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Synthesis of α,β-dicarbonylhydrazones by aerobic manganese-catalysed oxidation.

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Abstract. A practical, simple, and efficient manganese-catalysed oxidation of C(sp^2)-H bond in readily available β-carbonylenehydrazine under aerobic conditions has been developed. This protocol exhibits a wide range of functional group tolerance in β-carbonylenehydrazines to afford α,β-dicarbonylhydrazones. Experimental and theoretical results suggest that the reaction very likely proceeds through a radical pathway via a hydrogen-atom-transfer process promoted by a Mn^{III} species.

Keywords: C-H oxidation; manganese catalysis; molecular oxygen; α,β-dicarbonyl compounds

Introduction

The activation of molecular oxygen for the selective oxidation of organic substrates is an essential transformation in organic chemistry at both a laboratorial and industrial level.[1] However, this transformation features important drawbacks such as the high kinetic stability of O_2 towards reactions at room temperature and the thermodynamic tendency of molecular oxygen to afford the total oxidation of the organic substrates (i.e. combustion). Thus, hydrocarbons usually react with O_2 via a complex free-radical pathway called autooxidation.[2] These reactions are typically not selective and offer little synthetic utility. Therefore, developing new selective procedures to oxidize C-H bonds under an aerobic atmosphere are particularly desirable.[3] Accordingly, both metal-free systems[4–6] and transition metal complexes[7–18] have been well-established to be active catalysts in this process.

On the other hand, the oxidation of a methylene group α to a carbonyl group to form vicinal dicarbonyl compounds is an important transformation which has many applications in organic synthesis as building blocks for the synthesis of bioactive molecules, especially those containing heterocycles.[19–24] Conventional reagents for accomplishing this transformation, including strong oxidants such as selenium oxide,[25] 2-iodoxybenzoic acid (IBX),[26] Dess–Martin reagent[27] or cerium(IV) salts,[28] often lead to further oxidation or side reactions because of the strong reaction conditions employed. Additionally, these processes usually require stoichiometric or large excess of oxidants and, consequently, generate substantial quantities of waste, which is increasingly considered undesirable due to environmental considerations. Therefore, searching for a mild and green procedure is timely.[29–32]

We recently reported the synthesis of the β-ketoenehydrazines **2a** and **2g**, and their use as precursors of monoanionic bidentate ligands coordinated to Ni(II) and Cu(II) complexes.[33] During the attempts of synthesis of the corresponding coordination compound of Mn(II), by the reaction of **2a** with $Mn(OAc)_2$ in aerobic conditions (Scheme 1), we observed the presence of a unexpected new product. This was identified by MS, NMR spectroscopic analysis and single crystal X-ray structure (see below Figure 2) as the α,β-diketohydrazone **3a**, which is the oxidation product of **2a**.

In this paper, we describe a mild and practical protocol for manganese-catalysed aerobic oxidation of C(sp^2)-H bonds in β-carbonylenehydrazine compounds to afford novel α,β-dicarbonylhydrazones. To the best of our knowledge, this is the first reported synthesis of a α,β-dicarbonylhydrazone framework.

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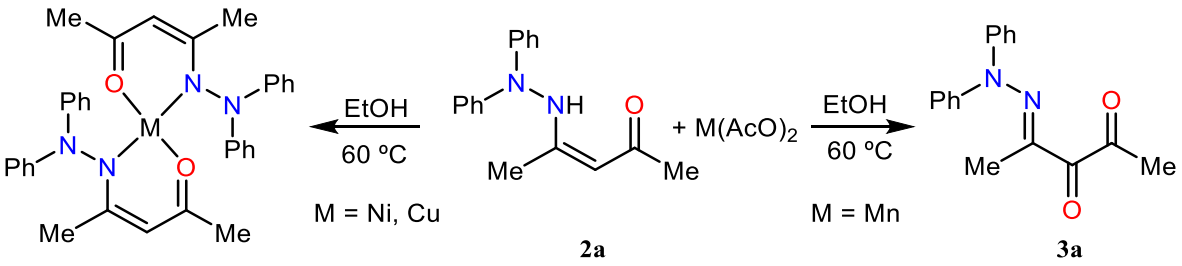
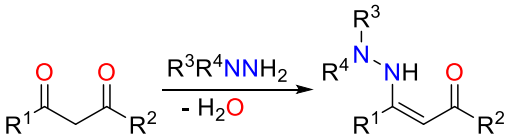


Scheme 1. Synthesis of compound **3a** and related Ni and Cu complexes under aerobic conditions

Results and Discussion

Starting β-carbonylenehydrazines compounds, **2a-o**, were easily obtained, using literature procedures,[34,35] by treating the readily available β-dicarbonyl compounds, **1a-f**, and the corresponding N,N-disubstituted hydrazine, $R^3R^4NNH_2$. The results are summarised in Table 1. Compounds **2a-i** were isolated as brown crystalline solids, while the methylphenylhydrazine derivatives **2j-l** and the dimethylhydrazine derivatives **2m-o** were isolated as brownish oils. Analytical and spectroscopic characterization suggested for all of them a β-carbonylenehydrazine structure that is preferential respecting to the others possible tautomers.[33] For instance, the ^{1}H NMR spectra shown a singlet at 4.6-5.9 ppm that was attributed to the C-H proton in the α position. Additionally, compounds **2a-e**, **2g-k** and **2m-n** showed a low-field singlet at 9.6-12.7 ppm that were attributed to the N-H hydrazinic proton, which suggested the presence of a strong intramolecular hydrogen bond with the carbonyl oxygen atom,[36] and should be responsible for the stabilisation of the β-carbonylenehydrazine isomer in the enehydrazine-hydrazone tautomerism.[33] Conversely, the signal corresponding to the NH hydrazinic proton for the cyclohexane-1,3-dione derivatives **2f**, **2l** and **2o** were found to be shifted to high-field (7.0-9.0 ppm), showing that intramolecular hydrogen bond was impeded in these compounds. The β-carbonylenehydrazine structure was confirmed by X-ray diffraction in compounds **2c** and **2i** (Figure 1). Selected bond distances and angles are given in Table S1 (Supporting Information). Both compounds were characterised by a strong intramolecular hydrogen bond between the hydrogen atom attached to the N1 atom and the O1 oxygen atom (N-H···O distances of 2.125 and 2.031 Å for **2c** and **2i**, respectively). This interaction imposes a planar distribution of the O1-C1-C2-C3-N1 atoms (maximum deviation from the plane of 0.01 Å). The C1-C2 bond length is longer than the C2-C3 one (*ca.* 1.43 *versus ca.* 1.36 Å, respectively) and the C1-O1 distance is typical of a carbonyl moiety (around 1.22 Å). These data are in agreement with a localised β-carbonylenehydrazine formulation. The pyramidalization at the N2 atom is reduced with a deviation of the N2 atom from the plane defined for the substituents of 0.02 and 0.31 Å for **2c** and **2i**, respectively.

Table 1. Synthesis of β-carbonylenehydrazines **2a-o**.



1a-f **2a-o**

R^1	R^2	R^3	R^4	Product	Yield (%)[a]
Me	Me	Ph	Ph	**2a**[b]	57
Me	Ph	Ph	Ph	**2b**	51
Me	OMe	Ph	Ph	**2c**	73
Me	OEt	Ph	Ph	**2d**[c]	72
Me	NEt_2	Ph	Ph	**2e**	40
-$(CH_2)_3$-		Ph	Ph	**2f**	14
Me	Me	Ph	Me	**2g**[b]	68
Me	Ph	Ph	Me	**2h**	73
Me	OMe	Ph	Me	**2i**	30
Me	OEt	Ph	Me	**2j**	96
Me	NEt_2	Ph	Me	**2k**	22
-$(CH_2)_3$-		Ph	Me	**2l**	53
Me	Me	Me	Me	**2m**[d]	69
Me	Ph	Me	Me	**2n**	99
-$(CH_2)_3$-		Me	Me	**2o**	99

[a] Isolated yield. [b] Reported in ref. [33]. [c] Reported in ref. [35]. [d] Reported in ref. [34].

The β-ketoenehydrazine **2g** was selected as the appropriate substrate to establish a general procedure for the oxidation. Reactions were carried out on the 0.5 mmol scale using ethanol as solvent and one bar of oxygen pressure at 60ºC The reactions were monitored by ^{1}H NMR analysis and the results are summarised in Table 2. Several common first-row transition-metal salts were initially tested as catalysts. It is worth mentioning that spontaneous oxygenation of the β-ketoenehydrazine does not occur in the absence of metal complex catalyst (entry 1). No oxidation reaction of substrate **2g** was also observed in the presence of zinc(II) or nickel(II) salts, such as

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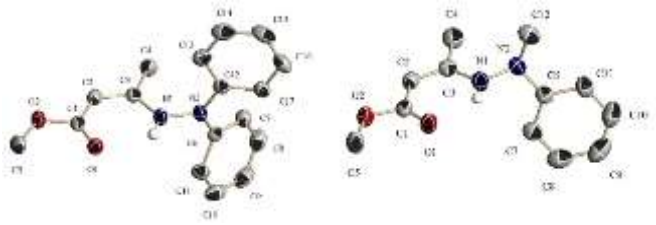
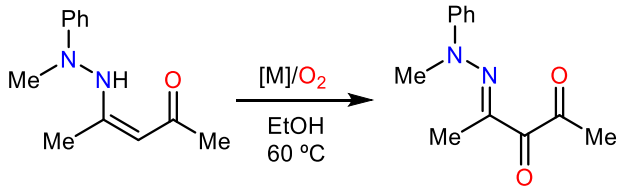
$Zn(OAc)_2$ (entry 2) and $Ni(OAc)_2$ (entry 3). Copper or iron salts, such as $Cu(OAc)_2$ (entry 4) and $FeCl_3$ (entry 5), only afforded low yields of the oxidised product after 18 h of reaction. As we expected, manganese(II) salts afforded the best yield for the vicinal dicarbonyl compound **3g**. When $MnBr_2$ was used as the Mn(II) source, a 70% yield of **3g** was obtained after 18 h at 60 ºC (entry 6), while almost complete formation of **3g** was observed with $Mn(OAc)_2$ as catalyst under the same reaction conditions (entry 7). At this point, the catalytic oxidation was repeated, maintaining $Mn(OAc)_2$ as catalyst, but testing several reaction parameters in order to optimize the reaction. Thus, the yield to compound **3g** decreased by reducing the reaction time to 1h (24%, entry 8) or to 2h (72%, entry 9), respectively. Finally, the reaction was also incomplete both by using air at atmospheric pressure (75%, entry 10) or by decreasing the temperature to 25 ºC (83%, entry 11).



2c **2i**

Figure 1. X-Ray structures of compounds **2c** and **2i**. Hydrogen atoms were omitted for clarity with the exception of the N-H atom.

Table 2. Screening of reaction conditions for the oxidation of β-ketoenehydrazines.[a)]

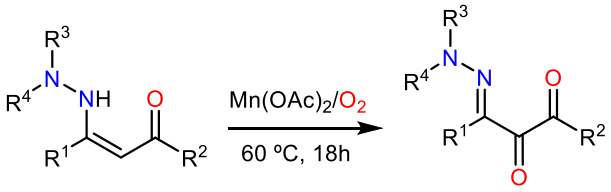


2g **3g**

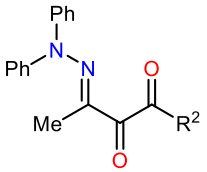
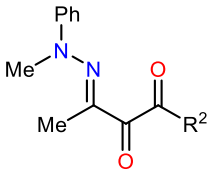
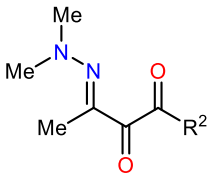
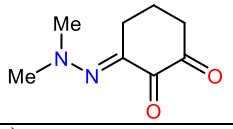
Entry	Catalyst	Yield, %[b)]
1	-	-
2	$Zn(OAc)_2$	-
3	$Ni(OAc)_2$	-
4	$Cu(OAc)_2$	<10
5	$FeCl_3$	<5
6	$MnBr_2$	70
7	$Mn(OAc)_2$	>95
8[c)]	$Mn(OAc)_2$	24
9[d)]	$Mn(OAc)_2$	72
10[e)]	$Mn(OAc)_2$	75
11[f)]	$Mn(OAc)_2$	83

[a)] Reaction conditions: catalyst (0.0125 mmol), β-ketoenehydrazine **2g** (0.5 mmol), EtOH (10 mL), oxidant: O_2 (1 atm). T = 60 ºC, t = 18 h. [b)] Determined by ^1H NMR analysis. [c)] t = 1 h. [d)] t = 2 h. [e)] Air at atmospheric pressure. [f)] T = 25 ºC.

Table 3. Synthesis of vicinal α,β-dicarbonylhydrazones by aerobic Mn-catalysed oxidation.[a)]



2a-o **3a-e,g-k,m-o**

Product		Yield %[b)]
	R^2 = Me, **3a**	31
	R^2 = Ph, **3b**	76
	R^2 = OMe, **3c**	66
	R^2 = OEt, **3d**	97
	R^2 = NEt_2, **3e**	62
	R^2 = Me, **3g**	91
	R^2 = Ph, **3h**	71
	R^2 = OMe, **3i**	59
	R^2 = OEt, **3j**	73
	R^2 = NEt_2, **3k**	46
	R^2 = Me, **3m**	38[c)]
	R^2 = Ph, **3n**	50
	**3o**	43

[a)] Reaction conditions: catalyst: $Mn(OAc)_2 \cdot 4H_2O$ (0.0125 mmol), β-keto-enehydrazine (0.5 mmol), solvent: EtOH (10 mL), oxidant: O_2 (1 atm), t = 18 h, T = 60 °C. [b)] Isolated yield. [c)] Yield determined by NMR.

In order to generalise the developed procedure, different β-carbonylenehydrazines with different functional groups were tested, using $Mn(OAc)_2$ as manganese(II) source and the optimised reaction conditions described in Table 2 (entry 7). The results obtained in this study are shown in Table 4. In general, the system yielded moderate to good yields of the corresponding vicinal α,β-dicarbonylhydrazones, including α,β-diketones (**3a,b,g,m,h,n,o**), α,β-ketoesters (**3c,d,i,j**), and α,β-ketoamides (**3e,k**), while no reaction were found for the cyclohexane-1,3-dione derivatives **2f** and **2l** Compounds **3a** and **3c-l** were isolated as crystalline solids, while the diphenylhydrazone **3b** and the dimethylhydrazone derivatives **3m-o** were isolated as orange oils. Analytical and spectroscopic data confirmed the formation of the α,β-dicarbonylhydrazone derivatives **3a-e**. **3g-k** and **3m-o**, respectively. For instance, the two singlets, corresponding to the C-H proton in the α position and the N-H hydrazinic proton observed in compounds **2** disappeared in the ^1H NMR spectra, while a new signal at 187-205 ppm, corresponding to a new carbonyl group appeared in the $^{13}C\{^1H\}$ NMR spectra.

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The molecular structure of some of these derivatives was confirmed by X-ray crystallography. Structures of diphenylhydrazone derivatives **3a**, **3c** and **3d** and methylphenylhydrazone derivatives **3i** and **3k** are shown in Figure 2, while selected bond distances and angles are given in Table S1 (Supporting Information). The C=O distances of **3** compounds are again typical of carbonyl bonds, being that of the α carbonyl group slightly shorter (around 1.20 Å) than that of the β carbonyl group (around 1.22 Å). The hydrazone N1-C3 bond is typical of a N=C double bond (ca. 1.30 Å), while the value of ca. 1.33 Å for the N1-N2 distance is indicative of a N-N single bond. All these compounds showed as common structural features: (i) a similar torsion angle between the two carbonyl groups, which is close to 90º; and (ii) a planar arrangement of the N2-N1-C3-C2-O3 atoms (maximum deviation from the plane less of 0.03 Å).

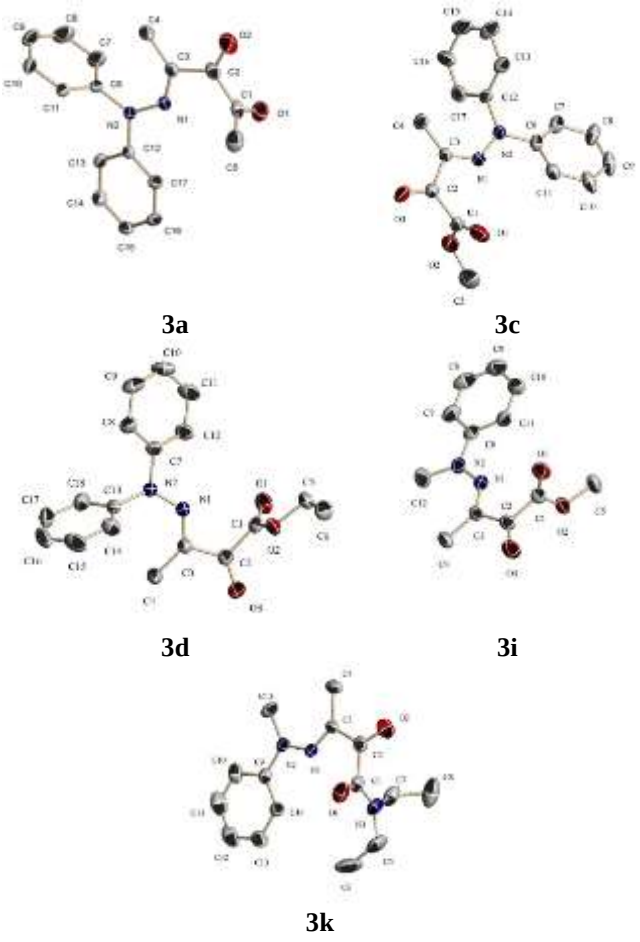
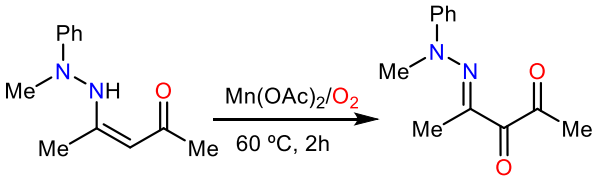


Figure 2. X-Ray structures of compounds **3a,c,d,i,k**. Hydrogen atoms were omitted for clarity

Additional studies were further conducted in order to gain insights into the reaction mechanism. The effect of different additives in the aerobic Mn-catalysed oxidation of the β-ketoenehydrazine **2g**, under the optimal reaction conditions, is showed in Table 4. The reaction time was set to 2 h in order to be sure that the reactions did not run to completion, allowing a fair comparison of activity. The addition of

Table 4. Influence of additives in the aerobic Mn-catalysed oxidation of β-ketoenehydrazines.[a)]



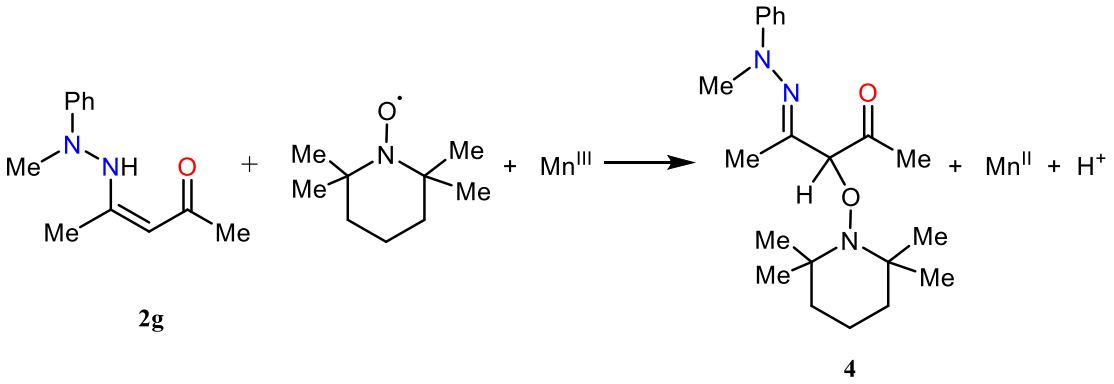
2g **3g**

Entry	Catalyst	Additive	Yield%[b)]
1	$Mn(OAc)_2$	-	72
2	$Mn(OAc)_2$	Bipy (1 eq)	92
3	$Mn(OAc)_2$	Bipy (4 eq)	88
4	$Mn(OAc)_2$	Tempo (1eq)	20 [c)]
5	$Mn(OAc)_2$	Tempo (4eq)	8 [d)]
6 [e)]	$Mn(OAc)_2$	Tempo (1eq)	0 [f)]

[a)] Reaction conditions: catalyst (0.0125 mmol), β-keto-enehydrazine **2g** (0.5 mmol), EtOH (10 mL), oxidant: O_2 (1 atm). T = 60 ºC, t = 2 h. [b)] Determined by ^{1}H NMR analysis. [c)] TEMPO-substrate adduct **4** was obtained in 20% yield. [d)] TEMPO-substrate adduct **4** was obtained in 25% yield. [e)] Reaction carried out under N_2 atmosphere and 18 h. [f)] TEMPO-substrate adduct **4** was not observed.

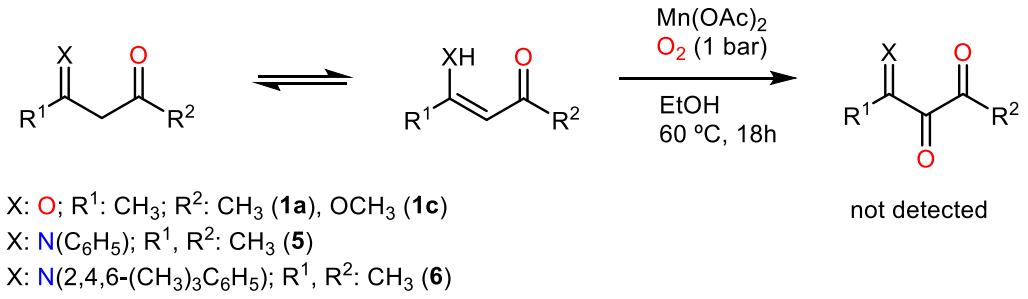
one equivalent of 2,2'-bipyridine (bipy) led to a slight increase of the yield of the vicinal α,β-dicarbonylhydrazone **3g** (entry 2) respecting to the reaction performed without additive (entry 1). A similar result was observed when an excess of bipy (4 eq) was added (entry 3). These results could be compatible with a reaction mechanism involving species that contain either the β-ketoenehydrazine or its monoanionic form as a bidentate ligand coordinated to the manganese complex, in a similar way that the previously observed with Ni(II) and Cu(II) complexes.[33] Thus, the presence of bipy, which is well-known to form 1:1 complexes with manganese(II) acetate,[37,38] could share with this ligand the metal coordination sphere, which give an increase in the yield of the oxidation catalytic process. However, the data are not conclusive proofs of coordination of substrates **2** to manganese. By other hand, the addition of one equivalent of the radical scavenger 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) into the reaction system led to the partial suppression of the oxidation process (entry 4). When an excess of TEMPO (4 eq) was added (entry 5), further decrease of the oxidation product **3g** was observed, although no complete suppression was achieved. Interestingly, a new species was detected, which could be identified by NMR and ESI-MS analysis as the TEMPO-substrate adduct **4**, obtained by the α-oxyamination of the β-ketoenehydrazine **2g** and the free radical TEMPO. α-Oxyamination between 1,3-dicarbonyl compounds and TEMPO has been already reported.[39–42] The formation of this adduct was almost undetectable when reacted

compound **2g** and TEMPO in the absence of oxygen (entry 6). However, the adduct could be obtained in a

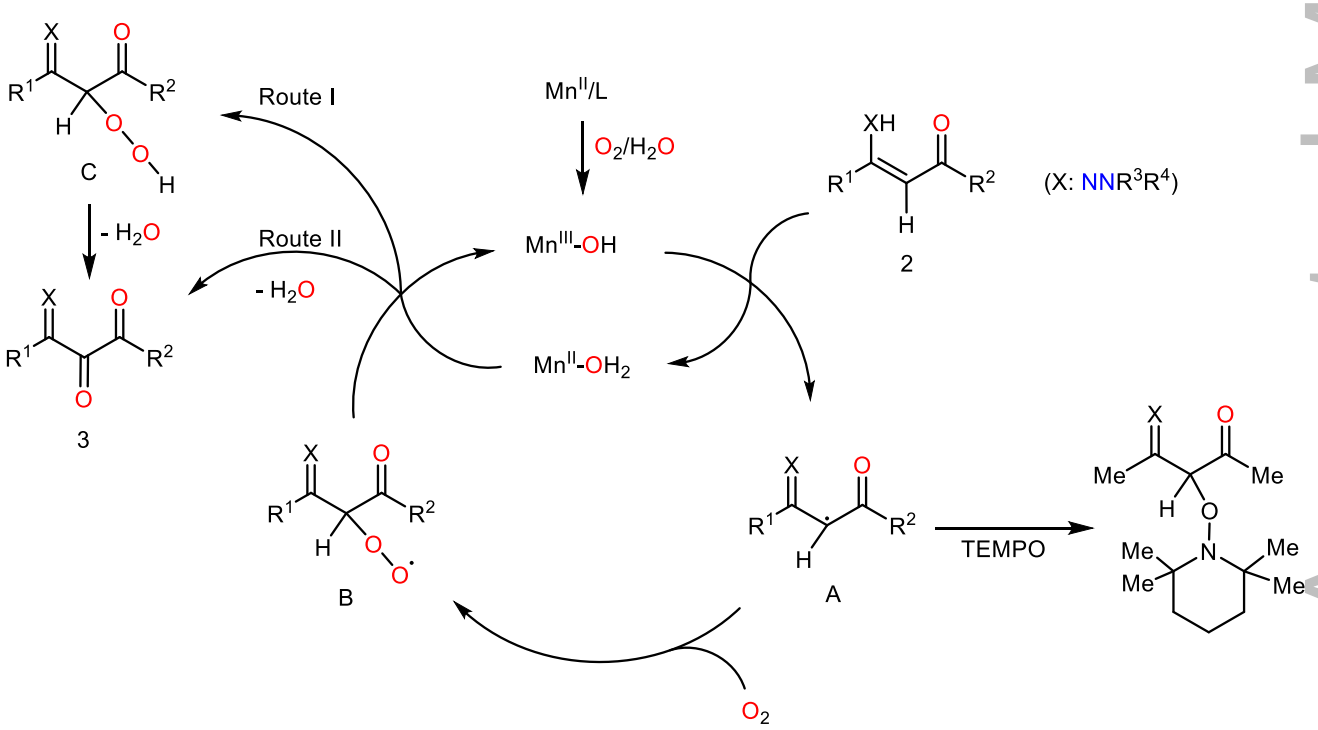


2g **4**

Scheme 2. Synthesis of the adduct **4**.



Scheme 3. Studies on the reaction mechanism.



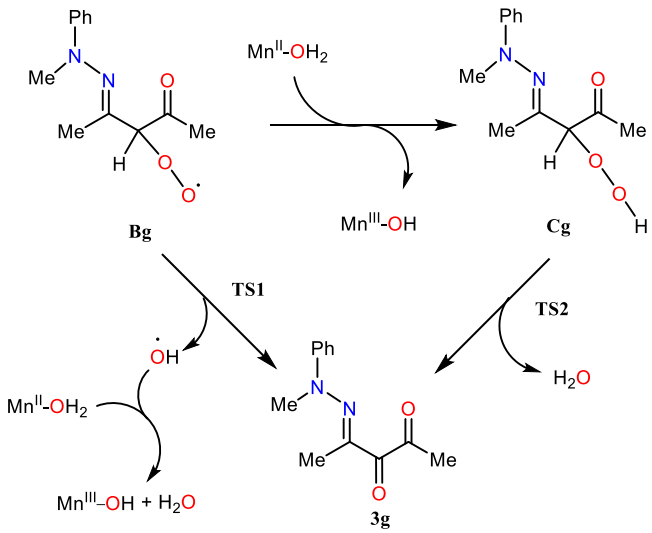
Scheme 4. Proposed mechanism for the O_2 activation by Mn(II) and the subsequent C-H oxidation.

45 % yield by the reaction of compound **2g** and TEMPO using $Mn(OAc)_3$ as stoichiometric oxidant (Scheme 2). These results support a radical pathway promoted by Mn^{III}, which is obtained by the oxidation of Mn^{II} with molecular oxygen.

The oxidation process is specific for β-carbonylenehydrazine substrates. Thus, as shown in

Scheme 3, oxidation of α-C-H bonds were not observed in β-dicarbonyl compounds, such as 2,4-pentanedione (**1a**) or methyl 3-oxobutanoate (**1c**), in the presence of $Mn(OAc)_2$ as catalyst and the optimised reaction conditions described in Table 2. The same negative result was obtained with β-ketoenamine compounds, such as **5** or **6**, obtained by the condensation of 2,4-pentanedione (**1a**) and the corresponding aniline

Based on the control experiments, a plausible mechanism for this reaction is proposed in Scheme 4. Firstly, Mn^{II} complex is oxidised to a hidroxo Mn^{III} species under aerobic conditions.[43–45] Subsequently, the β-carbonylenehydrazine compound **2** is converted into the related radical species **A** via a hydrogen-atom (H·)-transfer (HAT) process,[46,47] which is promoted by the Mn^{III} species, via formation a Mn^{III}-enolate.[44,45,48,49] The formation of radical species **A** is demonstrated by the formation of the TEMPO-substrate adduct. This fact suggests that **A** may react with oxygen to get the peroxide radical species **B**. Finally, two alternative routes can be proposed for the last step of the mechanism to afford compound **3**: (*Route I*) protonation of peroxide species **B** to afford the hydroperoxide species **C**, followed by elimination of water and (*Route II*) elimination of OH radical from the peroxido radical species **B**.



Scheme 5. Pathways for the formation of **3g** from peroxido radical species **B**, *Route II*, and from the hydroperoxide species **C**, *Route I*.

In order to gain further insights into the oxidation mechanism, selected Density Functional Theory (DFT) calculations were performed. Geometry optimizations without symmetry restrictions were carried out with compounds **2** and **3**. The selected combination of method and basis sets provides a good structural description of these compounds based on the comparison of the structural parameters of the optimised structures with those experimentally determined by X-ray diffraction (see optimised structures in Table S4, Supporting Information). The oxidation reactions from **2** to **3** are clearly exergonic with Gibbs energy values within the range -64 – -70 kcal· mol^{-1} (see Table S4). Compounds **2g** and **3g** were selected to analyse further details. In particular, the last step of the mechanism to afford complex **3g** was investigated (Scheme 5). Intermediates **Bg** and **Cg** were optimised and transition states for both pathways, **TS1** and **TS2**, respectively, were located (see these structures in Figure 3). The $\Delta G^{\neq}$ barrier for the water extrusion from **Cg**, 39.7 kcal· mol^{-1}, is higher than the OH radical elimination from **Bg**, 33.7 kcal· mol^{-1}, suggesting that the latter process is probably the last step in the oxidation mechanism from **2g** toward **3g** (i.e. *Route II* in Scheme 4).

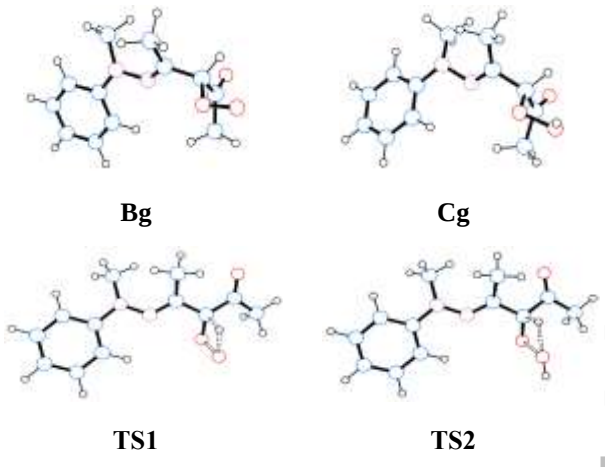


Figure 3. Optimised structures of the intermediates **Bg** and **Cg** and transition states **TS1** and **TS2**.

Conclusion

In summary, we have developed a mild and practical approach for the synthesis of α,β-dicarbonylhydrazones from β-carbonylenehydrazines in the presence of $Mn(OAc)_2$ under molecular oxygen. Our study have shown that manganese-catalysed aerobic oxidation of $C(sp^2)$-H bonds in β-carbonylenehydrazine compounds occur through a mechanism that involve radical species via HAT process. The study of further applications of this research is underway.

Experimental Section

General Information. Synthetic reactions were performed under aerobic conditions. Solvents were purified appropriately prior to use, using standard procedures. Chemicals were obtained from commercial sources and used as supplied. Infrared spectra were recorded on a Perkin-Elmer FT-IR Spectrum Two (pressed KBr pellets).

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NMR spectra were recorded using Bruker AMX-300 or Avance III spectrometers at the Centro de Investigaciones, Tecnología e Innovación (CITIUS) of the University of Sevilla. $^{13}C\{^1H\}$ and ^1H shifts were referenced to the residual solvent signals and all data are reported in ppm downfield from TMS. High-resolution mass spectra were carried out by using a Q-Exactive Hybrid Quadrupole-Orbitrap Mass Spectrometer from Thermo Scientific at CITIUS of the University of Sevilla.

Synthesis of β-carbonylenehydrazines. The syntheses of β-carbonylenehydrazines compounds **2a** and **2g** have been reported previously by us.[33] Compounds **2d**[35] and **2m**[34] have been previously described, but the experimental procedures employed vary slightly and are here described.

(Z)-3-(2,2-diphenylhydrazinyl)-1-phenyl-but-2-en-1-one, 2b: NEt_3 (0.84 mL, 6 mmol) was added to a solution of N,N-diphenylhydrazine hydrochloride (1.37 g, 6 mmol) in toluene (15-25 mL). After 5–10 min of stirring, 1-phenyl-butane-1,3-dione (1.0 g, 6 mmol) was also added and the resulting mixture was stirred at 80 °C for 20 h. The mixture was filtered and the resulting toluene solution was concentrated to dryness. The residue was purified by chromatography (1:20 AcOEt / Petroleum ether as eluyent) obtaining a brown crystalline solid identified as **2b** (1.0 g, 51% yield). IR (KBr, cm^{-1}): 3055, 1587, 1577, 1542, 1492, 1421 ,1377, 1318, 1273, 1181, 1082, 1064, 1026, 999, 931, 908, 847, 806, 772, 752, 711, 693, 681, 619, 613, 567, 536, 503. ^1H NMR ($CDCl_3$, 300 Hz): δ 2.15 (s, 3H, C*H*$_3$–CNN), 5.88 (s, 1H, CO–C*H*–CNN), 7.06-7.12 (t, 2H, J = 7.2 Hz, C*H* para, Ph–N), 7.18-7.22 (m, 4H, C*H* ortho, Ph–N), 7.31-7.37 (m, 4H, C*H* meta, Ph–N), 7.42-7.50 (m, 3H, C*H* meta and para, Ph–CO), 7.94-7.97 (d, 2H, J = 7.5 Hz, C*H* ortho, Ph–CO), 12.66 (s, 1H, N*H*). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75,47 Hz): δ 18.8 (s, *C*H$_3$–CNN), 92.5 (s, CO–*C*H–CNN), 119.5 (s, *C* ortho, Ph–N), 123.4 (s, *C* para, Ph–N), 127.3 (s, *C* meta, Ph–CO), 128.3 (s, *C* ortho, Ph–CO), 129.4 (s, *C* meta, Ph–N), 131.1 (s, *C* para, Ph–CO), 139.6 (s, *C* ipso, Ph–CO), 146.3 (s, *C* ipso, Ph–N), 166.3 (s, *C*NN), 189.2 (s, *C*O). ESI-MS: found m/z 329.165 for [**2b** +1]$^+$, calculated for $C_{22}H_{20}N_2O$, 328.158.

(Z)-methyl 3-(2,2-diphenylhydrazinyl)but-2-enoate, 2c: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N,N-diphenylhydrazine hydrochloride (1.25 g, 5.50 mmol), Et_3N (0.77 mL, 5.50 mmol) and methyl 3-oxobutanoate (0.50 mL, 4.59 mmol). Compound **2c** was obtained as a brown crystalline solid (0.952 g, 73% yield). IR (KBr, cm^{-1}): 3653, 3266, 3089, 3064, 3039, 3026, 3009, 2950, 2926, 2839, 2596, 2491, 2316, 2208, 2102, 2055, 1942, 1868, 1742, 1663, 1613, 1591, 1493, 1460, 1451, 1434, 1383, 1332, 1315, 1274, 1189, 1169, 1124, 1080, 1055, 1030, 1005, 934, 917, 904, 883, 789, 750, 694, 620, 540, 504, 432, 422, 407, 404. ^1H NMR ($CDCl_3$, 300 Hz): δ 1.98 (s, 3H, C*H*$_3$–CNN), 3.71 (s, 3H, OC*H*$_3$), 4.70, (s, 1H, CO–C*H*–CNN), 7.04-7.12 (m, 2H, C*H* para, Ph), 7.16-7.20 (m, 4H, C*H* ortho, Ph), 7.30-7.36 (m, 4H, C*H* meta, Ph), 10.19 (s, 1H, N*H*). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75,47 Hz): δ 18.5 (s, *C*H$_3$–CNN), 50.4 (s, O*C*H$_3$), 84.5 (s, CO–*C*H–CNN), 119.1 (s, *C* ortho, Ph), 123.0 (s, *C* para, Ph), 129.3 (s, *C* meta, Ph), 146.6 (s, *C* ipso, Ph), 163.2 (s, *C*NN), 170.4 (s, *C*O). ESI-MS: found m/z 283.144 for [**2c** +1]$^+$, calculated for $C_{17}H_{18}N_2O_2$, 282.137.

(Z)-ethyl 3-(2,2-diphenylhydrazinyl)but-2-enoate, 2d: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N,N-diphenylhydrazine hydrochloride (1.063 g, 4.67 mmol), Et_3N (0.66 mL, 4.67 mmol) and ethyl 3-oxobutanoate (0.50 mL, 3.89 mmol). Compound **2d** was obtained as a brown crystalline solid (0.803 g, 72% yield). IR (KBr, cm^{-1}): 3418, 3279, 3053, 3028, 2979, 2939, 2897, 1669, 1609, 1592, 1524, 1492, 1457, 1383, 1334, 1296, 1241, 1163, 1147, 1065, 1028, 992, 93, 888, 864, 824, 790, 757, 694, 602, 539, 512, 483. ^1H NMR ($CDCl_3$, 300 Hz): δ 1.31 (t, 3H, J = 6.9 Hz, OCH$_2$C*H*$_3$), 1.96 (s, 3H, C*H*$_3$–CNN), 4.16 (c, 2H, J = 7.2 Hz, OC*H*$_2$CH$_3$), 4.67 (s, 1H, CO–C*H*–CNN), 7.06 (m, 4H, C*H* ortho, Ph), 7.16 (m, 2H, C*H* para, Ph), 7.31 (m, 4H, C*H* meta, Ph), 10.17 (s, 1H, N*H*). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75,47 Hz): δ 14.5 (s, OCH$_2$*C*H$_3$), 18.5 (s, *C*H$_3$–CNN), 58.9 (s, O*C*H$_2$CH$_3$), 84.9 (s, CO–*C*H–CNN), 119.1 (s, *C* ortho, Ph), 122.9 (s, *C* para, Ph), 129.3 (s, *C* meta, Ph), 146.6 (s, *C* ipso, Ph),163.1 (s, *C*NN), 170.1 (s, *C*O). Elemental analyses calculated for $C_{32}H_{40}MoN_4O_7$: C, 55.81; H, 5.85; N, 8.14. Experimental: C, 56.88; H, 5.60; N, 8.03%.

(Z)-3-(2,2-diphenylhydrazinyl)-N,N-diethylbut-2-enamide, 2e, and its tautomer 3-(2,2-diphenylhydrazineylidene)-N,N-diethylbutanamide, 2e': This tautomer mixture was prepared following a procedure analogous to that described for compound **2b**, but using N,N-diphenylhydrazine hydrochloride (0.834 g, 3.67 mmol), Et_3N (0.52 mL, 3.67 mmol) and N,N-diethyl-3-oxobutanamide (0.5 mL, 3.06 mmol). The resulting residue was purified by chromatography (1:3 AcOEt / Petroleum ether as eluent) obtaining a brown crystalline solid identified as the tautomer 1:1 mixture **2e** and **2e'**, according to NMR analysis (0.40 g, 40% yield). IR (KBr, cm^{-1}): 3653, 3321, 3190, 3088, 3063, 3038, 3025, 2933, 2873, 2595, 2364, 2333, 2241, 1940, 1857, 1788, 1722, 1620, 1591, 1492, 1460, 1433, 1412, 1379, 1362, 1313, 1276, 1220, 1206, 1177, 1150, 1118, 1112, 1098, 1080, 1049, 1029, 997, 958, 932, 915, 905, 889, 830, 771, 750, 694, 654, 620, 587, 548, 506, 488, 467, 451, 444, 439, 432, 426, 420, 416, 413, 406, 403. ^1H NMR ($CDCl_3$, 300 Hz): δ 1.13-1.26 (m, 12H, NCH$_2$C*H*$_3$, **2e** and **2e'**), 1.67 (s, 1H, CO–C*H*$_2$–CNN, **2e'**), 1.87 (s, 3H, C*H*$_3$–CNN, **2e'**), 1.95 (s, 3H, C*H*$_3$–CNN, **2e**), 3.39-3.48 (m, 8H, NC*H*$_2$CH$_3$, **2e** and **2e'**), 3,52 (s, 1H, CO–C*H*$_2$–CNN, **2e'**), 4.72, (s, 1H, CO–C*H*–CNN, **2e**), 7.00-7.09 (m, 8H, C*H* ortho, Ph, **2e** and **2e'**), 7.17-7.20 (m, 4H, C*H* para, Ph, **2e** and **2e'**), 7.26-7.33 (m, 8H, C*H* meta, Ph, **2e** and **2e'**), 11.14 (s, 1H, N*H*, **2e**). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75,47 Hz): δ 13.0 (s, *C*H$_3$–CNN, **2e'**), 14.3, 19.1 (s, NCH$_2$*C*H$_3$, **2e** and **2e'**), 19.9 (s, *C*H$_3$–CNN, **2e**), 40.0 (s, CO–*C*H$_2$–CNN, **2e'**), 42.2, 44.4 (s, NCH$_2$CH$_3$, **2e** and **2e'**), 84.5 (s, CO–*C*H–CNN, **2e**), 119.1 121.3 (s, *C* ortho, Ph, **2e** and **2e'**), 122.4-123.0 (s, *C* para, Ph, **2e** and **2e'**), 129.0, 129.1 (s, *C* meta, Ph, **2e** and **2e'**), 147.0, 148.1 (s, *C* ipso, Ph, **2e** and **2e'**), 160.2 (s, *C*NN, **2e'**), 166.5 (s, *C*NN, **2e**), 167.9 (s, *C*O, **2e**), 169.3 (s, *C*O, **2e'**). ESI-MS: found m/z 324.206 for [**2e** +1]$^+$, calculated for $C_{20}H_{25}N_3O$, 323.200.

(Z)-3-(2,2-diphenylhydrazinyl)-cyclohex-2-enone, 2f: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N,N-diphenylhydrazine hydrochloride (1.277 g, 5.6 mmol), Et_3N (0.79 mL, 5.6 mmol) and cyclohexane-1,3-dione (0.648 g, 5.6 mmol). Compound **2f** was obtained as a brown crystalline solid (0.559 g, 36% yield). IR (KBr, cm^{-1}): 3191, 2943, 1587, 1573, 1526, 1489, 1457, 1427, 1360, 1333, 1313, 1295, 1241, 1183, 1139, 1075, 1029, 995, 966, 912, 886, 860, 826, 746, 690, 625, 557, 508, 489, 461, 442, 407. ^1H NMR ($CDCl_3$, 300 Hz): δ 1.80 (t, 2H, J = 6 Hz, CH$_2$-C*H*$_2$-CH$_2$), 2.09 (t, 2H, J = 6.3 Hz, CH$_2$-C*H*$_2$-CNN), 2.32 (t, 2H, J = 6 Hz, CO–C*H*$_2$-CH$_2$), 5.51 (s, 1H, CO–C*H*–CNN), 6.93-7.03 (m, 6H, C*H* ortho and para, Ph), 7.17 (t, 4H, J = 8.1 Hz, C*H* meta, Ph), 8.95 (s, 1H, N*H*). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75,47 Hz): δ 21.8 (s, CH$_2$-*C*H$_2$-CH$_2$), 26.1 (s, CH$_2$-*C*H$_2$-CNN), 36.6 (s, CO-*C*H$_2$-CH$_2$), 97.2 (s, CO–*C*H–CNN), 119.3 (s, *C* ortho, Ph), 123.0 (s, *C* para, Ph), 129.2 (s, *C* meta, Ph), 145.4 (s, *C* ipso, Ph), 165.6 (s, *C*NN), 198.6 (s, *C*O). ESI-MS: found m/z 279.150 for [**2f** + H]$^+$, calculated for $C_{18}H_{18}N_2O$, 278.142.

(Z)-3-(2-methyl-2-phenylhydrazinyl)-1-phenyl-but-2-en-1-one, 2h: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N-methylphenylhydrazine (0.2 mL, 2.55 mmol) and 1-phenyl-butane-1,3-dione (0.425 g, 2.55 mmol) at 55 ºC for 20 h. The resulting residue was purified by chromatography (1:20 AcOEt / Petroleum ether as eluent) obtaining a yellow crystalline solid identified as **2h** (0.50 g, 73% yield). IR (KBr, cm^{-1}): 2989, 1597, 1574,

1545, 1497, 1444, 1428, 1379, 1276, 1189, 1117, 1094, 1081, 988, 932, 876, 852, 821, 802, 753, 712, 674, 551, 505. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.16 (s, 3H, C*H*$_3$–CNN), 3.23 (s, 3H, C*H*$_3$–NN), 5.84 (s, 1H, CO–C*H*–CNN), 6.09-6.95 (m, 3H, C*H* ortho and para, Ph–N), 7.29-7.34 (m, 2H, C*H* meta, Ph–N), 7.45-7.48 (m, 3H, C*H* meta and para, Ph–CO), 7.94-7.97 (m, 2H, C*H* ortho, Ph–CO), 12.15 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 18.4 (s, *C*H$_3$–CNN), 42.5 (s, *C*H$_3$–NN), 91.6 (s, CO–*C*H–CNN), 113.6 (s, *C* ortho, Ph–N), 120.5 (s, *C* para, Ph–N), 127.3 (s, *C* meta, Ph–N), 128.3 (s, *C* meta, Ph–CO), 129.3 (s, *C* ortho, Ph–CO), 131.0 (s, *C* para, Ph–CO), 139.7 (s, *C* ipso, Ph–CO), 150.2 (s, *C* ipso, Ph–N), 166.5 (s, *C*NN), 189.0 (s, *C*O). ESI-MS: found m/z 267.150 for [**2h** +1]$^+$, calculated for $C_{17}H_{18}N_2O$, 266.142.

(Z)-methyl-3-(2-methyl-2-phenylhydrazinyl)but-2-enoate, 2i: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N,N-methylphenylhydrazine (0.56 mL, 4.59 mmol) and methyl 3-oxobutanoate (0.5 mL, 4.59 mmol) at 55 ºC for 20 h. The resulting residue was purified by chromatography (1:5 AcOEt / Petroleum ether as eluent) obtaining a brown crystalline solid identified as **2i** (0.30 g, 30% yield). IR (KBr, cm^{-1}): 3436, 3249, 3093, 3061, 3036, 2990, 2956, 2909, 2880, 2842, 2811, 2650, 2608, 2531, 2466, 2310, 2204, 2094, 2055, 1987, 1943, 1927, 1851, 1838, 1785, 1656, 1599, 1490, 1458, 1450, 1435, 1410, 1378, 1346, 1312, 1274, 1208, 1188, 1168, 1119, 1082, 1058, 1029, 1013, 998, 975, 933, 882, 869, 822, 787, 751, 732, 693, 647, 623, 568, 545, 515, 486, 407. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.98 (s, 3H, C*H*$_3$–CNN), 3.16 (s, 3H, C*H*$_3$–NN), 3.70 (s, 3H, OC*H*$_3$), 4.66, (s, 1H, CO–C*H*–CNN), 6.90 (m, 3H, C*H* ortho and para, Ph), 7.30 (dt, J = 7.8 Hz, J = 1.5 Hz, 2H, C*H* meta, Ph), 9.65 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 18.2 (s, *C*H$_3$–CNN), 42.1 (s, *C*H$_3$–NN), 50.3 (s, 1C, O*C*H$_3$), 83.1 (s, CO–*C*H–CNN), 113.1 (s, *C* ortho, Ph), 120.0 (s, *C* para, Ph), 129.3 (s, *C* meta, Ph), 150.6 (s, *C* ipso, Ph), 163.3 (s, *C*NN), 170.5 (s, *C*O). ESI-MS: found m/z 221.128 for [**2i** +1]$^+$, calculated for $C_{12}H_{16}N_2O_2$, 220.121.

(Z)-ethyl 3-(2-methyl-2-phenylhydrazinyl)but-2-enoate, 2j: An excess of N,N-methylphenylhydrazine (1.13 mL, 9.37 mmol) was added to ethyl 3-oxobutanoate (0.80 mL, 6.25 mmol) and the mixture was stirred at 0 °C for 4 h and, additionally, for 72 h at room temperature. A reddish oil was collected and washed with diethylether (10 mL) and purified by column chromatography (1:5 AcOEt / Petroleum ether as eluent) obtaining a brownish oil identified as **2j** (1.40 g, 96% yield). IR (KBr, cm^{-1}): 3426, 2977, 2940, 2804, 2740, 2679, 2603, 2530, 2493, 2347, 1477, 1435, 1399, 1385, 1365, 1172, 1079, 1037, 850, 806, 458. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.34 (t, J = 7.2 Hz, 3H, OCH$_2$C*H*$_3$), 1.97 (s, 3H, C*H*$_3$–CNN), 3.16 (s, 3H, C*H*$_3$–NN), 4.17 (c, J = 7.2 Hz, 2H, OC*H*$_2$CH$_3$), 4.66, (s, 1H, CO–C*H*–CNN), 6.94 (m, 3H, C*H* ortho and para, Ph), 7.30 (dt, J = 7.7 Hz y J = 2.4 Hz, 2H, C*H* meta, Ph), 9.67 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 14.2 (s, OCH$_2$*C*H$_3$), 18.5 (s, *C*H$_3$–CNN), 42.2 (s, *C*H$_3$–NPh), 58.7 (s, 1C, O*C*H$_2$CH$_3$), 83.5 (s, CO–*C*H–CNN), 115.5 (s, *C* ortho, Ph), 120.1 (s, *C* para, Ph), 128.9 (s, *C* meta, Ph), 150.7 (s, *C* ipso, Ph), 165.4 (s, *C*NN), 170.1 (s, *C*O). ESI-MS: found m/z 235.144 for [**2i** +1]$^+$, calculated for $C_{13}H_{18}N_2O_2$, 234.137.

(Z)-N,N-diethyl-3-(2-methyl-2-phenylhydrazinyl)but-2-enamide, 2k and its tautomer N,N-diethyl-3-(2-methyl-2-phenylhydrazineylidene)butanamide, 2k' This tautomer mixture was prepared following a procedure analogous to that described for compound **2j**, but using N,N-methylphenylhydrazine (0.50 mL, 3.05 mmol) and N,N-diethyl-3-oxobutanamide (0.37 mL, 3.05 mmol) at 80 ºC for 20 h. Compound **2k** and **2k'** were obtained as a brownish oil (0.163 g, 22% yield). NMR analysis indicated that compound **2k** and **2k'** were isolated as 1:1 tautomer mixture. IR (KBr, cm^{-1}): 3477, 3174, 3092, 3062, 3025, 2974, 2933, 2874, 2806, 2600, 2446, 2072, 1929, 1839, 1640, 1616, 1600, 1493, 1452, 1433, 1412, 1379, 1362, 1312, 1279, 1244, 1221, 1186, 1149, 1114, 1096, 1031, 1014, 994, 956, 931, 879, 830, 784, 770, 753, 695, 644, 624, 615, 590, 425. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.11-1.23 (m, 12H, NCH$_2$C*H*$_3$, **2k** and **2k'**), 1.93 (s, 3H, C*H*$_3$–CNN, **2k'**), 2.07 (s, 3H, C*H*$_3$–CNN, **2k**), 2.25, 3,01 (s, 1H, CO–C*H*$_2$–CNN, **2k'**), 3.06 (s, 3H, C*H*$_3$–NN, **2k'**), 3.13 (s, 3H, C*H*$_3$–NN, **2k**), 3.33-3.51 (m, 8H, NC*H*$_2$CH$_3$, **2k** and **2k'**), 4.72, (s, 1H, CO–C*H*–CNN, **2k**), 6.83-6.92 (m, 6H, C*H* ortho and para, Ph, **2k** and **2k'**), 7.21-7.27 (m, 2H, C*H* meta, Ph, **2k** and **2k'**), 10.55 (s, 1H, N*H*, **2k**). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.9 (s, *C*H$_3$–CNN, **2k'**), 14.1, 14.2, 18.6, 18.8 (s, NCH$_2$*C*H$_3$, **2k** and **2k'**), 23.3 (s, *C*H$_3$–CNN, **2k**), 37.5 (s, CO–*C*H$_2$–CNN, **2k'**), 40.1 (s, s, *C*H$_3$–NN, **2k'**), 42.0-42.3 (s, N*C*H$_2$CH$_3$, **2k** and **2k'**), 43.9 (s, *C*H$_3$–NN, **2k**), 83.2 (s, CO–*C*H–CNN, **2k**), 113.0-115.2 (s, *C* ortho, Ph, **2k** and **2k'**), 119.3, 119.8 (s, *C* para, Ph, **2k** and **2k'**), 128.7-129.0 (s, *C* meta, Ph, **2k** and **2k'**), 150.8, 151.1 (s, *C* ipso, Ph, **2k** and **2k'**),160.4 (s, *C*NN, **2k**), 167.7 (s, *C*NN, **2k'**), 168.0 (s, *C*O, **2k**), 169.4 (s, *C*O, **2k'**). ESI-MS: found m/z 262.192 for [**2k** +1]$^+$, calculated for $C_{15}H_{23}N_3O$, 261.184.

(Z)-3-(2-methyl-2-phenylhydrazinyl)-cyclohex-2-enone, 2l: This compound was prepared following a procedure analogous to that described for compound **2b**, but using N,N-methylphenylhydrazine (0.20 mL, 2.55 mmol) and cyclohexane-1,3-dione (0.295 g, 2.55 mmol) at 55 ºC for 20 h. Compound **2l** was obtained as an orange oil (0.290 g, 53% yield). IR (KBr, cm^{-1}):3200, 2943, 1570, 1519, 1494, 1453, 1426, 1362, 1339, 1286, 1238, 1180, 1137, 1110, 1030, 997, 967, 860, 830, 750, 690, 586, 493, 467. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.93 (t, 2H, J = 6.3 Hz, CH$_2$-C*H*$_2$-CH$_2$), 2.23 (t, 2H, J = 6.6 Hz, CH$_2$-C*H*$_2$-CNN), 2.36 (sa, 2H, CO–C*H*$_2$-CH$_2$), 3.01 (s, 3H, C*H*$_3$), 5.36 (s, 1H, CO–C*H*–CNN), 6.73 (d, 2H, C*H* ortho, Ph), 6.84 (t, 1H, J = 7.2 Hz, C*H* para, Ph), 7.21 (t, 4H, J = 7.8 Hz, C*H* meta, Ph), 7.44 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 21.8 (s, CH$_2$-*C*H$_2$-CH$_2$), 26.4 (s, CH$_2$-*C*H$_2$-CNN), 36.6 (s, CO–*C*H$_2$-CH$_2$), 39.5 (s, *C*H$_3$), 97.0 (s, CO–*C*H–CNN), 113.1 (s, *C* ortho, Ph), 119.9 (s, *C* para, Ph), 129.1 (s, *C* meta, Ph), 148.7 (s, *C* ipso, Ph), 164.4 (s, *C*NN), 198.3 (s, *C*O). ESI-MS: found m/z 217.133 for [**2l** + H]$^+$, calculated for $C_{13}H_{16}N_2O$, 216.126.

(Z)-4-(2,2-dimethylhydrazinyl)pent-3-en-2-one, 2m: This compound was prepared following a procedure analogous to that described for compound **2b**, but using but using N,N-dimethylhydrazine (2.2 mL, 22 mmol) and pentane-2,4-dione (1.7 mL, 22 mmol). The resulting reddish oil was purified by cold trap distillation obtaining a brownish oil identified as **2m** (2.15 g, 69% yield). IR (KBr, cm^{-1}): 3433, 3233, 3158, 2989, 2956, 2928, 2901, 2861, 2823, 2781, 2492, 2121, 1858, 1612, 1572, 1515, 1468, 1431, 1377, 1358, 1287, 1228, 1195, 1161, 1094, 1061, 1018, 980, 907, 876, 836, 731, 657, 629, 459, 431, 420, 414, 411, 408, 401. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.92 (s, 3H, C*H*$_3$–CNN), 2.01 (s, 3H, C*H*$_3$–CO), 2.54 (s, 6H, (C*H*$_3$)$_2$NN), 4.85 (s, 1H, CO–C*H*–CN), 11.12 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 17.8 (s, *C*H$_3$–CNN), 28.4 (s, *C*H$_3$–CO), 47.0 (s, (*C*H$_3$)$_2$NN), 93.2 (s, CO–*C*H–CNN), 162.7 (s, *C*NN), 194.7 (s, *C*O). ESI-MS: found m/z 143.118 for [**2m** + H]$^+$, calculated for $C_7H_{14}N_2O$, 142.111.

(Z)-3-(2,2-dimethylhydrazinyl)-1-phenyl-but-2-en-1-one, 2n: This compound was prepared following a procedure analogous to that described for compound **2b**, but using but using N,N-dimethylhydrazine (0.26 mL, 3.38 mmol) and 3-hydroxy-1-phenyl-but-2-en-1-one (0.563 g, 3.38 mmol). The resulting brownish oil was evaporated to dryness and was identified as a pure **2n** (0.685 g, 99% yield). IR (KBr, cm^{-1}): 3059, 2990, 2956, 2860, 2823, 2781, 1595, 1573, 1543, 1486, 1464, 1444, 1425, 1374, 1319, 1288, 1221, 1177, 1160, 1090, 1068, 1051, 1027, 1014, 999, 921, 853, 804, 730, 687, 678, 618, 594, 566, 480, 441. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.17 (s, 3H, C*H*$_3$–CNN), 2.60 (s, 6H, (C*H*$_3$)$_2$NN), 5.58 (s, 1H, CO–C*H*–CN), 7.40 (m, 3H, C*H* meta and para, Ph), 7.87 (m, 2H, C*H* ortho, Ph), 11.75 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 18.6 (s, *C*H$_3$–CNN), 48.4 (s, (*C*H$_3$)$_2$NN), 90.1

(s, CO–*C*H–CNN), 127.0 (s, *C* ortho, Ph), 128.1 (s, *C* meta, Ph), 130.5 (s, *C* para, Ph), 140.1 (s, *C* ipso, Ph), 164.8 (s, *C*NN), 187.7 (s, *C*O). ESI-MS: found m/z 205.133 for [**2n** + H]$^+$, calculated for $C_{12}H_{16}N_2O$, 204.126.

(Z)-3-(2,2-dimethylhydrazinyl)-cyclohex-2-enone, 2o: This compound was prepared following a procedure analogous to that described for compound **2b**, but using but using N,N-dimethylhydrazine (0.34 mL, 4.34 mmol) and 3-hydroxy-cyclohex-2-enone (0.501 g, 4.34 mmol). The resulting orange oil was evaporated to dryness and was identified as a pure **2o** (0.655 g, 99% yield). IR (KBr, cm^{-1}): 3191, 3041, 2989, 2931, 1600, 1563, 1525, 1462, 1435, 1363, 1341, 1316, 1293, 1234, 1190, 1160, 1140, 1061, 1023, 1009, 969, 914, 860, 839, 768, 686, 607, 575, 519, 495, 445, 432. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.88 (q, 2H, J = 6.3 Hz, CH_2-C*H*$_2$-CH_2), 2.24 (t, 4H, J = 6.3 Hz, CO–C*H*$_2$-CH_2-C*H*$_2$-CNN), 2.47 (s, 6H, (C*H*$_3$)$_2$NN), 5.52 (s, 1H, CO–C*H*–CN), 7.00 (s, 1H, N*H*). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 21.9 (s, CH_2-*C*H_2-CH_2), 26.9 (s, CH_2-*C*H_2-CNN), 36.8 (s, (*C*H$_3$)$_2$NN), 46.4 (s, CO–*C*H_2-CH_2), 95.9 (s, CO–*C*H–CNN), 163.9 (s, *C*NN), 197.4 (s, *C*O). ESI-MS: found m/z 155.118 for [**2o** + H]$^+$, calculated for $C_8H_{14}N_2O$, 154.111.

General procedure for the synthesis of α,β-dicarbonylhydrazones. The reactor (a 100 mL Fisher Porter vessel equipped with a lipped heavy-wall borosilicate glass tube, a stirrer flea, a stainless steel lid sealed with a toric joint and held in place with a coupling) was charged with $Mn(AcO)_2$ (3.1 mg, 0.0125 mmol), ethanol (10 mL), and the corresponding β-carbonylenehydrazine substrate (0.5 mmol), in the aforementioned order. The reactor was sealed with an oxygen atmosphere (1 bar) and heated to the corresponding temperature (60 ºC) maintaining constant stirring (600 rpm) in a thermostated oil bath for 18 h. Upon completion the reactor was immediately cooled to -4 ºC, evaporating to dryness by using a rotavap and the residue was then extracted with diethyl ether (10 mL). The resulting solution was filtered with 0.45 μm nylon syringe filter, dried ($MgSO_4$) and cooled at -20 ºC.

(E)-4-(2,2-diphenylhydrazono)pentane-2,3-dione, 3a: Yellow crystalline solid (0.043 g, 31% yield). IR (KBr, cm^{-1}): 3411, 3062, 3011, 2931, 2856, 2564, 1958, 1887, 1711, 1671, 1588, 1560, 1489, 1456, 1436, 1364, 1351, 1332, 1232, 1173, 1133, 1076, 1043, 1028, 1006, 969, 951, 916, 904, 888, 847, 831, 782, 765, 745, 698, 652, 594, 556, 522, 506, 495, 436, 419. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.39 (s, 3H, C*H*$_3$–CNN), 2.47 (s, 3H, C*H*$_3$–CO), 7.12-7.15 (m, 4H, C*H* ortho, Ph), 7.27 (t, J = 5.4 Hz, 2H, C*H* para, Ph), 7.39 (t, J = 8.1 Hz, 4H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.3 (s, *C*H$_3$–CNN), 27.8 (s, *C*H$_3$–CO), 123.1 (s, *C* ortho, Ph), 126.4 (s, *C* para, Ph), 129.4 (s, *C* meta, Ph), 139.8 (s, CH_3–*C*NN), 144.8 (s, *C* ipso, Ph), 194.8 (s, CO–*C*O–CNN), 205.6 (s, CH_3–*C*O). ESI-MS: found m/z 303.110 for [**3a** + Na]$^+$, calculated for $C_{17}H_{16}N_2O_2$, 280.121.

(E)-3-(2,2-diphenylhydrazono)-1-phenyl-butane-1,2-dione, 3b: The resulting residue was purified by chromatography (1:20 AcOEt / Petroleum ether as eluent) obtaining a brownish oil identified as **3b** (0.130 g, 76% yield). IR (KBr, cm^{-1}): 3333, 3062, 2968, 2925, 1716, 1679, 1589, 1554, 1487, 1450, 1368, 1331, 1314, 1275, 1243, 1200, 1174, 1130, 1080, 1026, 1001, 969, 946, 914, 896, 873, 818, 781, 752, 740, 730, 706, 688, 660, 624, 616, 586, 553, 521, 499, 455. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.53 (s, 3H, C*H*$_3$–CNN), 6.96-6.99 (d, 4H, J = 7.2 Hz, C*H* ortho, Ph–N), 7.18-7.31 (m, 6H, C*H* meta and para, Ph–N), 7.53 (t, 2H, J = 7.5 Hz, C*H* meta, Ph–CO), 7.63 (t, 1H, J = 7.5 Hz, C*H* para, Ph–CO), 7.98 (d, 2H, J = 7.2 Hz, C*H* ortho, Ph–CO),. ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.3 (s, *C*H$_3$–CNN), 123.0 (s, *C* ortho, Ph–N), 126.4 (s, *C* para, Ph–N), 128.8 (s, *C* meta, Ph–CO), 129.1 (s, *C* ortho, Ph–CO), 129.3 (s, *C* meta, Ph–N), 134.0 (s, *C* para, Ph–CO), 141.3 (s, *C* ipso, Ph–CO), 144.7 (s, *C* ipso, Ph–N), 166.7 (s, *C*NN), 195.2 (s, Ph-*C*O), 198.3 (s, CO–*C*O–CNN). ESI-MS: found m/z 365.126 for [**3b** +Na]$^+$, $C_{22}H_{18}N_2O_2$, calculated for 342.137.

(E)-methyl 3-(2,2-diphenylhydrazono)-2-oxobutanoate, 3c: Starting with 0,41 mmol of compound **2c** and 0,01 mmol of $Mn(AcO)_2$. Yellow crystalline solid (0.080 g, 66% yield). IR (KBr, cm^{-1}): 3419, 2952, 1741, 1673, 1640, 1590, 1556, 1487, 1430, 1385, 1370, 1341, 1315, 1292, 1245, 1197, 1172, 1136, 1044, 968, 949, 902, 818, 763, 724, 699, 626, 527, 498, 411. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.38 (s, 3H, C*H*$_3$–CNN), 3.93 (s, 3H, OC*H*$_3$), 7.15-7.18 (m, 4H, C*H* ortho, Ph), 7.25-7.30 (m, 2H, C*H* para, Ph), 7.35-7.40 (m, 4H, , C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 11.9 (s, *C*H$_3$–CNN), 52.1 (s, O*C*H$_3$), 123.1 (s, *C* ortho, Ph), 126.5 (s, *C* para, Ph), 129.3 (s, *C* meta, Ph), 139.1 (s, *C*NN), 144.5 (s, *C* ipso, Ph), 167.8 (s, MeO–*C*O), 187.8 (s, CO–*C*O–CNN). ESI-MS: found m/z 319.105 for [**3c** +Na]$^+$, calculated for $C_{17}H_{16}N_2O_3$, 296.116.

(E)-ethyl 3-(2,2-diphenylhydrazono)-2-oxobutanoate, 3d: Yellow crystalline solid (0.151 g, 97% yield). IR (KBr, cm^{-1}): 3459, 3337, 3094, 3061, 3004, 2982, 2969, 2947, 2905, 2878, 2578, 2533, 2346, 2063, 1963, 1949, 1926, 1883, 1852, 1809, 1792, 1739, 1675, 1587, 1559, 1485, 1458, 1450, 1428, 1394, 1372, 1336, 1314, 1289, 1275, 1248, 1199, 1174, 1072, 1154, 1135, 1045, 1026, 973, 956, 935, 901, 872, 841, 754, 725, 697, 626, 522, 498, 414. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.42 (t, 6H, J = 6.8 Hz, OCH_2C*H*$_3$), 2.07 (s, 3H, C*H*$_3$–CNN), 4.43 (c, 4H, J = 7.2 Hz, OC*H*$_2$CH$_3$), 7.18-7.21 (m, 4H, C*H* ortho, Ph), 7.28-7.31 (m, 2H, C*H* para, Ph), 7.37-7.44 (m, 4H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.0 (s, *C*H$_3$–CNN), 14.3 (s, OCH_2*C*H$_3$), 61.6 (s, O*C*H$_2$CH$_3$), 123.2 (s, *C* ortho, Ph), 126.4 (s, *C* para, Ph), 129.3 (s, *C* meta, Ph), 139.2 (s, *C*NN), 144.5 (s, *C* ipso, Ph), 167.5 (s, EtO–*C*O), 188.1 (s, CO–*C*O–CNN). ESI-MS: found m/z 333.120 for [**3d** +Na]$^+$, calculated for $C_{18}H_{18}N_2O_3$, 310.132.

(E)-3-(2,2-diphenylhydrazono)-N,N-diethyl-2-oxobutanamide, 3e: Yellow crystalline solid (0.105 g, 62% yield). IR (KBr, cm^{-1}): 3325, 3065, 3042, 2978, 2937, 2877, 2538, 2332, 2245, 1952, 1877, 1736, 1672, 1641 1591, 1564, 1490, 1457, 1382, 1368, 1332, 1314, 1280, 1209, 1178, 1154, 1130, 1103, 1074, 1051, 1026, 1003, 946, 912, 855, 821, 783, 752, 728, 700, 693, 646, 625, 587, 499, 447, 436, 429, 424, 406, 402. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.18 (t, J = 5.9 Hz, 3H, NCH_2C*H*$_3$), 1.29 (t, J = 6.1 Hz, 3H, NCH_2C*H*$_3$) 1.41 (s, 3H, C*H*$_3$–CNN), 3.25 (c, 2H, NC*H*$_2$CH$_3$), 3.52 (c, J = 6.6 Hz, 2H, NC*H*$_2$CH$_3$), 7.18 (d, J = 4.5 Hz, 4H, C*H* ortho, Ph), 7.25 (t, J = 3.6 Hz, 2H, C*H* para, Ph), 7.36 (t, J = 8.1 Hz, 4H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.2, 12.9 (s, NCH_2*C*H$_3$), 13.8 (s, *C*H$_3$–CNN), 38.3, 42.1 (s, N*C*H$_2$CH$_3$), 123.1 (s, *C* ortho, Ph), 126.2 (s, *C* para, Ph), 129.2 (s, *C* meta, Ph), 140.0 (s, *C*NN), 144.9 (s, *C* ipso, Ph), 169.1 (s, Et$_2$N–*C*O), 192.2 (s, CO–*C*O–CNN). ESI-MS: found m/z 338.186 for [**3e** +H]$^+$, calculated for $C_{20}H_{23}N_3O_2$, 337.179.

(E)-4-(2-methyl-2-phenylhydrazono)pentane-2,3-dione, 3g: Colorless crystalline solid (0.096 g, 91%yield). IR (KBr, cm^{-1}): 3413, 3066, 2981, 2925, 2616, 2250, 1940, 1860, 1715, 1665, 1598, 1552, 1493, 1458, 1433, 1371, 1347, 1334, 1315, 1238, 1179, 1115, 1044, 1032, 997, 984 956, 877, 788, 757, 694, 644, 575, 443, 428, 422, 402. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.14 (s, 3H, C*H*$_3$–CNN), 2.37 (s, 3H, C*H*$_3$–CO), 3.69 (s, 3H, C*H*$_3$–NN), 7.10 (t, J = 6.6 Hz, 1H, C*H* para, Ph), 7.18 (d, J = 7.8 Hz, 2H, C*H* ortho, Ph), 7.33 (t, J = 7.2 Hz, 2H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 13.1 (s, *C*H$_3$–CNN), 27.8 (s, *C*H$_3$–CO), 41.9 (s, *C*H$_3$–NN), 118.1 (s, *C* ortho, Ph), 124.2 (s, *C* para, Ph), 129.2 (s, *C* meta, Ph), 137.1 (s, *C*NN), 147.9 (s, *C* ipso, Ph), 194.7 (s, CO–*C*O–CNN), 205.9 (s, CH_3–*C*O). ESI-MS: found m/z 241.095 for [**3g** +Na]$^+$, calculated for $C_{12}H_{14}N_2O_2$, 218.106.

(E)-3-(2-methyl-2-phenylhydrazono)-1-phenyl-butane-1,2-dione, 3h: yellow crystalline solid (0.100 g, 71%yield). IR (KBr, cm^{-1}): 1681, 1663, 1595, 1582, 1545, 1487, 1461,

1447, 1370, 1332, 1314, 1277, 1243, 1216, 1176, 1160, 1114, 1103, 1074, 1033, 1010, 1001, 944, 898, 865, 827, 794, 781, 755, 731, 705, 689, 656, 616, 596, 513, 478, 461. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.33 (s, 3H, C*H*$_3$–CNN), 3.69 (s, 3H, C*H*$_3$–NN), 6.94 (d, 2H, J = 7.8 Hz, C*H* ortho, Ph–N), 7.02 (t, 1H, J = 7.2 Hz, C*H* para, Ph–N), 7.19 (t, 2H, J = 8.4 Hz, C*H* meta, Ph–N), 7.49 (t, 2H, J = 7.2 Hz, C*H* meta, Ph–CO), 7.60 (t, 1H, J = 7.5 Hz, C*H* para, Ph–CO), 7.90 (d, 2H, J = 6.9Hz, C*H* ortho, Ph–CO). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 13.3 (s, *C*H$_3$–CNN), 41.4 (s, *C*H$_3$–NN), 117.7 (s, *C* ortho, Ph–N), 123.9 (s, *C* para, Ph–N), 128.7 (s, *C* meta, Ph–CO), 128.9 (s, *C* meta, Ph–N), 129.1 (s, *C* ortho, Ph–CO), 133.8 (s, *C* para, Ph–CO), 134.2 (s, *C* ipso, Ph–CO), 138.4 (s, *C* ipso, Ph–N), 147.6 (s, *C*NN), 194.9 (s, Ph–*C*O), 198.3 (s, CO–*C*O-CNN). ESI-MS: found m/z 303.110 for [**3h** +Na]$^+$, calculated for $C_{17}H_{16}N_2O_2$, 280.121.

(E)-methyl 3-(2-methyl-2-phenylhydrazono)-2-oxobutanoate, 3i: Colorless crystalline solid (0.069 g., 59% yield). IR (KBr, cm^{-1}): 3457, 3067, 3014, 2957, 2849, 1947, 1737, 1674, 1641, 1556, 1490, 1455, 1439, 1424, 1371, 1353, 1334, 1296, 1244, 1211, 1181, 1156, 1117, 1050, 1033, 1008, 957, 894, 818, 787, 747, 760, 729, 692, 516, 478, 410. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.17 (s, 3H, C*H*$_3$–CNN), 3.73 (s, 3H, C*H*$_3$–NN), 3.87 (s, 3H, OC*H*$_3$), 7.14 (t, 3H, J = 7.8 Hz, C*H* para, Ph), 7.24 (m, 2H, C*H* ortho, Ph), 7.34 (dt, J = 7.2 Hz y J = 1.5 Hz, 2H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.8 (s, *C*H$_3$–CNN), 42.5 (s, *C*H$_3$–NN), 51.9 (s, O*C*H$_3$), 118.1 (s, *C* ortho, Ph), 124.3 (s, *C* para, Ph), 129.1 (s, *C* meta, Ph), 136.2 (s, *C*NN), 147.9 (s, *C* ipso, Ph),167.9 (s, MeO–*C*O), 187.6 (s, CO–*C*O–CNN). ESI-MS: found m/z 257.090 for [**3i** +Na]$^+$, calculated for $C_{12}H_{14}N_2O_3$, 234.100.

(E)-ethyl 3-(2-methyl-2-phenylhydrazono)-2-oxobutanoate, 3j: Starting with 0,62 mmol of compound **2j** and 0,016 mmol of $Mn(AcO)_2$.The resulting residue was purified by chromatography (1:5 AcOEt / Petroleum ether as eluent) obtaining a colorless crystalline solid identified as **3j** (0.112 g, 73% yield). IR (KBr, cm^{-1}): 3399, 1572, 1419, 1344, 1212, 1154, 1006, 1028, 956, 769, 666, 555, 502. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.39 (t, J = 7.2 Hz, 3H, OCH$_2$C*H*$_3$), 2.17 (s, 3H, C*H*$_3$–CNN), 3.69 (s, 3H, C*H*$_3$–NN), 4.37 (c, J = 7.2 Hz, 2H, OC*H*$_2$CH$_3$), 7.13-7.38 (m, 5H, C*H*, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.8 (s, *C*H$_3$–CNN), 14.2 (s, OCH$_2$*C*H$_3$), 41.5 (s, *C*H$_3$–NN), 61.4 (s, OCH$_2$CH$_3$), 118.1 (s, *C* ortho, Ph), 124.21 (s, *C* para, Ph), 129.0 (s, *C* meta, Ph), 136.3 (s, *C*NN), 147.9 (s, *C* ipso, Ph), 167.5 (s, EtO–*C*O), 187.8 (s, CO–*C*O–CNN). ESI-MS: found m/z 271.106 for [**2j** +Na]$^+$, calculated for $C_{13}H_{16}N_2O_3$, 248.116.

(E)-N,N-diethyl-3-(2-methyl-2-phenylhydrazono)-2-oxobutanamide, 3k: Colorless crystalline solid (0.063 g, 46% yield). IR (KBr, cm^{-1}): 3421, 3061, 2988, 2941, 2455, 1950, 1864, 1796, 1670, 1636, 1598, 1587, 1557, 1492, 1478, 1463, 1448, 1440, 1383, 1369, 1337, 1316, 1287, 1232, 1186, 1154, 1118, 1079, 1050, 1033, 1012, 987, 966, 947, 897, 846, 787, 758, 732, 691, 640, 596, 516, 429. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.11 (t, 3H, J = 7.2 Hz, NCH$_2$C*H*$_3$), 1.25 (t, 3H, J = 7.2 Hz, NCH$_2$C*H*$_3$), 2.22 (s, 3H, C*H*$_3$–CNN), 3.18 (c, 2H, J = 6.9 Hz, NC*H*$_2$CH$_3$), 3.51 (c, 2H, J = 6.9 Hz, NC*H*$_2$CH$_3$), 3.71 (s, 3H, C*H*$_3$–NN), 7.07 (t, 1H, J = 1.5 Hz, C*H* para, Ph), 7.24-7.33 (m, 4H, C*H* ortho and meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 12.8, 13.1 (s, NCH$_2$*C*H$_3$), 13.7 (s, *C*H$_3$–CNN), 38.2 (s, *C*H$_3$–NN), 41.3, 42.0 (s, NC*H*$_2$CH$_3$), 117.6 (s, *C* ortho, Ph), 123.6 (s, *C* para, Ph), 128.9 (s, *C* meta, Ph), 137.5 (s, *C*NN), 148.1 (s, *C* ipso, Ph), 169.2 (s, Et$_2$N–*C*O), 192.0 (s, CO–*C*O–CNN). ESI-MS: found m/z 298.152 for [**3k** +Na]$^+$, calculated for $C_{15}H_{21}N_3O_2$, 275.163.

(E)-4-(2,2-dimethylhydrazono)pentane-2,3-dione, 3m: The resulting dark orange oil contains the started material **2m**. Attempts of purification by chromatography failed due to the decomposition of product in the silica column. Yield was calculated by NMR integration (38% yield). IR (KBr, cm^{-1}): 3417, 2988, 2958, 2928, 2862, 2784, 2244, 1711, 1658, 1610, 1556, 1468, 1433, 1371, 1303, 1228, 1164, 1138, 1098, 1044, 1019, 953, 917, 820, 772, 733, 452, 444, 431, 422, 415, 409. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.06 (s, 3H, C*H*$_3$–CNN), 2.23 (s, 3H, C*H*$_3$–CO), 3.19 (s, 6H, (C*H*$_3$)$_2$NN). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 11.6 (s, *C*H$_3$–CNN), 27.7 (s, *C*H$_3$–CO), 48.3 (s, (*C*H$_3$)$_2$NN), 133.7 (s, *C*NN), 201.6 (s, CO–*C*O–CNN), 206.2 (s, CH$_3$–*C*O). ESI-MS: found m/z 157.097 for [**3m** + H]$^+$, calculated for $C_7H_{12}N_2O_2$, 156.090.

(E)-3-(2,2-dimethylhydrazinyl)-1-Phenyl-butane-1,2-dione, 3n: The resulting residue was purified by chromatography (1:1 AcOEt / Petroleum ether as eluent) obtaining an orange oil identified as **3n** (0.054 g, 50%). IR (KBr, cm^{-1}): 2957, 2864, 1713, 1681, 1655, 1596, 1580, 1534, 1490, 1449, 1426, 1370, 1319, 1293, 1221, 1176, 1101, 1070, 1026, 1001, 965, 921, 883, 854, 737, 711, 688, 661, 616, 566, 536, 441. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 2.22 (s, 3H, C*H*$_3$–CNN), 3.10 (s, 6H, (C*H*$_3$)$_2$NN), 7.43 (m, 3H, C*H* ortho and para, Ph), 7.80 (m, 2H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 11.6 (s, *C*H$_3$–CNN), 46.3 (s, (*C*H$_3$)$_2$NN), 128.5 (s, *C* ortho, Ph), 128.9 (s, *C* meta, Ph), 133.4 (s, *C* para, Ph), 134.5 (s, *C* ipso, Ph), 165.0 (s, *C*NN), 194.4 (s, Ph–*C*O), 198.5 (s, CO-*C*O-CNN). ESI-MS: found m/z 219.113 for [**3n** + H]$^+$, calculated for $C_{12}H_{14}N_2O_2$, 218.106.

(E)-3-(2,2-dimethylhydrazinyl)-cyclohexane-1,2-dione, 3o: dark brown oil (0.036 g, 43% yield). IR (KBr, cm^{-1}): 3420, 3198, 3045, 2989, 2929, 2361, 2341, 1604, 1565, 1528, 1460, 1384, 1366, 1262, 1235, 1192, 1161, 1141, 1024, 915, 840, 801, 688, 668, 608, 575, 527, 496, 446, 432. ^{1}H NMR ($CDCl_3$, 300 Hz): δ 1.91 (q, 2H, J = 6 Hz, CH$_2$-C*H*$_2$-CH$_2$), 2.17 (m, 2H, CH$_2$-C*H*$_2$-CNN), 2.26 (t, 2H, J = 6 Hz, CO–C*H*$_2$-CH$_2$), 2.44 (s, 6H, (C*H*$_3$)$_2$NN), 5.08, 5.54 (s, 2H, CO–C(O*H*)$_2$–CNN). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 20.9 (s, CH$_2$-*C*H$_2$-CH$_2$), 26.2 (s, CH$_2$-*C*H$_2$-CNN), 35.8 (s, (*C*H$_3$)$_2$NN), 46.0 (s, CO–*C*H$_2$-CH$_2$), 96.7 (s, CO–*C*(OH)$_2$–CNN), 161.1 (s, *C*NN), 196.7 (s, *C*O). ESI-MS: found m/z 169.097 for [**3o** + H]$^+$, calculated for $C_8H_{12}N_2O_2$, 168.090.

Synthesis of the adduct (E)-4-(2-methyl-2-phenylhydrazineylidene)-3-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)pentan-2-one, 4: To a solution of $Mn(AcO)_3$ (138.2 mg, 0.5 mmol) in dried MeOH (10 mL) were added compound **2g** (0.102 g, 0.5 mmol) and TEMPO (0.078 g, 0.5 mmol) under N_2 atmosphere. The mixture was stirred at 60 ºC for 24 h. After cooling to room temperature, the mixture was concentrated to dryness and extracted with diethylether. The organic solution was filtered and concentrated under reduced pressure. The product was purified by chromatography (40:3 petroleum ether/EtOAc). Compound **4** was obtained as a yellow orange solid (0.81 g, 45% yield). IR (KBr, cm^{-1}): 2926, 2854, 1719, 1671, 1598, 1555, 1493, 1462, 1375, 1361, 1278, 1261, 1239, 1178, 1133, 1065, 1044, 1026, 994, 957, 877, 787, 752, 734, 692, 645, 596, 573, 520. ^{1}H NMR ($CDCl_3$, 500 Hz, at 10 ºC): δ 0.92-1.64 (m, 18H, TEMPO), 2.04 (s, 3H, C*H*$_3$–CNN), 2.38 (s, 3H, C*H*$_3$–CO), 3.11 (s, 3H, C*H*$_3$–NN), 5.27, (s, 1H, CO–C*H*–CNN), 7.00 (d, 3H, J = 6.9 Hz, C*H* ortho and para, Ph), 7.35 (t, J = 7.8 Hz, 2H, C*H* meta, Ph). ^{13}C{^{1}H} NMR ($CDCl_3$, 75,47 Hz): δ 13.8 (s, *C*H$_3$–CNN), 16.0 (s, CH$_2$, TEMPO), 26.7 (s, *C*H$_3$–CO), 31.7, 33.0 (s, CH$_3$, TEMPO), 39.1 (s, CH$_2$, TEMPO), 40.8 (s, 1C, *C*H$_3$-NN), 58.5, 59.3 (s, C, TEMPO), 95.4 (s, CO–CH–CNN), 114.7 (s, *C* ortho, Ph), 119.5 (s, *C* para, Ph), 127.8 (s, *C* meta, Ph), 150.1 (s, *C* ipso, Ph), 164.7 (s, CH$_3$–*C*NN), 204.8 (s, Me–*C*O). ESI-MS: found m/z 382.25 for [**4** +Na]$^+$, calculated for $C_{21}H_{33}N_3O_2$, 359.24).

X-ray crystallography. Crystals of suitable size for X-ray diffraction analysis of **2c**, **2i**, **3a**, **3c**, **3d**, **3i** and **3k** were coated with dry perfluoropolyether and mounted on glass fibres and fixed in a cold nitrogen stream (T = 213 K) to the goniometer head. Data collection were performed on a Bruker-Nonius X8Apex-II CCD diffractometer, using monochromatic radiation λ(Mo K$_\alpha$) = 0.71073 Å, by means

of ω and φ scans with a width of 0.50 degree. The data were reduced (SAINT)[50] and corrected for absorption effects by the multi-scan method (SADABS).[51,52] The structures were solved by direct methods (SIR-2002[53]) and refined against all F^2 data by full-matrix least-squares techniques (SHELXL-2016/6)[54,55] minimizing $w[F_o^2-F_c^2]^2$. All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were included from calculated positions and refined riding on their respective carbon atoms with isotropic displacement parameters. A summary of cell parameters, data collection, structure solution, and refinement for these seven crystal structures are given in the Supplementary Information (ESI). CCDC 1836191-1836197 contain the supplementary crystallographic data for this paper. The corresponding crystallographic data were deposited with the Cambridge Crystallographic Data Centre as supplementary publications. The data can be obtained free of charge *via* www.ccdc.ac.uk/data.request/cif.

Computational Details. The electronic structure and geometries of compounds **2** and **3** and intermediates **Bg** and **Cg** were computed using density functional theory at the B3LYP level,[56,57] using the 6-311+G** basis set for all the atoms. Molecular geometries of the compounds **2c,i** and **3a,c,d,i,k** were optimised starting from the crystallographic coordinates. Frequency calculations were carried out at the same level of theory to identify all of the stationary points as transition states (one imaginary frequency, **TS1** and **TS2**) or as minima (zero imaginary frequencies) and to provide the thermal correction to free energies at 298.15 K and 1 atm. The DFT calculations were performed using the Gaussian 09 suite of programs.[58] Coordinates of all optimised compounds are reported in the Supporting Information.

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FULL PAPER

Synthesis of α,β-dicarbonylhydrazones by aerobic manganese-catalysed oxidation.

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