trost, Taran and co-workers have reported the phosphine-catalyzed α-addition of activated methylenes to deficient-electronic alkynes for the preparation of vinylesters.[6]

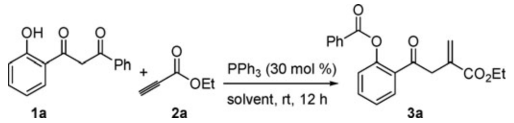
Recently, we have also described the PPh_3-catalyzed α-addition of 1,3-dicarbonyl compounds to acetylenic ketones and the α-addition of aromatic aldehydes to terminal alkynoates to provide various vinylesters.[7] In continuation of our interest in developing new addition reactions, we further investigate the possibility of α-addition reactions of 1-(*o*-hydroxyaryl)-1,3-diketones to terminal alkynoates in the presence of PPh_3. Fortunately, an unexpected α-addition reaction occurred, involving carbon–carbon bond cleavage. Chemical transformations *via* carbon–carbon bond cleavage have received much attention in recent years because new skeletons can be constructed directly by such reactions.[8] However, most of those reactions rely on transition metal catalysis. Herein, we report the PPh_3-catalyzed α-addition of 1-(*o*-hydroxyaryl)-1,3-diketones to terminal alkynoates, involving carbon–carbon bond cleavage, for the synthesis of multifunctional vinylesters.

Our studies were initiated by the addition of 0.3 equiv. of PPh_3 to a solution of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione (**1a**) and 1.1 equiv. of ethyl propiolate (**2a**) under various reaction conditions; the results are shown in Table 1. The reaction of **1a** with **2a** in the presence of PPh_3 in CH_2Cl_2 at room temperature for 12 h afforded a colorless solid in 59% yield that was characterized as compound **3a** by NMR and HRMS spectra. The structure of **3a** was further confirmed unambiguously using single crystal X-ray analysis (Fig. 1 in ESI†).

The amount of PPh_3 catalyst has a slight effect on this reaction. Desired product **3a** was obtained in 51% yield when 20 mol% PPh_3 was used. The yield of the product was not improved by further increasing the amount of PPh_3. The yield of **3a** was unsuccessfully improved under reflux conditions but decreased sharply when the reaction was stirred at 0 °C. PPh_3 as a catalyst was crucial for the course of this reaction. The use of other organic bases, such as tributylphosphine, 1,4-diazabicyclo[2,2,2]-octane (DABCO), triethylamine (Et_3N) and pyridine, did not give the desired product. The choice of Et_2O and toluene as solvents gave the desired product **3a** in 58 and 59% yields, respectively. With tetrahydrofuran (THF), acetone or dimethylformamide (DMF), **3a** was produced in a relatively low yield.

With the reaction conditions optimized for the formation of **3a**, subsequently we investigated the scope and limitations of this reaction. Various 1-(*o*-hydroxyaryl)-1,3-diketones were subjected to the reaction under the standard conditions; representative results are shown in Table 2. When R^1 was an aromatic group, the reaction worked smoothly, giving the

Table 1 The reaction of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione (**1a**) with ethyl propiolate (**2a**)



Entry	Equiv. **1a**	Equiv. **2a**	Solvent	Yield (%)[a]
1	1.0	1.1	CH_2Cl_2	59
2	1.0	1.1	CH_2Cl_2	51[b]
3	1.0	1.1	CH_2Cl_2	60[c]
4	1.0	1.5	CH_2Cl_2	59
5	1.5	1.0	CH_2Cl_2	58
6	1.0	1.1	CH_2Cl_2	< 5[d]
7	1.0	1.1	CH_2Cl_2	61[e]
8	1.0	1.1	Et_2O	58
9	1.0	1.1	Toluene	59
10	1.0	1.1	THF	49
11	1.0	1.1	Acetone	30
12	1.0	1.1	DMF	15

[a] Isolated yield. [b] 20 mol% of PPh_3 was used. [c] 40 mol% of PPh_3 was used. [d] At 0 °C. [e] At reflux.

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[b] *Department of Chemistry, University of Science and Technology of China, Hefei 230026, P. R. China*

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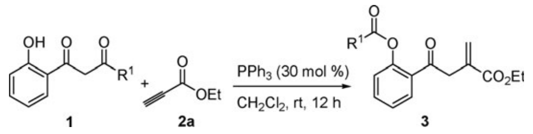
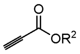
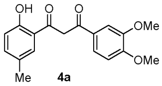
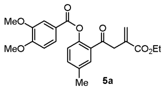
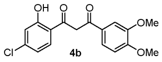
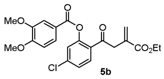
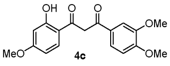
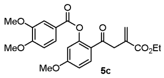
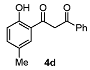
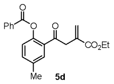
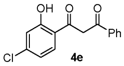
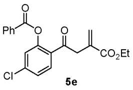
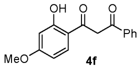
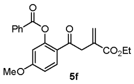
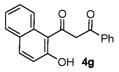
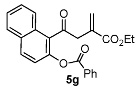
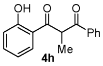
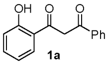
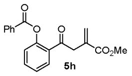
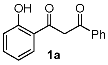
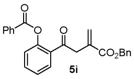
Table 2 Reactions of 1-(2-hydroxyphenyl)-3-aryl-1,3-diones with **2a** catalyzed by PPh$_3$ (30 mol%)



Entry	R^1	Product	Yield (%)^a
1	C_6H_5	**3a**	59
2	4-$CH_3OC_6H_4$	**3b**	70
3	3,4-$(CH_3O)_2C_6H_3$	**3c**	82
4	4-$CH_3C_6H_4$	**3d**	61
5	4-FC_6H_4	**3e**	40
6	4-ClC_6H_4	**3f**	45
7	4-BrC_6H_4	**3g**	48
8	4-$NO_2C_6H_4$	—	Trace
9	1-Thiophenyl	**3h**	41

[a] Isolated yield.

Table 3 Reactions of multi-substituted 1-(2-hydroxyaryl)-3-aryl-1,3-diones **4** with terminal alkynoates **2** catalyzed by PPh$_3$ (30 mol%)

Entry	Substrate		Product	Yield (%)^a
1	 4a	Et	 5a	78
2	 4b	Et	 5b	46
3	 4c	Et	 5c	51
4	 4d	Et	 5d	50
5	 4e	Et	 5e	26
6	 4f	Et	 5f	33
7	 4g	Et	 5g	45
8	 4h	Et	NR^b	—
9	 1a	Me	 5h	46
10	 1a	$C_6H_5CH_2$	 5i	55

[a] Isolated yield. [b] NR = no reaction.

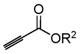
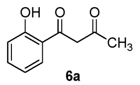
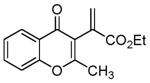
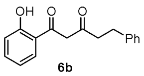
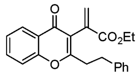
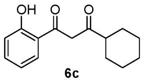
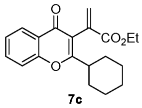
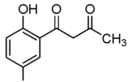
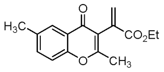
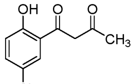
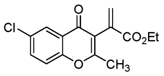
desired multifunctional vinylesters **3** in moderate to good yields. Clearly, the substituents on the aromatic ring had an effect on the reaction yield. Substrates with an electron-donating group on the aromatic ring gave better yields than those with an electron-withdrawing group on the aromatic ring. For example, substrates with 4-methoxy and 3,4-dimethoxy groups on the aromatic ring afforded the corresponding products **3b** and **3c** in 70 and 82% yields, respectively. However, the substrate with a nitro group in the *para*-position of the aromatic ring gave only a trace amount of the desired product under the same conditions. Notably, when a heteroaromatic 1,3-diketone, such as 1-(2-hydroxyphenyl)-3-(thiophen-2-yl) propane-1,3-dione, was subjected to this reaction, the corresponding product, **3h**, was obtained in 41% yield.

To further evaluate the scope of this reaction, multi-substituted 1-(2-hydroxyaryl)-3-aryl-1,3-diones **4a–h** were synthesized and tested under the standard conditions; these results are summarized in Table 3. The treatment of substrates **4a–c** with **2a** in the presence of 30 mol% PPh$_3$ afforded the corresponding products **5a–c** in 78, 46 and 51% yield, respectively. Substrates **4d–g** could be converted into the corresponding products, albeit with lower yields. However, no reaction was observed under the same conditions when α-substituted β-diketone **4h** was submitted to this reaction, which might be due to steric hindrance of the methyl group. On the other hand, terminal methyl and benzyl propiolates could also be transformed into the corresponding products **5h** and **5i** in moderate yields. In many cases, the moderate yields obtained in the reaction could be accounted for by the formation of other by-products, which could not be isolated by column chromatography.

We next extended the reaction to 1-(2-hydroxyaryl)-3-alkyl-1,3-dione substrates **6**. The desired multifunctional vinylesters **3** or **5** were not formed, but a new product was found when the reaction was carried out under the above standard conditions. For example, the exposure of 1-(2-hydroxyphenyl)butane-1,3-dione **6a** to **2a** in the presence of PPh$_3$ (30 mol%) at room temperature for 12 h gave a new structure of a chromone derivative in 49% yield, which was characterized as compound **7a** by NMR and HRMS spectra. The yield of **7a** increased to 59% when the reaction was performed at 0 °C for 24 h. Various multi-substituted 1-(2-hydroxyaryl)-3-alkyl-1,3-diones were also reacted smoothly with **2a** to give chromone derivatives in moderate yields; the experimental results are summarized in Table 4.

On the basis of these experiments and previous investigations,[6] a mechanistic pathway for this unexpected PPh$_3$-catalyzed α-addition reaction of 1-(*o*-hydroxyaryl)-1,3-diketones to ethyl propiolates is proposed in Scheme 1. The reaction could be triggered by the nucleophilic addition of PPh$_3$ to the electron-deficient multiple bond to produce zwitterion **8**, which then deprotonates the 1-(*o*-hydroxyaryl)-1,3-diketone to generate **9** and **10**. Intermediate **10** could give enolate **11** through a proton transfer step. Enolate **11** could then undergo a

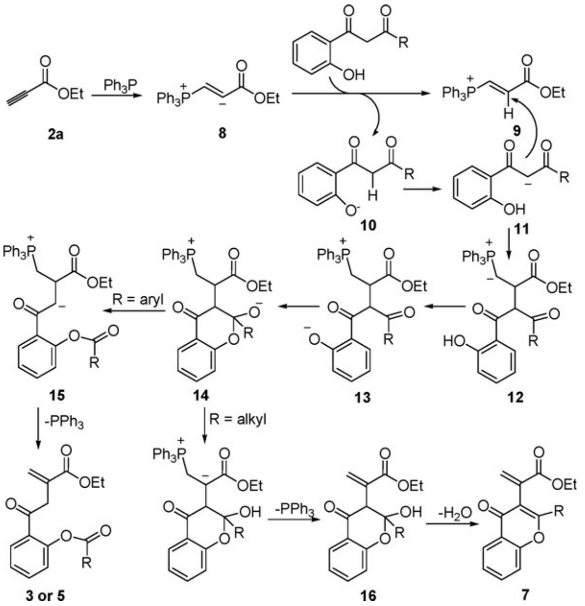
Table 4 Reactions of 1-(2-hydroxyaryl)-3-alkyl-1,3-diones with ethyl propiolate catalyzed by PPh_3 (30 mol%)

Entry	Substrate	 R^2	Product	Yield (%)[a]
1	 **6a**	Et	 **7a**	59
2	 **6b**	Et	 **7b**	46
3	 **6c**	Et	 **7c**	38
4	 **6d**	Et	 **7d**	40
5	 **6e**	Et	 **7e**	39

[a] Isolated yield.

α-C-addition to **9** to afford **12**, with the subsequent generation of **13** through another proton transfer step. Intermediate **13** might then undergo an intramolecular nucleophilic addition reaction to form intermediate **14**, which is the key intermediate of the reaction. When R is an aryl group, intermediate **14** would undergo a carbon–carbon bond cleavage to give **15**, followed by proton transfer and the elimination of PPh_3 to generate the desired product **3** or **5**. On the other hand, when R is an alkyl group, intermediate **14** would be transformed into **16** by proton transfer and the elimination of PPh_3. Subsequently, elimination of a molecule of water from **16** affords product **7**. A different product is obtained when R is varied from an aryl to an alkyl group, which might be ascribed to the more stabilized structure of an aromatic carbonyl group than that of an alkyl carbonyl group. When R is an aromatic group, the oxygen anion of intermediate **14** prefers to form a carbonyl group, which is well stabilized by the aromatic system. However, the mechanistic details for the formation of these products need further investigation.

In conclusion, we have described unexpected α-addition reactions of 1-(*o*-hydroxyaryl)-1,3-diketones to terminal alkynoates by means of PPh_3. The reaction of 1-(2-hydroxyphenyl)-3-aryl-1,3-diones with terminal alkynoates afforded multifunctional vinylesters in moderate to good yields under mild conditions. The unexpected transformation is proposed to proceed *via* an α-addition reaction and carbon–carbon bond cleavage. Meanwhile, 1-(2-hydroxyphenyl)-3-alkyl-1,3-diones resulted in the formation of chromone derivatives in moderate yields.



Scheme 1 A plausible mechanism for the reaction of 1-(*o*-hydroxyaryl)-1,3-diketones with **2a**.

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