RSC Advances

ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/advances

Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

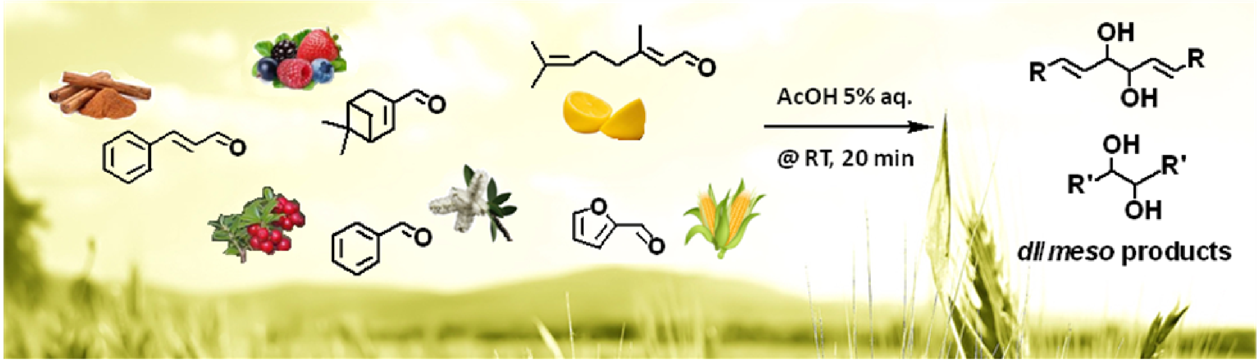
ARTICLE TYPE

Simple and Expeditious Pinacol Coupling of Non Usual α,β-Unsaturated Carbonyl Compounds in Water

Muriel Billamboz,[a] Nicolas Sotto,[a] Carole Chevrin-Villette[a] and Christophe Len*[a, b]

Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX

DOI: 10.1039/b000000x



Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

ARTICLE TYPE

Simple and Expeditious Pinacol Coupling of Non Usual α,β-Unsaturated Carbonyl Compounds in Water

Muriel Billamboz,[a] Nicolas Sotto,[a] Carole Chevrin-Villette[a] and Christophe Len*[a, b]

Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX
DOI: 10.1039/b000000x

Using zinc (0) in a 5 %v AcOH aqueous solution allowed the efficient pinacol coupling of aliphatic or aromatic unusual, α,β-unsaturated carbonyl compounds such as citral A in good to excellent yields (56-99%). It can also be successfully applied to acetophenone.

Pinacol coupling is one of the most used methods for the formation of diol *via* carbon-carbon bond. Although discovered in 1859,[1] this well documented reaction[2] remain studied and find many applications as the vicinal diols obtained are useful intermediates for the construction of biologically important natural or synthetic products.[3] These diols can also be transformed to numerous high value products, such as epoxides, ketones, aminoalcohols…

To perform this reaction, a variety of methods have been developed using mainly aromatic carbonyl compounds as starting materials. Among them, the most reliable systems use either simple low-valent metals such as Mg,[4] Mn,[5] Zn,[6] Al,[7] Zn-Cu couple,[8] or transition metal complexes such as Ti-, V- or Zr-derivatives.[9] Pinacol-type couplings were also developed by using toxic or expensive promoters (In,[10] Sm,[11] Ga,[12] and other metals[13]), in particular for the development of reaction with aliphatic derivatives that are commonly inert under classical conditions.[2a, 7b, 9a, 14]

Nowadays, due to the depletion of fossil resources, chemists are strongly encouraged to develop safer protocols, less hazardous synthesis, catalysis for the production of high value products and the use of benign solvents or renewable feedstocks. Starting form biosourced α,β-unsaturated carbonyl compounds such as citral, myrtenal, farnesal…, pinacol couplings are rarely studied. The corresponding diols were obtained in low yields and no report deals with their coupling in water as green solvent. For example, the reductive homo-coupling of geranial was described by electrochemical reduction in EtOH-Ph5 buffer in around 35% yield.[15] Moreover, starting from crotonaldehyde in presence of Al/$InCl_3$ in THF, the diol was prepared in 45% yield.[16] Otherwise, pinacol coupling of *trans* hex-2-enal was performed by TiI_4 in EtCN with 16% yield.[17]

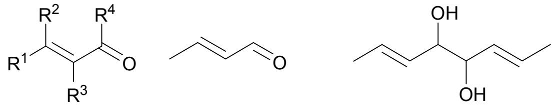


Fig. 1 **1** **1a** **2a (*dl/meso* isomers mixture)**

The aim of this work was to develop a green, simple and efficient methodology to form vicinal diols from natural green note aldehydes and more widely α,β-unsaturated derivatives **1** (Fig. 1). Crotonaldehyde **1a** affording the corresponding diol **2a** was selected as model substrate for our study.

Initially, the effect of solvent changes on the pinacol coupling of **1a** at room temperature in presence of 2 equivalents of zinc was examined. The results are summarized in Table 1.

Table 1 Optimization of reaction conditions for the pinacol coupling of crotonaldehyde **1a** with zinc (2 eq.) at rt

Entry	Solvent	Additive (eq)	Time (h)	**2a** (%)
1	THF/H_2O	none	15	traces
2	THF/H_2O	HCl (2eq)	15	1
3	THF/H_2O	H_2SO_4 (2eq)	15	4
4	THF/H_2O	AcOH (2eq)	15	36
5	THF/H_2O	NH_4Cl sat.	15	76
6	H_2O	none	15	11
7	H_2O	NH_4Cl sat.	15	27
8	H_2O	AcOH (2eq)	0.3	99
9	EtOH	AcOH (2eq)	0.3	99
10	EtOH/H_2O	AcOH (2eq)	15	39

The previously described medium THF/water[18] was initially tested. Without acidic additive or in the presence of strong acids, the pinacol coupling is very slow (Table 1, entries 1-3). For this medium, weak acids such as NH_4Cl or AcOH proved to be best promoters (Table 1, entries 4-5). Protic solvents (water, ethanol or a mixture of water and ethanol; Table1, entries 6-10) are ideal to conduct pinacol coupling reactions, especially in presence of AcOH as additive. Total conversions and excellent yields in only 20 minutes were obtained (Table 1, entries 8-9). In the topic of green chemistry, organic syntheses in water present many advantages in terms of safety and environmental aspects compared to organic solvents. Moreover, in the case of radical reactions, it was proved that solvent plays a crucial role and that water allows control of radical reactions.[19] As a consequence, water was selected as solvent for further optimization. Then, metallic source was screened (Table 2).

Among the 6 tested metals, only zinc, a cheap readily available metal, permitted to afford the corresponding diol 2a in good yield (Table 2).

Table 2 Screening of metal source

Entry	1	2	3	4	5	6
Metal	Zn	Mg	Al	Mn	Fe	Cu
Yield of 2a (%)	99	6	0	7	0	0

[a] For typical conditions: **1a** (2,3 mmol) was reacted with metal (2 eq.) in 5%v AcOH in water during 20 minutes at rt.

It was selected for further studies. As an acidic medium is required to maintain good kinetics, a screening of mineral and organic acids was then realized (Table 3). In our hands, yields were lower than 63% except for acetic acid (Table 3, entry 1).

Table 3 Screening of acids for the pinacol coupling of **1a**

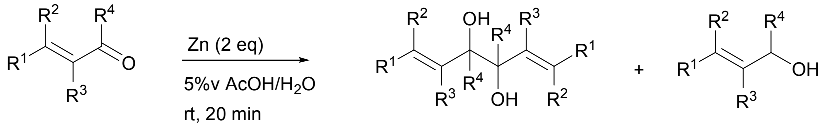
Entry	Acid (2 eq.)	**2a** (%)
1	AcOH	99
2	Citric acid	40
3	CH_3SO_3H	52
4	Tartric acid	63
5	H_2SO_4	30
6	HCl	29
7	NH_4Cl	33

[a] All reactions are carried out in presence of 2eq. of acid in water (5 mL total volume for 2,3 mmol of **1a**) during 20 minutes in presence of 2 eq. of zinc.

Combining all results, expeditious, simple and eco-compatible conditions were found for the efficient pinacol coupling of **1a:** 2 equivalents of zinc in a 5%v AcOH/H_2O medium during 20 minutes at room temperature. This new methodology was then applied to various α,β-unsaturated aldehydes and ketones as presented in table 4.

As depicted, α,β-unsaturated aldehydes reacted smoothly under these conditions to conduct to the desired pinacols in good to excellent yields. Various types of compounds have been used as substrates such as linear saturated enals **1a-c**, unsaturated enals **1d-e** or disubtituted enals **1f-j**. Comparison with an α,β-unsaturated ketone **1k** and an aliphatic aldehyde **1l** has been also made. Linear saturated enals **1a-c** reacted smoothly under the optimized conditions (Table 4, entries 1-3). Crotonaldehyde (**1a**) was totally converted with excellent yield and selectivity (Table 4, entry 1). Long chain linear derivatives: trans hex-2-enal (**1b**) and trans dec-2-enal (**1c**) led to the desired pinacol products in 79% and 78% yield, respectively (Table 4, entries 2-3). It should be noticed that non negligible amounts of the reduction side products, *i.e.* the allylic alcohols **3b** and **3c**, have been isolated in 21% and 10% yield, respectively. For this linear saturated enals, no diastereoselectivity has been observed during the reaction as

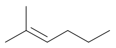
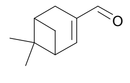
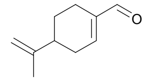
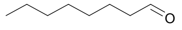
Table 4 Scope of the reaction for α,β-unsaturated compounds



1

2
mixture of *dl/meso* isomers

3
reduction product RP

Entry	N°	Substrate 1				Results (%)			Sel. (%)[a]	*dl/meso*[b]
		R^1	R^2	R^3	R^4	Conv.	2	3		
1	**a**	CH_3	H	H	H	100	99	0	100	42/58
2	**b**	CH_3-$(CH_2)_2$	H	H	H	100	79	21	79	37/63
3	**c**	CH_3-$(CH_2)_6$	H	H	H	94	78	10	89	42/58
4	**d**	CH_3-$(CH_2)_4$-CH=CH-	H	H	H	63	61	0	100	0/100
5	**e**	Ph	H	H	H	91	63	28	70	43/57
6	**f**	CH_3	H	CH_3	H	100	90	8	92	0/100
7	**g**	CH_3-CH_2	H	CH_3	H	100	65	0	100	0/100
8	**h**		CH_3	H	H	100	56	0	100	39/61
9	**i**					93	67	10	87	0/100
10	**j**					80	71	6	92	0/100
11	**k**	Ph	H	H	Ph	100	-	-	ND	ND[c]
12	**l**					0	-	-	-	-

[a] Selectivity is defined as **2**/(**2**+**3**). [b] The *dl/meso* ratio was determined by 1H NMR of the crude product. [c] For entry 11, the major product resulted from a cascade of reductive coupling and cyclization of chalcone, as previsouly described[20] (product **4**)

Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

ARTICLE TYPE

pinacols **2a-c** are obtained as a mixture of *dl* and *meso* isomers with a slightly excess of the *meso* isomer (Table 4, entries 1-3). When using unsaturated enals **1d-e**, lower yields were obtained (Table 4, entries 4-5, 61 and 63% yield, respectively). This lower reactivity can be explained by a higher stability of the ketyl radical. Cinnamaldehyde (**1e**), as an aromatic α,β-unsaturated aldehyde, gave **2e** in only 63% yield with a non negligible amount of the reduction product **3e** (Table 4, entry 5). This can be the result of an enhancement of the radical stability by the aromatic moiety. Disubstituted enals **1f-j** also reacted fast under the optimized conditions, but with slightly lower yields than their less hindered analogues (Table 4, entries 6-10). For these derivatives, the increase of the steric hindrance around the carbonyl group has a dramatic effect on the *dl/meso* ratio. The **2f** and **2g** *meso* isomers, with a methyl group on the α position, are obtained selectively (Table 4, entries 6-7). It is noteworthy than citral A (**1h**), a long chain hindered natural aliphatic α,β-unsaturated aldehyde reacted well under these conditions to conduct to a mixture of *meso* and *dl* isomers (Table 4, entry 8). To our knowledge, it is the first time that citral A (**1g**) proved to be a good substrate for pinacol coupling in water. Moreover, natural cyclic α,β-unsaturated aldehydes such as myrtenal (**1i**) and perillaldehyde (**1j**) were also successfully converted into pinacol coupling products **2i** and **2j** with a total selectivity for the *meso* isomers (Table 4, entries 9-10). The reactivity towards pinacol coupling of these cyclic hindered compounds was never described before. For this family of hindered enals **1f-j**, it is notable that a substituent on the α position led to total selectivity towards the *meso* isomer. Less reactive α,β-unsaturated ketone, chalcone **1k,** was then submitted to these optimized reaction conditions without success (Table 4, entry 11).

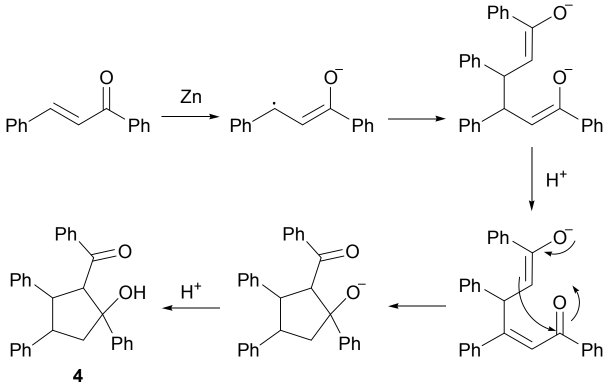
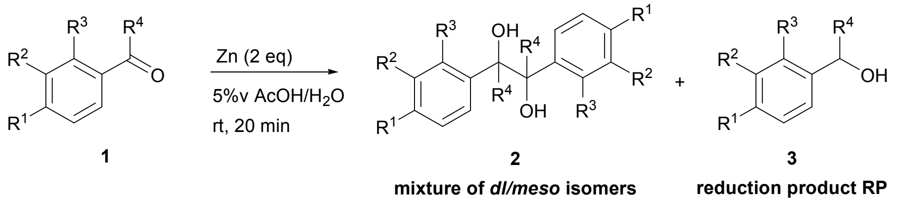
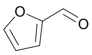


Fig. 2 Product **4** formation pathway

Table 5 Scope of the reaction for aromatic compounds



Entry	N°	Substrate 1				Results (%)			Sel (%)[a]	*dl/meso*[b]
		R^1	R^2	R^3	R^4	Conv.	2	3		
1	**m**	H	H	H	H	96	51	45	53	38/62
2	**n**	CH_3	H	H	H	80	54	26	67	48/52
3	**o**	Cl	H	H	H	80	13	67	16	26/74
4	**p**	Br	H	H	H	64	40	24	62	27/73
5	**q**	NO_2	H	H	H	46	0	0	Reduction of NO_2	
6	**r**	H	Cl	Cl	H	90	38	52	42	16/84
7	**s**					100	51	39	57	32/68
8	**t**	H	H	H	CH_3	80	75	0	100	56/44
9	**u**	Cl	H	H	CH_3	80	75	4	95	57/43
10	**v**	Ph	H	H	Ph	10	0	10	0	-

[a] Selectivity is defined as **2**/(**2**+**3**). [b] The *dl/meso* ratio was determined by ^{1}H NMR of the crude product.

In fact, the previously described cyclodimerization product **4,** resulting from a reductive coupling/cyclization cascade (Fig. 2), is mainly isolated in 65% yield.[20] As expected, aliphatic aldehyde such as octanal (**1l**) did not coupled under these simple conditions (Table 4, entry 12).

This simple and efficient methodology was then extended to classical aromatic carbonyl compounds (Table 5). Aromatic aldehydes reacted fast under these conditions, but, as observed for cinnamaldehyde (**1e**) (Table 4, entry 5), the amount of reduction products **3m** - **3s** is high (Table 5, entries 1-7) and sometimes mainly obtained (Table 5, entries 3 and 6). One possible explanation is that kinetics of reaction is too high to let the possibility to ketyl radicals to meet and coupled effectively. For acetophenone derivatives, which are less reactive in single electron transfer, this medium is very interesting and promoted efficiently the ketyl radicals formation and its coupling, allowing the formation of pinacol **2t** and **2u** from acetophenone (**1t**) and 4-chloroacetophenone (**1u**) with 75% yield (Table 5, entries 8-9). Much hindered ketone, exemplified by benzophenone (**1v**), did not coupled under these conditions and only reduction product **3v** is obtained in low yield after 20 minutes (Table 5, entry 10).

Conclusions

A simple, green and expeditious methodology for pinacol coupling of α,β-unsaturated aldehydes and acetophenone derivatives has been established in 5%v AcOH in water. Zinc as cheap readily available reductant and acetic acid as promoter are used to obtain high value added pinacol products in only 20 minutes at room temperature in good to excellent yields. Natural compounds such as citral A, myrtenal or perillaldehyde proved to react smoothly under these conditions. Works are still in progress to enhance the selectivity of the coupling reaction for aromatic compounds and α,β-unsaturated ketones.

Notes and references

[a] *Sorbonne Universités, Université de Technologie de Compiègne, Ecole Supérieure de Chimie Organique et Minérale, EA 4297 Transformations Intégrées de la Matière Renouvelable, Centre de Recherches de Royallieu, CS 60319, F-60205 Compiègne cedex, France. Fax: +33 (0)3 44 97 15 91; Tel: +33 (0)3 44 23 88 28; E-mail: christophe.len@utc.fr*

[b] *Departement of Chemistry, University of Hull, Hull 6 HU6 7RX, England.*

† Electronic Supplementary Information (ESI) available: experimental procedures, products description and ^{1}H and ^{13}C NMR spectra. See DOI: 10.1039/b000000x/

‡ This work was performed, in partnership with the SAS PIVERT, within the frame of the French Institute for the Energy Transition (Institut pour la Transition Energétique (ITE) P.I.V.E.R.T. (www.institut-pivert.com) selected as an Investment for the Future ("Investissements d'Avenir"). This work was supported, as part of the Investments for the Future, by the French Government under the reference ANR-001-01.

1 (a) R. Fitting, *Justus Leibigs Ann. Chem.,* 1859, **110**, 23; (b) G. Zhao, C. Yang, L. Guo, H. Sun, R. Lin and W. Xia, *J. Org. Chem.,* 2012, **77**, 6302; (c) J.-T. Li, C. Du and X.-L. Zhai, *Synth. Commun.*, 2012, **42**, 820.

2 For recent reviews, see: (a) M. Meciarova, S. Toma and P. Babiak, *Chem. Pap.,* 2001, **55**, 302; (b) C.-J. Li, *Chem. Rev.,* 2005, **105**, 3095; (c) S.P. Morcillo, D. Miguel, A.G. Campana, L. Alvares de Cienfuegos, J. Justicia and J.M. Cuerva, *Org. Chem. Front.*, 2014, **1,** 15; (d) T. Hirao, *Pure Appl. Chem.,* 2005, **77**, 1539; (e) B. S. Terra and F. Macedo Jr, *Arkivoc*, 2012, 134; (f) P.G. Steel, *J. Chem. Soc., Perkin Trans 1,* 2001, 2727; (g) A. Chatterjee and N.N. Joshi, *Tetrahedron,* 2006, **62**, 12137; (h) J.-T. Li, S.-X. Wang, G.-F. Chen and T.-S. Li, *Curr. Org. Synth.,* 2005, **2**, 415.

3 (a) T. Wirth. *Angew. Chem., Int. Ed. Engl.,* 1996, **35**, 61; (b) M. Avalos, R. Babiano, P. Cintas, J.L. Jimenze and J.C. Palacios. *Recent Res. Dev. Org. Chem.,* 1997, **1**, 159.

4 (a) W.-C. Zhang and C.-J. Li, *J. Chem. Soc., Perkin Trans. 1*, 1998, 3131; (b) M. Mecarova and S. Toma, *Green Chem.*, 1999, **1**, 257; (c) W.-C. Zhang and C.-J. Li, *J. Org. Chem.*, 1999, **64**, 3230; (d) H. Maekawa, Y. Yamamoto, H. Shimada, K. Yoneruma and I. Nishiguchi, *Tetrahedron Lett.*, 2004, 45, 3869; (e) A. Fürstner, R. Csuk, C. Rohrer and H. Weidmann, *J. Chem. Soc., Perkin Trans 1*, 1988, 1729.

5 (a) C.-J. Li, Y. Meng and X.-H. Yi, *J. Org. Chem.* 1997, **62**, 8632; (b) R.D. Rieke and S.-H. Kim, *J. Org. Chem.*, 1998, **63**, 5235.

6 (a) B.K. Hazarika and D. K. Dutta, *Synth. Commun.* 2011, **41**, 1088; (b) J.-H. So, M.-K. Park and P.J. Boudjouk, *J. Org. Chem.,* 1988, **53**, 5871.

7 (a) S.-Z. Yuan, Z.-Y. Wang and Z. Li, *Chin. J. Chem.*, 2006, **24**, 141; (b) Y. Mitoma, I. Hashimoto, C. Simion, M. Tashiro and N. Egashira, *Synth. Commun*. 2008, **38**, 3243; (c) S. Bhar and C. Panja, *Green Chem.,* 1999, **1**, 253; (d) A.A.P. Schreibmann, *Tetrahedron Lett.*, 1970, **11**, 4271 and references herein.

8 P. Delair and J.-L. Luche, *J. Chem. Soc.,Chem. Commun.*, 1989, 398.

9 (a) J.L. Oller-Lopez, A.G. Campana, J.M. Cuerva and J.E. Oltra, *Synthesis*, 2005, **15**, 2619; (b) A. Clerici and O. Porta, *J. Org. Chem.,* 1982, **47**, 2852; (d) F.R. Askham and K.M. Carroll, *J. Org. Chem.,* 1993, **58**, 7328; (f) T. Hirao, M. Asahara, Y. Muguruma and A. Ogawa, *J. Org. Chem.*, 1998, **63**, 2812; (g) T. Hirao, B. Hatano, Y. Imamoto and A. Ogawa, *J. Org. Chem.*, 1999, **64**, 7665.

10 H.J. Lim, G. Keum, S.B. Kang, B.Y. Chung and Y. Kim, *Tetrahedron Lett.,* 1998, **39**, 4367.

11 S. Matsukawa and Y. Hinakubo, *Org. Lett.*, 2003, **5**, 1221.

12 Z.Y. Wang, S.Z. Yuan, Z.G. Zha and Z.D. Zhang, *Chin. J. Chem.*, 2003, **21**, 1231.

13 (a) R.L. Halterman, J.P. Porterfield and S. Mekala, *Tetrahedron Lett.* 2009, **50**, 7172; (b) T. Hirao, *Pure Appl. Chem.*, 2005, **77**, 1539; (c) P.G. Steel, *J. Chem. Soc., Perkin Trans 1,* 2001, 2727; (d) S. Arai, Y. Sudo and A. Nashida, *Chem. Pharm. Bull.*, 2004, **52**, 287.

14 (a) B.P. Mundy, R. Srinivasa, Y. Kim and T. Dolph, *J. Org. Chem.*, 1982, **47**, 1657; (b) J.C. Johnston, J.D. Faulkner, L. Mandell and R.A. Day Jr, *J. Org. Chem*., 1976, **41**, 2611.

15 J.C. Johnston, J.D. Faulkner, L. Mandell and R.A. Day Jr, *J. Org. Chem.*, 1976, **41**, 2611.

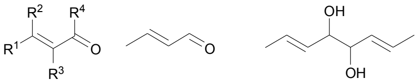
16 S. Ohtaka, K. Mori and S. Uemura, *Heteroatom Chem.*, 2001, **12**, 309.

17 M. Shimizu, H. Goto and R. Hayakawa, *Org. Lett.*, 2002, **4**, 4097.

18 M. Billamboz, J-C. Legeay, F. Hapiot, E. Monflier and C. Len, *Synthesis*, 2012, **44**, 137.

19 (a) H. Yorimitsu, T. Nakamura, H. Shinokubo, K. Oshima, K. Omoto and H. Fujimoto, *J. Am. Chem. Soc.*, 2000, **122**, 11041; (b) M.-O. Simon and C.-J. Li, *Chem. Soc. Rev.*, 2012, **41**, 1415.

20 (a) G. Zhao, C. Yang, L. Guo, H.Sun, R. Lin and W. Xia, *J. Org. Chem.,* 2012, **77**, 6302; (b) J.-T. Li, C. Du and X.-L. Zhai, *Synth. Commun.*, 2012, **42**, 820.



1 **1a** **2a (*dl/meso* isomers mixture)**

Fig. 1 α,β-unsaturated derivatives **1**, crotonaldehyde **1a** and the diol **2a**.

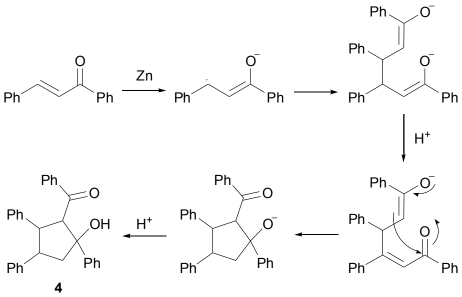


Fig. 2 Product **4** formation pathway.

Table 1 Optimization of reaction conditions for the pinacol coupling of crotonaldehyde **1a** with zinc (2 eq.) at rt

Entry	Solvent	Additive (eq)	Time (h)	**2a** (%)
1	THF/H_2O	none	15	traces
2	THF/H_2O	HCl (2eq)	15	1
3	THF/H_2O	H_2SO_4 (2eq)	15	4
4	THF/H_2O	AcOH (2eq)	15	36
5	THF/H_2O	NH_4Cl sat.	15	76
6	H_2O	none	15	11
7	H_2O	NH_4Cl sat.	15	27
8	H_2O	AcOH (2eq)	0.3	99
9	EtOH	AcOH (2eq)	0.3	99
10	EtOH/H_2O	AcOH (2eq)	15	39

Table 2 Screening of metal source

Entry	1	2	3	4	5	6
Metal	Zn	Mg	Al	Mn	Fe	Cu
Yield of **2a** (%)	99	6	0	7	0	0

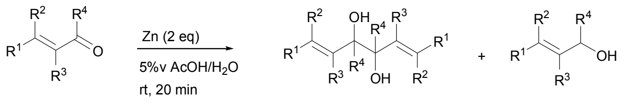
[a] For typical conditions: **1a** (2,3 mmol) was reacted with metal (2 eq.) in aqueous AcOH (5%v) during 20 minutes at rt.

Table 3 Screening of acids for the pinacol coupling of **1a**

Entry	Acid (2 eq.)	**2a** (%)
1	AcOH	99
2	Citric acid	40
3	CH_3SO_3H	52
4	Tartric acid	63
5	H_2SO_4	30
6	HCl	29
7	NH_4Cl	33

[a] All reactions are carried out in presence of 2eq. of acid in water (5 mL total volume for 2,3 mmol of **1a**) during 20 minutes in presence of zinc (2 eq.).

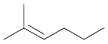
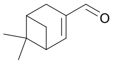
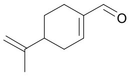
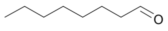
Table 4 Scope of the reaction for α,β-unsaturated compounds **1a-l**



1

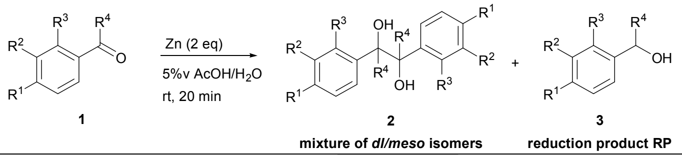
2
mixture of *dl/meso* isomers

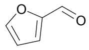
3
reduction product RP

Entry	N°	R^1	R^2	R^3	R^4	Conv. (%)	**2** (%)	**3** (%)	Sel. (%)	*dl* / *meso*
1	**a**	CH_3	H	H	H	100	99	0	100	42/58
2	**b**	CH_3-$(CH_2)_2$	H	H	H	100	79	21	79	37/63
3	**c**	CH_3-$(CH_2)_6$	H	H	H	94	78	10	89	42/58
4	**d**	CH_3-$(CH_2)_4$-CH=CH-	H	H	H	63	61	0	100	0/100
5	**e**	Ph	H	H	H	91	63	28	70	43/57
6	**f**	CH_3	H	CH_3	H	100	90	8	92	0/100
7	**g**	CH_3-CH_2	H	CH_3	H	100	65	0	100	0/100
8	**h**		CH_3	H	H	100	56	0	100	39/61
9	**i**					93	67	10	87	0/100
10	**j**					80	71	6	92	0/100
11	**k**	Ph	H	H	Ph	100	-	-	ND	ND[c]
12	**l**					0	-	-	-	-

[a] Selectivity is defined as **2**/(**2**+**3**). [b] The *dl/meso* ratio was determined by 1H NMR of the crude product. [c] For entry 11, the major product resulted from a cascade of reductive coupling and cyclization of chalcone, as previsouly described[i] (product **4**)

Table 5 Scope of the reaction for aromatic compounds **1m-s**



Entry	N°	R^1	R^2	R^3	R^4	Conv. (%)	**2** (%)	**3** (%)	Sel. (%)	*dl* / *meso*
1	**m**	H	H	H	H	96	51	45	53	38/62
2	**n**	CH_3	H	H	H	80	54	26	67	48/52
3	**o**	Cl	H	H	H	80	13	67	16	26/74
4	**p**	Br	H	H	H	64	40	24	62	27/73
5	**q**	NO_2	H	H	H	46	0	0	Reduction of NO_2	
6	**r**	H	Cl	Cl	H	90	38	52	42	16/84
7	**s**					100	51	39	57	32/68
8	**t**	H	H	H	CH_3	80	75	0	100	56/44
9	**u**	Cl	H	H	CH_3	80	75	4	95	57/43
10	**v**	Ph	H	H	Ph	10	0	10	0	-

[a] Selectivity is defined as **2**/(**2**+**3**). [b] The *dl/meso* ratio was determined by ^{1}H NMR of the crude product.