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One-Pot Sustainable Synthesis of Tertiary Alcohols by Combining Ruthenium-Catalysed Isomerisation of Allylic Alcohols and Chemoselective Addition of Polar Organometallic Reagents in Deep Eutectic Solvents

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Abstract: The Ru(IV)-catalysed redox isomerisation of allylic alcohols has, for the first time, been successfully assembled with the chemoselective addition of organolithium or organomagnesium reagents to the *in situ* formed ketones, en route to tertiary alcohols, employing *Deep Eutectic Solvents* as environmentally friendly reaction media. The overall transformation, which formally involves three consecutive and different steps such as (i) the reduction of a C–C double bond, (ii) the oxidation of a secondary carbinol moiety, and (iii) a chemoselective C–C bond formation, takes place in protic and biorenewable eutectic mixtures in a sequential one-pot fashion using a commercially and easily available catalytic system, with excellent conversions (up to 99% yield), at room temperature and under air in the last step, with no concomitant reduction or enolisation processes, and with high atom economy, in agreement with the principles of the so-called *Green Chemistry*

Introduction

The search for new ways of perfecting chemo- and regioselectivity, functional group tolerance and reaction yield still represents a great and major challenge in synthetic organic chemistry, both for academics and industry.¹ Most environmental legislation worldwide recognise the urgency to develop atom-economical reactions which are critical for the reduction of waste stream in the chemical industry,² and that make use of more environmentally benign and bio-renewable solvents jointly with milder reaction conditions.³ This justifies the flourishing in recent years of a plethora of new one-pot processes involving multiple stoichiometric/catalytic events mainly because of their intrinsic environmental, practical, and economic advantages (for example, minimisation of waste-production, time- and energy-consuming, and tedious purification steps).⁴ Among these, the potential of assembling transition-metal-catalysed reactions⁵ with main group-mediated (RLi/R₂Mg) organic transformations remains

particularly attractive and appealing as both methodologies constitute two of the most important pillars in the toolbox of synthetic organic chemistry.⁶ However, the vast majority of examples reported in the literature, which combine transition-metal catalysis with organomagnesium (e.g. Kumada-Corriu coupling)⁷ or organolithium chemistry,⁸ still rely on massive use of hazardous, toxic and dry volatile organic solvents (VOCs) (e.g. Et₂O, THF, toluene, etc.),⁹ of inert atmosphere, and of low temperatures (up to –78 °C) in order to avoid the fast degradation the above polar organometallic reagents usually undergo.

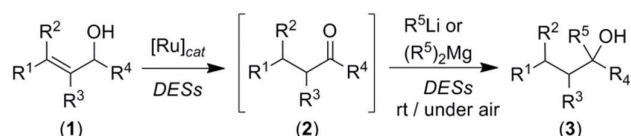
With the ultimate goal of solving these pitfalls, the so-called *Deep Eutectic Solvents* (DESs) have recently been introduced and investigated by our groups as innovative and unconventional *green* reaction media for running both nucleophilic addition and substitution reactions promoted by Grignard and organolithium reagents at room temperature and under air.¹⁰ DESs, which share many physico-chemical properties with traditional ionic liquids (e.g. thermal stability, low vapour pressure, non-flammability, easy of recycling, etc.), are biodegradable fluids generally composed of two or three safe and inexpensive components able to engage with each other via hydrogen bond interactions, thereby forming eutectic mixtures with melting points much lower than that of the individual components.^{11,12} Thanks to their unusual and unexpected solvent properties and minimal ecological footprint, in the last years their use has been successfully extended also to biocatalysis,¹³ organocatalysis,¹⁴ solar technology,¹⁵ and transition-metal-catalysis.¹⁶

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Building on recent findings in organometallic reactions and metal-catalysed isomerisations run in unconventional reaction media,^{10,17,18} herein we wish to report an unprecedented and *greener* synthesis of highly substituted tertiary alcohols **3** by exploiting a one-pot combination of a Ru(IV)-catalysed redox isomerisation of allylic alcohols **1** with the chemoselective addition of organolithium and organomagnesium reagents to the *in situ* formed ketones **2** in *DESs* (Scheme 1). The overall transformation involves three consecutive and different steps: (i) reduction of the allylic C–C double bond, (ii) oxidation of the secondary alkyl/aryl carbinol moiety, and (iii) chemoselective C–C bond formation *via* polar organometallic reagents. The following features of the proposed methodology are remarkable: the overall transformation in selected eutectic mixtures takes place under mild and *green* reaction conditions, in the absence of additives or co-catalyst, and without any halfway isolation/purification step starting from commercially and easily available substrates. Thus, *DESs* come close to being the ideal candidates to cross the frontier between transition-metal-catalysed and main group-mediated organic transformations in a sustainable way.

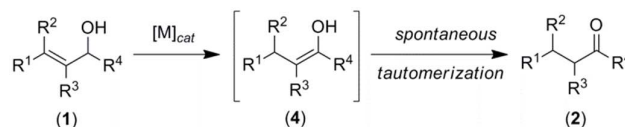


Scheme 1. Ru-catalysed allylic alcohol isomerisation combined with the chemoselective addition of organolithium/organomagnesium reagents in a one-pot process using *DESs* as green solvents.

Results and Discussion

Redox isomerisation of α -vinylbenzyl alcohol (**1a**) catalysed by acetate Ru(IV)-complex $[\text{Ru}(\eta^3\text{-C}_{10}\text{H}_{16})\text{Cl}(\kappa^2\text{-O, O-CH}_3\text{CO}_2)]$ (**5b**) in different *DESs*

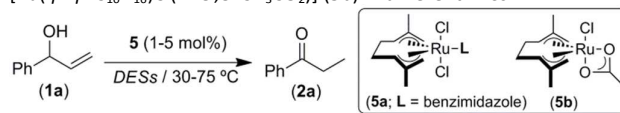
The redox isomerisation of readily available allylic alcohols catalysed by transition-metal complexes is a convenient and direct synthetic pathway to obtain saturated carbonyl compounds in quantitative yields and usually under mild reaction conditions.¹⁹ This metal-catalysed reaction is based on the capability of transition-metal complexes to promote the migration of carbon-carbon double bond of allylic alcohol **1** to produce a transient enolate intermediate **4**, which suffers the spontaneous tautomerisation into the corresponding carbonyl compound **2** (Scheme 2). This is a much more attractive transformation (from a *Green Chemistry* point of view)³ than those based on classic stoichiometric reactions, which usually involve the use of: (i) a two-step sequential oxidation and reduction processes (with low atom-economy), and (ii) highly reactive, toxic and expensive reagents.



Scheme 2. Metal-catalysed redox isomerisation of allylic alcohols.

The gradual emergence of this metal-catalysed transformation as a modern synthetic approach²⁰ has boosted an increasing interest in the search for new catalytic systems capable to work in unconventional solvents as reaction media.^{21,22} In this context, some of us have recently reported that the monomeric ruthenium(IV) complex $[\text{Ru}(\eta^3\text{-C}_{10}\text{H}_{16})\text{Cl}_2(\kappa^1\text{-N-benzimidazole})]$ (**5a**) (Table 1) was an efficient and selective catalyst (10 mol%) for the quantitative isomerisation of aromatic allylic alcohols into the corresponding ketones in *DESs*, however, after 24 h reaction time.^{16f} In order to improve these results, we set out to investigate the catalytic activity of the acetate ruthenium(IV) complex $[\text{Ru}(\eta^3\text{-C}_{10}\text{H}_{16})\text{Cl}(\kappa^2\text{-O, O-CH}_3\text{CO}_2)]$ (**5b**) (Table 1), which previously proved to be a competent catalyst for the isomerisation of α -vinylbenzyl alcohol (**1a**) both in water and in the ionic liquid $[\text{BMIM}][\text{BF}_4]$ (BMIM = 1-butyl-3-methylimidazolium).^{17b}

Table 1. Isomerisation of α -vinylbenzyl alcohol (**1a**) into propiophenone (**2a**) catalysed by the acetate ruthenium(IV) complex $[\text{Ru}(\eta^3\text{-C}_{10}\text{H}_{16})\text{Cl}(\kappa^2\text{-O, O-CH}_3\text{CO}_2)]$ (**5b**) in different *DESs*.^[a]



Entry	<i>DES</i>	$[\text{Ru}]^{\text{[b]}}$	Temp (°C)	Time (h)	Yield (%) ^[c]
1	1ChCl/2Urea	5	50	0.5	99
2	1ChCl/2Urea	2.5	50	1.5	98
3	1ChCl/2Urea	1	50	2	1
4	1ChCl/2Urea	5	30	24	99
5	1ChCl/2EG	5	50	0.5	92
6	1ChCl/2Gly	5	50	0.5	98
7	5ChCl/2Prol	5	50	0.5	1
8	1ChCl/2H ₂ O	5	50	0.5	1
9	1ChCl/2Lac	5	50	0.5	1
10	1ChCl/2Fruc	5	75	0.5	99
11	1ChCl/1Sorb	5	75	0.5	99
12	2Fruc/3Urea	5	75	0.5	99
13	2Prol/5Gly	5	75	0.5	1
14	9Lac/1Alan	5	75	0.5	1

^[a] Reaction conditions: α -vinylbenzyl alcohol (**1a**, 0.5 mmol) under Ar atmosphere at 30–75 °C in 0.5 g of the desired *DES*. ^[b] Catalyst loading 1–5 mol% in Ru. ^[c] Calculated by GC.

Firstly, the activity of complex **5b** was assessed in a model reaction (Table 1) by using the archetypal eutectic mixture 1ChCl/2Urea as the solvent. When a solution of α -vinylbenzyl alcohol (**1a**) in the eutectic mixture 1ChCl/2Urea was heated at 50 °C with a catalyst loading of 5 mol%, propiophenone (**2a**) formed in 99% yield after 30 min only (entry 1, Table 1), thereby clearly improving the previous result obtained with complex **5a**.^{16f} Trying to

find the limits of our catalytic system, we also decreased both the catalyst loading and the temperature for this isomerisation. The use of lower catalytic loading, however, slowed down the reaction considerably: with 2.5 mol% in [Ru], quantitative conversion was only achieved after 90 min (entry 2, Table 1), whereas with 1 mol% in [Ru], the reaction did not even generate the product (entry 3, Table 1). Remarkably, complex **5b** quantitatively isomerised allylic alcohol **1a** into **2a** under very mild reaction conditions (30 °C) but after 24 h reaction time (entry 4, Table 1). Then, we also investigated the nature of the composition of *DES*s on the outcome of the reaction. While other *ChCl*-based eutectic mixtures containing ethylene glycol (*EG*, entry 5, Table 1) or glycerol (*Gly*, entry 6, Table 1) proved to be similarly effective in promoting the formation of **2a** in almost quantitative yield after 30 min and working at 50 °C, those based on *L*-proline (*Prol*, entry 7, Table 1), water (entry 8, Table 1) or lactic acid (*Lac*, entry 9, Table 1) did have a dramatic impact on the isomerisation process as no transformation occurred. Quantitative conversion of **1a** into **2a** also took place smoothly employing sugar-based eutectic mixtures [for example, *D*-fructose (*Fruc*) and *D*-sorbitol (*Sorb*)], however, at a higher temperature (75 °C) (entries 10–11, Table 1). Finally, the use of the non-ionic eutectic mixture *2Fruc/3Urea* allowed the quantitative formation of propiophenone (**2a**) at high temperatures (75 °C, entry 12, Table 1) while the amino acid-based *DES*s (*2Prol/5Gly* and *9Lac/1Alan* (*L*-alanine), entries 13–14, Table 1) totally hampered the catalytic reaction.

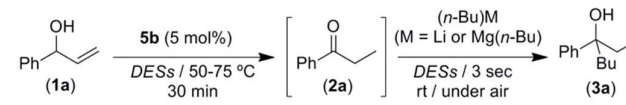
Since the eutectic mixture *1ChCl/2Urea* displayed the best results in terms of both reaction time and yield, and bearing in mind that one of the major advantages associated with the use of eutectic mixtures as *green* solvent in metal-catalysed organic reactions¹⁶ is the easiness to recycle the catalytic system after its use (which is a very important step for industrial application in *Green Chemistry*),²³ we decided to investigate the level of reusability of our catalytic system by taking, as a model reaction, the isomerisation of the α -vinylbenzyl alcohol (**1a**). We found that catalyst **5b** could be recycled up to three consecutive runs, thereby leading to an accumulative TON value of 297. For the first two cycles only 0.5–1.5 h were needed to achieve quantitative conversions [1st cycle: 0.5 h (99%); 2nd cycle: 1.5 h (99%)], while 20 h were required starting from the third cycle for quantitative conversions (99%), probably because of the leaching of the ruthenium catalyst during work-up. This is the first example reported on the study of the recyclability of a catalytic system in the isomerisation of aromatic allylic alcohols in *DES*s,^{16f} which allows a decrease of the amount of the catalyst needed per mole of final product.

One-pot sequential redox isomerisation of allylic alcohols (**1a-f**) catalysed by complex **5b**, and chemoselective addition of R_1Li/R_2Mg in different *DES*s

During the last few years, the ruthenium-catalysed redox isomerisation of allylic alcohols in unconventional solvents (like water, glycerol or ionic liquids) has been fruitfully coupled with a variety of concomitant organic processes (e.g. C–C bond formations,²⁴ reductions²⁵ or bio-amination²⁶) giving rise to a new family of valuable one-pot transformations.²⁷ In the light of the

above results we envisioned that a modular combination of Ru(IV)-catalysed isomerisation of allylic alcohols with the chemoselective addition of R_1Li/R_2Mg reagents to the resulting ketones in *DES*s would allow a straightforward, one-pot access to a library of structurally diverse tertiary alcohols under mild, simple and environmentally friendly reaction conditions.

Table 2. Direct conversion of α -vinylbenzyl alcohol (**1a**) into 3-phenylheptan-3-ol (**3a**) through the one-pot combination of Ru-catalysed isomerisation and chemoselective addition of *n*-BuLi or *n*-Bu₂Mg in different *DES*s.^[a]



Entry	<i>DES</i>	Temp (°C)	<i>n</i> -BuM (Eq.)	Yield (%) ^[b]
1	<i>1ChCl/2Urea</i>	50	<i>n</i> -BuLi (3)	68
2	<i>1ChCl/2EG</i>	50	<i>n</i> -BuLi (3)	97
3	<i>1ChCl/2EG</i>	50	<i>n</i> -BuLi (2)	66
4	<i>1ChCl/2EG</i>	50	<i>n</i> -BuLi (1)	25
5	<i>1ChCl/2Gly</i>	50	<i>n</i> -BuLi (3)	68
6	<i>2Fruc/3Urea</i>	75	<i>n</i> -BuLi (3)	69
7	<i>1ChCl/2Fruc</i>	75	<i>n</i> -BuLi (3)	95
8	<i>1ChCl/1Sorb</i>	75	<i>n</i> -BuLi (3)	80
9	<i>1ChCl/2Urea</i>	50	<i>n</i> -Bu ₂ Mg (3)	87
10	<i>1ChCl/2EG</i>	50	<i>n</i> -Bu ₂ Mg (3)	93
11	<i>1ChCl/2Gly</i>	50	<i>n</i> -Bu ₂ Mg (3)	85
12	<i>2Fruc/3Urea</i>	75	<i>n</i> -Bu ₂ Mg (3)	15
13	<i>1ChCl/2Fruc</i>	75	<i>n</i> -Bu ₂ Mg (3)	50
14	<i>1ChCl/1Sorb</i>	75	<i>n</i> -Bu ₂ Mg (3)	93
15	H ₂ O ^[c]	75	<i>n</i> -Bu ₂ Mg (3)	37

^[a] Reaction conditions: α -vinylbenzyl alcohol (**1a**, 0.5 mmol), under Ar atmosphere at 50–75 °C, 5 mol% Ru(IV) catalyst in 0.5 g of the desired *DES*. Commercially available 1.6 M solution in hexanes of *n*-BuLi and 1.0 M in heptane for *n*-Bu₂Mg were added at rt and under air. ^[b] Calculated by GC. ^[c] Isomerisation reaction was completed in 5 min in water using 1 mol% in Ru.

To this end, we selected as a model reaction the isomerisation of α -vinylbenzyl alcohol (**1a**) to ketone **2a**, followed by the addition of *n*-BuLi/*n*-Bu₂Mg as the organometallic reagent (Table 2) in different *DES*s. The mixture containing **1a** and the ruthenium catalyst **5b** (5 mol% in Ru) was preliminarily warmed (50–75 °C) in the selected *DES* to promote the anticipated isomerisation. Once the conversion of **1a** into propiophenone (**2a**) was completed (30 min, GC analysis), *n*-BuLi was directly added to the mixture without isolating the intermediate ketone, and the mixture stirred for a few seconds. Remarkably, working at room temperature (rt) and under air (conditions traditionally prohibitive for organolithium reagents), almost quantitative formation of the expected tertiary alcohol 3-phenylheptan-3-ol (**3a**) was observed after a few sec stirring in *1ChCl/2EG* (97%, entry 2, Table 2) or *1ChCl/2Fruc* (95%, entry 7, Table 2). The replacement of *EG* or *D*-fructose by other H-bond donors like urea (entry 1, Table 2), *Gly* (entry 5, Table 2) or *D*-sorbitol (entry 8, Table 2), as well as the use of *ChCl*-free *DES*s (entry 6, Table 2) led to lower conversions. In all cases, the one-pot formation of **3a** starting from **1a** took place chemoselectively, with no additional side products observed in the crude reaction mixture. It is worth noting that by progressively lowering the equivalents of *n*-BuLi from 3 to 1, the addition reaction of the organometallic reagent to the *in situ* formed ketone **2a** proved to be less effective

leading to a poorer recovery (from 97 to 25% yield) of the expected tertiary alcohol **3a** (entries 2–4, Table 2).

We next investigated the chemoselective addition of the organomagnesium reagent *n*-Bu₂Mg to **2a** at rt and under air. Similarly to the reactions run with organolithium reagents, the best results were obtained using the eutectic mixture 1*ChCl*/2*EG* as the reaction medium, which allowed the one-pot formation of **3a** in up to 93% yield just after a few seconds (entry 10, Table 2). While with different *ChCl*-based eutectic mixtures (1*ChCl*/2*Urea*, 1*ChCl*/2*Gly*, 1*ChCl*/2*Fruc*, and 1*ChCl*/1*Sorb*) butylated alcohol **3a** could be recovered in 50–93% yield, (entries 9,11,13,14, Table 2), total reaction yield decreased considerably in 2*Fruc*/3*Urea* (15%) (entry 12, Table 2) and in water (37%) (entry 15, Table 2). These results are thus consistent with our previous assumption on the dual role played by the biorenewable ammonium salt *ChCl* (vitamin B4) in the addition reactions of polarised organometallic reagents in *DESs*.^{10a} On the one side, *ChCl* is the H-bond acceptor needed for the synthesis of the biorenewable and *green* eutectic mixture, while on the other side this ammonium salt permits the kinetic activation of the organomagnesium reagent (*n*-Bu₂Mg) through the *in situ* formation of an halide enriched magnesiate (R₂MgCl) as a highly nucleophilic reagent capable to undergoing a very fast addition.^[28,29]

Table 3. Direct conversion of α -vinylbenzyl alcohol (**1a**) into tertiary alcohols **3a–e** through the one-pot combination of Ru-catalysed isomerisation and chemoselective addition of RLi/RMgX in *DESs*.^[a]

<i>DES</i>	RM ^[b]	Temp (°C)	Product	Yield (%) ^[c]
1 1 <i>ChCl</i> /2 <i>EG</i>	<i>n</i> -BuLi	50	3a	97
2 1 <i>ChCl</i> /2 <i>EG</i>	MeLi	50	3b	87
3 1 <i>ChCl</i> /2 <i>EG</i>	<i>s</i> -BuLi	50	3c	85
4 1 <i>ChCl</i> /2 <i>EG</i>	PhLi	50	3d	90
5 1 <i>ChCl</i> /2 <i>EG</i>	EtMgBr	50	3e	45
6 2 <i>Fruc</i> /3 <i>Urea</i>	MeLi	75	3b	12
7 H ₂ O ^[d]	MeLi	75	3b	50

^[a] Reaction conditions: α -vinylbenzyl alcohol (**1a**, 0.5 mmol), under Ar atmosphere at 50–75 °C, 5 mol% Ru(IV) catalyst in 0.5 g of the desired *DES* for 30 min. ^[b] 3 eq. of commercially available 1.6 M solution of *n*-BuLi in hexanes, 1.6 M solution of MeLi in Et₂O, 1.8 M solution of PhLi in dibutyl ether, 1.4 M solution of *s*-BuLi in cyclohexanes and 1.0 of EtMgBr in THF were added at rt and under air. ^[c] Calculated by GC. ^[d] Isomerisation reaction was completed in 5 min in water using 1 mol% in Ru.

Having identified the best eutectic mixture 1*ChCl*/2*EG* for the one-pot conversion of **1a** into **3a**, we next extended our studies to other organolithium and organomagnesium reagents to probe the scope of this transformation. As can be seen from the results reported in Table 3, similarly to *n*-BuLi (entry 1, Table 3), both aliphatic (MeLi, *s*-BuLi) and aromatic (PhLi) organolithium reagents provided the expected, saturated tertiary alcohols **3b–d** in excellent yields and chemoselectivities (85–90%; entries 2–4, Table 3) at rt and under air with no other by-products detected, the remaining being starting ketone **2a** only. As for the less reactive Grignard reagents, EtMgBr exhibited a somewhat reduced reactivity in the 1*ChCl*/2*EG* eutectic mixture generating alcohol **3e** in only 45% yield

under the above conditions (entry 5, Table 3). Similarly to what observed in the addition of *n*-Bu₂Mg to the transiently form propiophenone **2a** (Table 2), the addition of MeLi to **1a** either in 2*Fruc*/3*Urea* or in water provided alcohol **3b** in yields not higher than 50% (entries 6–7, Table 3). This corroborates even more the crucial role played by *ChCl* in these nucleophilic additions.

To expand further the scope of this new one-pot strategy in terms of the nature of the substrate, we finally studied the metal-catalysed isomerisation/addition of a series of allylic alcohols (**1a–f**, Table 4) promoted by *n*-BuLi or *n*-Bu₂Mg in two different biorenewable eutectic mixtures: 1*ChCl*/2*EG* and 1*ChCl*/1*Sorb*. Pleasingly, both aryl (**1a–e**) and aliphatic (**1f**) allylic alcohols could be converted into the corresponding butylated (**3a,f–i**) or methylated (**3j**) tertiary alcohols in very good yields (up to 99%, Table 4) under mild reaction conditions and without any additional step of purification or isolation of transiently formed ketones **2a–f**, an important point for the development of *greener* synthetic protocols. Intriguingly, for each substrate, the best yields corresponded to the higher polarised organometallic reagent (*n*-BuLi) in 1*ChCl*/2*EG* as the eutectic mixture, whereas the opposite was true in 1*ChCl*/1*Sorb*. In the presence of an *ortho*-substituent (**1b**), longer reaction times (up to 4 h) were required to achieve satisfactory yields of the final isomerised product (**3f**) (entries 5–8, Table 4). As for the electronic properties of the aromatic substituent, while the presence of a *para*-methyl group still allowed the formation of **3g** in high yield after only 45 min (entries 9–12, Table 4), a *para*-bromo substituent (like in the derivative **1d**) increased the reaction time to up to 3 h for the formation of **3h** (entries 13–16, Table 4). Interestingly, however, no competing processes such as benzylic metalation and Li-Br exchange could be observed for **1c** and **1d**, respectively. The naphthalene-based allylic alcohol **1e** also reacted smoothly, thereby providing the butylated alcohol **3i** in yields to up to 90% after 3 h reaction time (entries 17–20, Table 4). Finally, aliphatic allylic alcohol **1f** furnished the saturated methylated alcohol **3j** in up to 87% yield, and in very short reaction times (10 min) (entries 21–22, Table 4).

Conclusions

In summary, we report an unprecedented, *greener*, efficient and operationally simple one-pot protocol for the synthesis of tertiary alcohols in high yields (up to 99%) successfully combining a quantitative ruthenium-catalysed isomerisation of a variety of allylic alcohols into the corresponding carbonyl compounds with a chemoselective nucleophilic addition promoted by polarised organometallic reagents (RLi/R₂Mg) and using biorenewable eutectic mixtures as environmentally friendly reaction media. Remarkably, the overall transformation, which formally involves three consecutive different steps such as (i) reduction of a C=C double bond, (ii) oxidation of a secondary carbinol moiety, and (iii) a chemoselective C–C bond formation, is carried out under mild reaction conditions, allows the addition of Grignard and organolithium reagents at rt and in the presence of air to transiently formed ketones, and takes place with no concomitant reduction or enolisation processes. It is worth noting that the

above-described one-pot tandem process takes place starting from allylic alcohols completely soluble in *DES* mixtures (as, similarly, are the corresponding *in situ* formed ketones) and is particularly favoured in terms of reaction yield in *ChCl*-based eutectic mixtures with respect to non-ionic *DES*s. This is consistent with the hypothesis^{10a} about a possible kinetic activation such alkylating reagents (R₁Li/R₂Mg) may undergo in the presence of quaternary ammonium salts to form highly nucleophilic halide enriched magnesiate or lithiate “ate” complexes capable to promote the addition reaction to carbonyl compounds in very short reaction times (a few sec), as in this case.³⁰ These results demonstrate that

environmentally friendly *DES*s can be the reaction media of choice for the efficient assembly of metal-catalysed and organometallic reactions in one-pot processes, and have implications in the future developments of new intriguing catalytic tandem reactions in a highly atom-economy fashion, which are known to be still affected by the formation of several by-products. Since this tandem reaction proceeds under *green* and mild reaction conditions, the practical application of this methodology provides a new eco-friendly synthetic tool for the synthesis of densely functionalised tertiary alcohols.

Table 4. Ru(IV)-catalysed allylic alcohol (**1a–f**) isomerisation combined with the chemoselective addition of organolithium/organomagnesium reagents in a one-pot process in *DES*s as green solvents.^[a]

Entry	Substrate	R ⁵ -M ^[b]	Product	<i>DES</i> ^[a]	Temp (°C)	Time	Yield (%) ^[c]
1		<i>n</i> -BuLi		1 <i>ChCl</i> /2 <i>EG</i>	50	0.5 h	97%
2		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /2 <i>EG</i>	50	0.5 h	93%
3		<i>n</i> -BuLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	0.5 h	80%
4		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /1 <i>Sorb</i>	75	0.5 h	93%
5		<i>n</i> -BuLi		1 <i>ChCl</i> /2 <i>EG</i>	50	4 h	90%
6		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /2 <i>EG</i>	50	4 h	74%
7		<i>n</i> -BuLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	4 h	46%
8		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /1 <i>Sorb</i>	75	4 h	75%
9		<i>n</i> -BuLi		1 <i>ChCl</i> /2 <i>EG</i>	50	45 min	99%
10		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /2 <i>EG</i>	50	45 min	86%
11		<i>n</i> -BuLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	45 min	45%
12		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /1 <i>Sorb</i>	75	45 min	75%
13		<i>n</i> -BuLi		1 <i>ChCl</i> /2 <i>EG</i>	50	3 h	96%
14		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /2 <i>EG</i>	50	3 h	86%
15		<i>n</i> -BuLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	3 h	72%
16		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /1 <i>Sorb</i>	75	3 h	90%
17		<i>n</i> -BuLi		1 <i>ChCl</i> /2 <i>EG</i>	50	3 h	75%
18		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /2 <i>EG</i>	50	3 h	68%
19		<i>n</i> -BuLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	3 h	72%
20		<i>n</i> -Bu ₂ Mg		1 <i>ChCl</i> /1 <i>Sorb</i>	75	3 h	90%
21		MeLi		1 <i>ChCl</i> /2 <i>EG</i>	50	10 min	66%
22		MeLi		1 <i>ChCl</i> /1 <i>Sorb</i>	75	10 min	87%

^[a] Reaction conditions: allylic alcohol (**1a–f**, 0.5 mmol) under Ar atmosphere at 50–75 °C, 5 mol% Ru(IV) catalyst, in 0.5 g of the desired *DES*. ^[b] 3 eq. of commercially available 1.6 M solution in hexanes of *n*-BuLi and 1.0 M in heptane for *n*-Bu₂Mg were added at rt and under air. ^[c] Calculated by GC.

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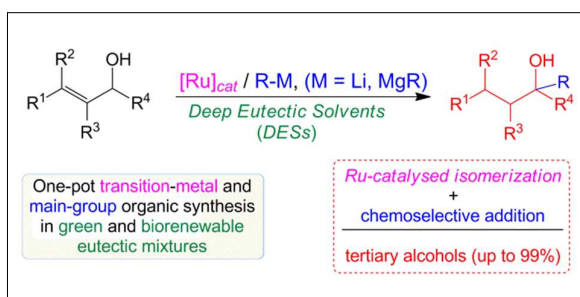
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Text for Graphical Abstract

Transition-metal complexes and polarised organometallic reagents play together in green solvents: A new environmentally friendly one-pot protocol for the synthesis of tertiary alcohols in *Deep Eutectic Solvents* is reported, establishing a new bridge between transition metal-catalysed and main-group mediated organic reactions in *green solvents*.