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Oxovanadium(IV) Complex Catalyzed Oxygenation of α,β-Unsaturated Carboxamide into 2,3-Epoxycarboxamide with Molecular Oxygen and an Aldehyde

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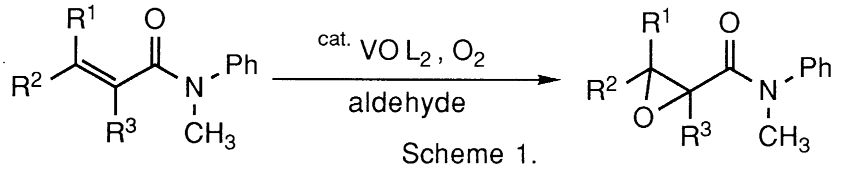
In the presence of a catalytic amount of bis(1,3-diketonato)oxovanadium(IV) complex, epoxidation of α,β-unsaturated carboxamides with molecular oxygen and an aldehyde proceeds smoothly at room temperature to give the corresponding 2,3-epoxycarboxamides in good yields.

Electron-deficient olefins are generally epoxidized by using nucleophilic peroxides, such as the sodium salt of hydrogen peroxide (NaOOH) or the sodium salt of *t*-butyl hydroperoxide,1) rather than carboxylic peracids. Recently, it has been reported that the combined use of alkyl lithium and *t*-butyl hydroperoxide is effective for the epoxidation of electron-deficient olefins, for example, α,β-unsaturated carboxamide, ketone, and carboxylic acid ester.2) Also, the condensation reaction of aldehyde or ketone with α-halogenated carboxylic acid ester or carboxamide is well known as the preparative method of 2,3-epoxycarboxylic acid derivatives (the Darzens Reaction).3) However, little study has been reported for epoxidation of electron-deficient olefins, as α,β-unsaturated carboxylic acid derivatives, with molecular oxygen as an oxidant.

Previously, we reported a useful method for the epoxidation of olefins using molecular oxygen (oxidant) and an aldehyde (reductant) in the presence of a catalytic amount of bis(1,3-diketonato)nickel(II)4) or tris(1,3-diketonato)iron(III).5) In the course of our continued study on the epoxidation of olefins, it was found that a catalytic amount of bis(1,3-diketonato)oxovanadium(IV)6) promoted oxygenation of 2,3- and 3,3-disubstituted acrylamides into the corresponding 2,3-epoxypropanamides in good yields.

In this communication, we would like to describe a novel oxygenation method of α,β-unsaturated carboxamides, which is hardly oxygenated with molecular oxygen, into 2,3-epoxycarboxamides with molecular oxygen (oxidant) and an aldehyde (reductant) using an oxovanadium(IV) complex catalyst.



Scheme 1.

LH=1,3-diketone

In the first place, the catalytic activities of several transition-metal complexes coordinated with acetylacetone in the formation of 2,3-epoxycarboxamide was examined by taking the epoxidation of *N*,3-dimethyl-

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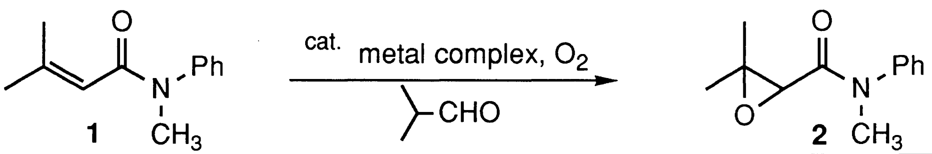
crotonanilide (**1**) with molecular oxygen and isobutyraldehyde as a model reaction. The results are summarized in Table 1.

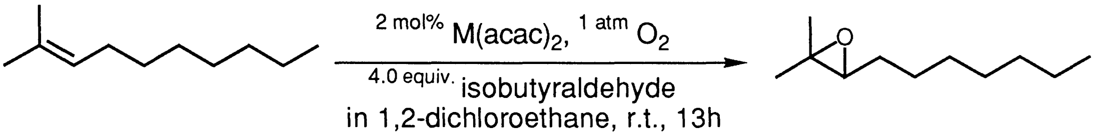
Table 1. Catalytic Activities of Several Transition-metal Complexes on Epoxidation of *N*,3-Dimethylcrotonanilide[a)]



Entry	Metal complex	Conversion of **1** /%	Yield of **2** /%
1	$Ni(acac)_2$	—	trace[b)]
2	$Fe(acac)_3$	33[b)]	26[c)]
3	**$VO(acac)_2$**	81[c)]	71[c)]

a) Reaction conditions; **1** 1.0 mmol, metal complex 0.02 mmol, isobutyraldehyde 4.0 mmol, 1,2-dichloroethane (solvent) 10 ml, 1 atm O_2, r.t.,12 h. b) Determined by GC. c) Isolated yield.

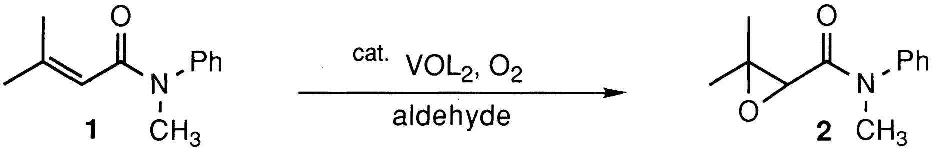
As shown in Table 1, when the reactions were carried out by using bis(acetylacetonato)nickel(II) or tris(acetylacetonato)iron(III), which exhibited excellent catalytic activity for epoxidation of aliphatic or aromatic olefins,[4,5)] *N*,3-dimethyl-2,3-epoxybutananilide (**2**) was formed in low yield (Entries 1 and 2). On the other hand, it was found that bis(acetylacetonato)oxovanadium(IV) is effectively employed as a catalyst on the oxygenation of **1** with molecular oxygen and isobutyraldehyde at room temperature to afford epoxide **2** in 71%

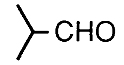
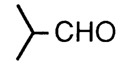
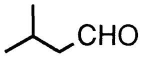
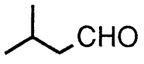


M	Conv.	Yield
M=Ni	100%	quant.
M=VO	≈0%	≈0%

Scheme 2.

Table 2. Improvement of Yield of 2,3-Epoxycarboxamide[a)]

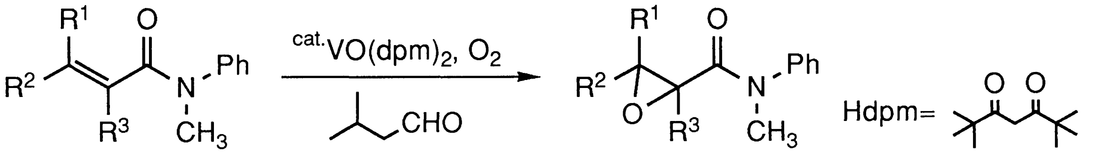


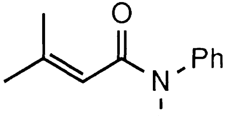
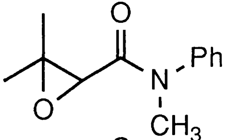
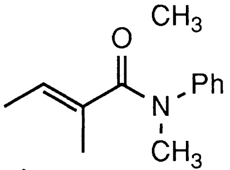
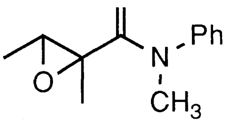
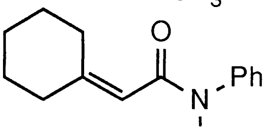
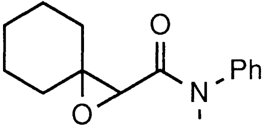
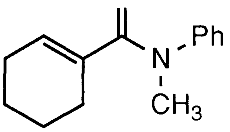
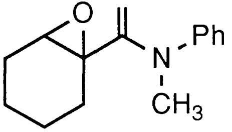
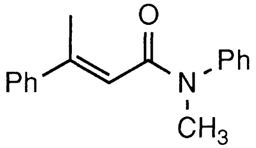
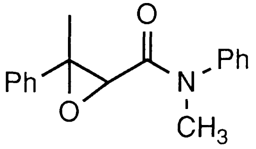
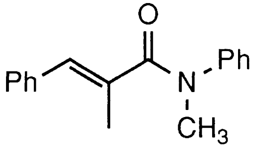
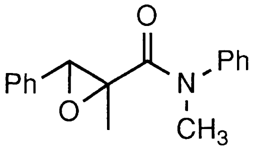
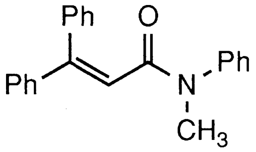
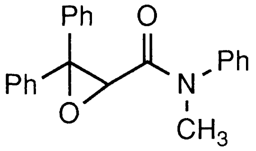
Entry	Catalyst	Aldehyde (equiv.)	Conversion of **1** /%[b)]	Yield of **2** /%[b)]
1	$VO(acac)_2$	 (4.0)	81	71
2	$VO(acac)_2$	 (8.0)	85	79
3	$VO(acac)_2$	 (8.0)	91	84
4	$VO(dpm)_2$	 (8.0)	92	87

a) Reaction conditions; **1** 1.0 mmol, VOL_2 0.02 mmol, 1,2-dichloroethane (solvent) 10 ml, 1 atm O_2, r.t.,12 h.
b) Isolated yield.

yield (Entry 3). It was posturated that the oxygenation of **1** would be promoted by VO(acac)$_2$, which could interact with amide group of α,β-unsaturated amide **1**, to afford the corresponding epoxide **2**, becouse, in the case of oxygenation of 2-methyl-2-decene, a simple aliphatic olefin, epoxidation reaction didn't proceed at all by use of VO(acac)$_2$ under similar reaction conditions (Scheme 2). When the epoxidation reaction was stopped half-way (stirred for 12 h), it was confirmed that isobutyraldehyde was consumed completely and 20% of α,β-unsaturated amide **1** still remained at this stage.

Table 3. Preparation of Various 2,3-Epoxycarboxamides[a)]



Entry	α,β-Unsaturated Carboxamide	2,3-Epoxy-carboxamide[b)]	Yield /%[c)]
1			87
2			84
3			81
4			90
5			71
6			73
7			69

a) Reaction conditions; α,β-unsaturated carboxamide 1.0 mmol, VO(dpm)$_2$ 0.02 mmol, isovaleraldehyde 8.0 mmol, 1,2-dichloroethane10 ml, r.t., 1 atm O$_2$, 12 h. b) All products gave satisfactory ^{1}H NMR and IR spectra. c) Isolated yield.

In the next place, various aldehydes were examined in order to improve the yield of epoxide **2**, and the results are listed in Table 2. It was shown there that when 8.0 equivalents of isovaleraldehyde to α,β-unsaturated amide **1** were employed, the yield of epoxide **2** was improved to 84% (Entry 3). Further, the effect of 1,3-diketone-type ligands in oxovanadium(IV) complexes on the yield of epoxide was examined, and it was found that yield of epoxide **2** was increased up to 87% when bis(dipivaloylmethanato)oxovanadium(IV) ($VO(dpm)_2$) was employed as a catalyst (Entry 4).

Next, the epoxidation reaction of several α,β-unsaturated carboxamides was tried according to the above procedure (see Table 3). In Entries 1 to 7, 2,3- and 3,3-disubstituted acrylamides were oxygenated into the corresponding 2,3-epoxypropanamides in good yields. Also, it was made clear that the above epoxidation procedure was successfully applied to aliphatic acyclic, aliphatic cyclic, and aromatic α,β-unsaturated carboxamide.

A typical procedure is described for the preparation of *N*,3-dimethyl-2,3-epoxybutananilide; to a solution of *N*,3-dimethylcrotonanilide (189 mg, 1.0 mmol) and $VO(dpm)_2$ (8.6 mg, 0.02 mmol) in 1,2-dichloroethane (10 ml) was added isovaleraldehyde (688 mg, 8.0 mmol) at room temperature under an oxygen atmosphere. After stirred for 12 h, the reaction mixture was extracted with ethyl acetate and washed with saturated potassium carbonate (5 ml) and brine, and then dried over Na_2SO_4. After removal of the solvent under reduced pressure, the residue was purified by preparative TLC on SiO_2 (hexane : AcOEt) to yield *N*,3-dimethyl-2,3-epoxybutananilide (178 mg, 87% yield).

It is noted that a catalytic amount of bis(dipivaloylmethanato)oxovanadium(IV) promotes the oxygenation of α,β-unsaturated carboxamide, which is hardly oxygenated with molecular oxygen, in the presence of aldehyde (reductant). Thus, this procedure provides a convenient method for the preparation of 2,3-epoxycarboxamides by direct oxygenation of the corresponding α,β-unsaturated carboxamides with molecular oxygen.

References

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