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Graphical Abstract

_N_-Heterocyclic carbene based ruthenium complexes for selective β-C(sp^3)-H functionalization of _N_-fused saturated cyclic amines

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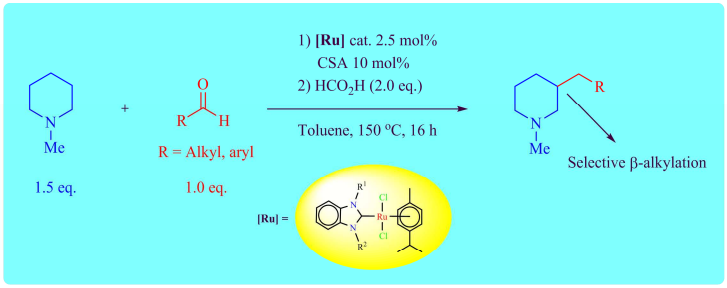

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ABSTRACT

Herein, a series of new ruthenium(II) complexes with the general molecular formula [$RuCl_2$(arene)(NHC)], (arene = η^6-*p*-cymene, NHC = *N*-heterocyclic carbene) were synthesized from *in situ* prepared silver(I)-NHCs by the transmetallation method. These complexes were fully characterized by analytical and spectral methods. Ruthenium(II) complexes were tested as promising catalyst for selective β-C(sp^3)-H functionalization of *N*-methylpiperidine with various aldehydes through hydrogen transfers in presence of external acidic additive. These eco-friendly cross-dehydrogenative couplings enable the production of C(3)-alkylated *N*-methylpiperidine derivatives without enamines with only carbon dioxide and water as benign by-product.

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1. Introduction

Cyclic amines are ubiquitous scaffolds in many natural products, biologically active compounds, and functional materials.[1-3] Considering the importance of these compounds, eco-friendly preparation of them still represents a challenging task for chemists.[4-6] In particular, various pharmaceutically relevant natural and synthetic molecules are functionalized cyclic amines with varied ring sizes. Selected examples of the bioactive cyclic amine derivatives are presented in Fig. 1.[7-9]

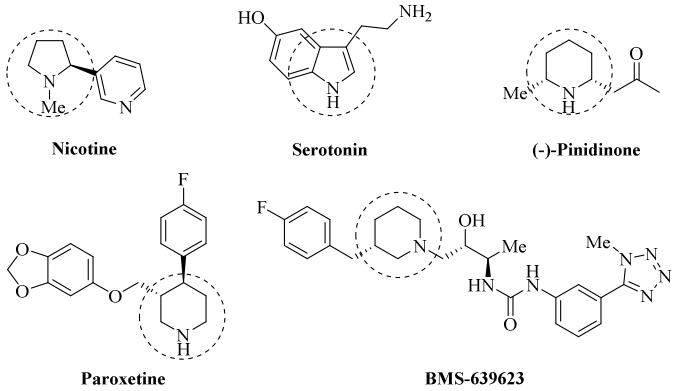


Fig. 1. Selected examples of biologically active cyclic amines.

Traditional methods to preparation of cyclic amines involve substitution reactions employing environmentally harmful alkyl halides[10-13] or reductive aminations using stoichiometric reducing agents.[14,15] These processes are wasteful and not atom economical. In the past decades, C-H bond functionalization involving activation of inert C-H bonds to allow direct C-C coupling has attracted considerable attention for the sythesis of amines.[16] This process minimizes the reaction steps and therefore the number of purification processes and the production of wastes and full fills the criteria of sustainability and green chemistry. Although C(sp^3)-H functionalization of saturated cyclic amines provides an important tool for the synthesis of various nitrogen containing derivatives including *N*-heterocycles, there are still many challenge for the C(sp^3)-H functionalization of them.[17]

Several functionalization at the α-position of saturated cyclic amines have been reported involving either activation of the α-C(sp^3)-H bond via formal oxidative addition to a transition metal[18] or oxidation by various types of oxidant into iminium intermediates followed by reaction with a nucleophile.[19] But as the β-C(sp^3)-H bond of unfunctionalized saturated cyclic amines is inert, their preparation requires multi step synthesis.[20] The first example of β-C(sp^3)-H functionalization of cyclic amine was performed upon oxidation in the presence of oxygen and platinum catalyst, followed by Michael addition leading to C(3)-substituted enamines, but with no additional hydrogenation.[21] One approach to perform C(sp^3)-H functionalization involves as the first step the *in situ* generation of reactive enamines via C(sp^3)-H activation and dehydrogenation as already shown in the presence of iridium[22] and cobalt catalysts.[23] Recently, the group of Bruneau has reported an extremely interesting and amazingly efficient reaction that allows for the formation of a new C-C bond by β-C(sp^3)–H functionalization of saturated cyclic amines with aldehydes catalyzed by (arene)ruthenium(II) complexes containing phosphino sulfonate as chelating ligands.[24] Then, Gaunt and co-workers have reported the transformation of aliphatic amines to β-lactams enabled by palladium catalyzed β-C–H carbonylation,[25] and followed by Yu and co-workers have described a directing group-assisted palladium catalyzed β-C(sp^3)–H arylation of saturated cyclic amines.[26]

Over the two past decades, *N*-heterocyclic carbenes (NHCs) have become ubiquitous ligands for homogeneous catalysis,[27] and transiton-metal complexes containing NHC ligands have been widely used in organometallic chemistry as an alternative to well known phosphine ligands for the synthesis of homogeneous catalysts.[28] Up to now, many examples of ruthenium-catalyzed β-C(sp^3)-H functionalization of saturated cyclic amines involving hydrogen transfers have been reported.[29,30] But, very few examples of the about the use of NHC ligands in related transformations are known.[31] In this connection, we have reported first example of ruthenium-NHC catalyzed β-C(sp^3)-H functionalization of *N*-fused saturated cyclic amines with aldehydes through hydrogen transfers in presence of external acidic additive in 2015.[32]

In the present article, we now described the synthesis and characterization of new benzimidazolium halides as NHC ligands (**1a**□**f**) and their corresponding new ruthenium complexes **2a-f**. These complexes were tested as promising catalyst for selective β-C(sp^3)-H functionalization of *N*-methylpiperidine with various aldehydes as electrophile in the presence of external acidic additive based on hydrogen transfers (Fig. 2). All ruthenium complexes were showed regioselective alkylation at the C(3) position of *N*-methylpiperidine via sequential dehydrogenation under non-oxidative conditions, C-C bond formation, and final transfer hydrogenation to produce C(3)-alkylated *N*-methylpiperidine.

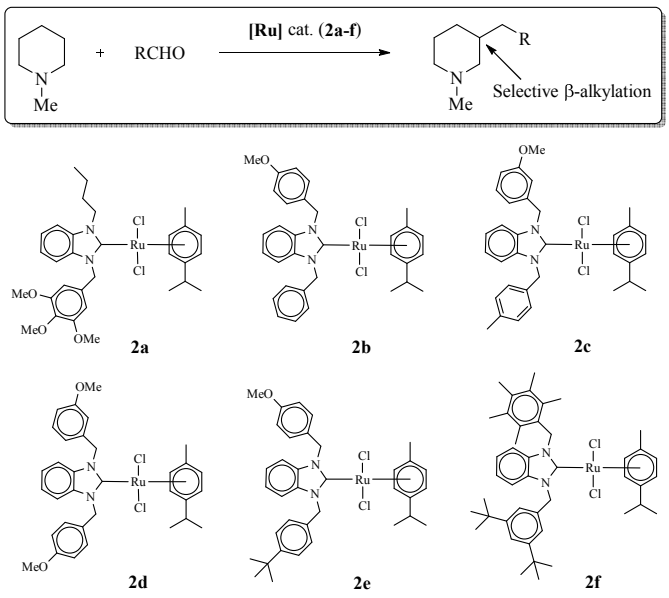


Fig. 2. Ruthenium catalyzed selective β-alkylation of *N*-methylpiperidine with aldehydes.

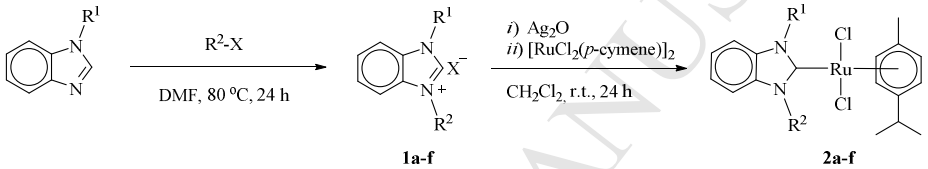
2. Results and discussion

2.1. Preparation of Benzimidazolium Halides

The benzimidazolium chlorides **1a**[33] and **1d**[34] were obtained as previously described in the literature. The benzimidazolium halides **1b, 1c, 1e** and **1f** were prepared by reacting *N*-(alkyl)-benzimidazole with various alkyl halides in DMF at 80 °C for 36 h. Benzimidazolium halides **1b, 1c, 1e** and **1f** are air and moisture stable both in the solid state and in solution. The structures of the these compounds were determined by their characteristic spectroscopic data and elemental analyses. In the ^{13}C NMR spectra of **1b, 1c, 1e** and **1f** compounds, the characteristic signals of the C(2) carbon (N*C*HN) were detected as typical singlets at 143.7, 143.7, 143.4 and 143.3 ppm, respectively. The ^{1}H NMR signals of the C(2)-*H* protons were observed as sharp singlets at chemical shifts of 12.12, 11.88, 11.72 and 10.53 ppm, respectively, for **1b, 1c, 1e** and **1f** further supporting the assigned structures. These NMR values are in line with those found for other benzimidazolium halides of the literature.[35] The formation of the benzimidazolium halides was also evidenced by their IR spectra, which showed CN bond absorption at 1559, 1557, 1555 and 1563 cm^{-1} for the respective CN bond vibrations of **1b, 1c, 1e** and **1f**.

2.2. Preparation of Ruthenium Complexes

The ruthenium(II) complexes **2a–f** were obtained in 41–86 % yields by transmetalation of the corresponding silver(I)-NHC adducts and $[RuCl_2(p\text{-cymene})]_2$. The air and moisture-stable ruthenium complexes are brown in colour and soluble in common chlorinated organic solvents. They are found to be diamagnetic and they were fully characterised by elemental analysis, ^{1}H and ^{13}C NMR, and IR spectroscopy. Their IR data each show a band at 1403, 1407, 1415, 1401, 1413 and 1410 cm^{-1} ($\nu_{(NCN)}$) and their ^{13}C NMR spectra each display a singlets at 189.8, 191.5, 190.6, 191.9, 191.3 and 189.9 ppm (N*C*HN), two evidences of the formationof a Ru–carbene bond.[36] The new compounds were prepared according to general reaction pathway depicted in Scheme 1. The analytical data are in good agreement with the compositions proposed for all the novel compounds we prepared, and are summarized in the Table 1.



	R^1	R^2	X
a,	*n*-Bu	$CH_2Ph(OMe)_3$-3,4,5	Cl
b,	$CH_2Ph(OMe)$-4	CH_2Ph	Cl
c,	$CH_2Ph(OMe)$-3	$CH_2Ph(Me)$-4	Cl
d,	$CH_2Ph(OMe)$-3	$CH_2Ph(OMe)$-4	Cl
e,	$CH_2Ph(OMe)$-4	$CH_2Ph(t\text{Bu})$-4	Br
f,	$CH_2Ph(Me)_5$-2,3,4,5,6	$CH_2Ph(t\text{Bu})_2$-3,5	Br

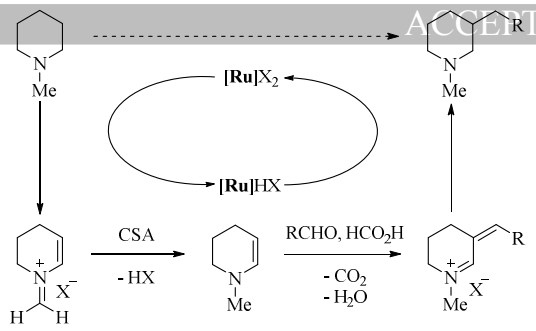
Scheme 1. Synthesis of benzimidazolium halides (**1a-f**) and ruthenium(II) complexes (**2a-f**).

Table 1
Physical and spectroscopic properties of new compounds.

Compound	Molecular Formula	Isolated yield (%)	M.p. (°C)	$\nu_{(CN)}$ (cm^{-1})	H(2) ^{1}H NMR (ppm)	C(2) ^{13}C NMR (ppm)
1a	$C_{22}H_{21}N_2OCl$	78	201-203	1559	12.12	143.7
1c	$C_{23}H_{23}N_2OCl$	87	144-145	1557	11.88	143.7
1e	$C_{26}H_{29}BrN_2O$	91	129-130	1555	11.72	143.4
1f	$C_{34}H_{45}BrN_2$	90	232-233	1563	10.53	143.3
2a	$C_{31}H_{40}Cl_2N_2O_3Ru$	73	262-263	1403	-	189.8
2b	$C_{32}H_{34}Cl_2N_2ORu$	86	186-187	1407	-	191.5
2c	$C_{33}H_{36}Cl_2N_2ORu$	75	193-194	1415	-	190.6
2d	$C_{33}H_{36}Cl_2N_2O_2Ru$	67	>350	1401	-	191.9
2e	$C_{36}H_{42}Cl_2N_2ORu$	41	229-230	1413	-	191.3
2f	$C_{44}H_{58}Cl_2N_2Ru$	74	294-295	1410	-	189.9

2.3. Optimization of the Reaction Conditions for β-Alkylation

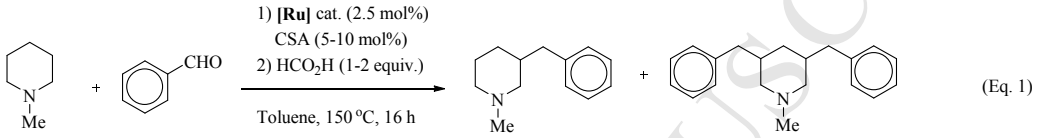
With these well-defined complexes in hand, we next undertook their preliminary evaluation in oxidant free C(sp^3)-H bond functionalization of saturated cyclic amines in the presence of electrophile. On the other hand, *N*-methylated amines represent an interesting class of biologically active compounds and selective functionalization keeping intact the methyl group is attractive. However, during β-alkylation, the competitive formation of *exo* and *endo*-cyclic iminium would result in undesired demethylation reaction through the attack of nucleophile on the resulting *exo*-cyclic iminium.[32] A plausible mechanism is depicted for give point to the role of camphor sulfonic acid (CSA) in Scheme 2.



Scheme 2. Proposed general pathway for the ruthenium catalyzed hydrogen transfer processes for the C(3)-alkylation of *N*-methylpiperidine.

For this purpose we decided to evaluate the challenging *N*-methylpiperidine material which can easily undergo hydrolysis of the methyl group under hydrogen transfer conditions. The screening of our new ruthenium complexes **2a**, **2b** and **2f** was performed in toluene with benzaldehyde, in the presence of 2.5 mol% ruthenium complex at 150 °C for 16 h (Table 2, Eq. 1). The addition of formic acid at the end of the reaction ensure complete conversion of the (C3)-alkylated enamine to the corresponding amines (Table 2, entries 1-5).

Table 2
Influence of the reaction conditions for ruthenium(II) catalyzed alkylation of *N*-methylpiperidine.[a]



(Eq. 1)

Entry	[Ru]	CSA (mol%)	HCO_2H (equiv.)	Ratio (**3a**/**4**)	Yield[b] (%)
1	2f	5 mol%	1.5	65/35	85
2	2f	10 mol%	1.5	75/25	80
3	**2f**	**10 mol%**	**2.0**	**100/0**	**92 (85)**[c]
4	2a	10 mol%	2.0	100/0	88
5	2b	10 mol%	2.0	100/0	85

[a] Reactions conditions: **[Ru]** cat. (2.5 mol%), *N*-methylpiperidine (1.5 mmol), benzaldehyde (1.0 mmol), toluene (1 mL), 150 °C, 16 h.
[b] GC yields were calculated with respect to aldehyde from the results of GC spectrometry.
[c] Isolated yields were shown in parentheses.

Firstly, we examined the reactivity of precatalyst **2f** in the presence of 5 mol% CSA along with of formic acid (1.5 eq.) (HCO_2H). In this case, formation of the expected β-alkylated product **3a** occured but side formation of the disusbstituted β-alkylated product reached a 65:35 ratio of **3a**:**4** (Table 2, entry 1). To overcome the undesired formation of the dialkylated product **4** we next examined the influence of the CSA amount. Thus, higher the catalytic loading of CSA to 10 mol% diminished side dialkylation reaching complete conversion and 75:25 ratio of **3a**:**4** (Table 2, entry 2). Comparing entries 1 and 2, the positive effect of CSA as additive was confirmed. Another strategy to reduce side dialkylation involved the use of a large excess of HCO_2H (2.0 eq.) to give a ratio up to 100:0 (Table 2, entry 3). The influence of the ruthenium complex was next investigated. Notably, complete conversions were obtained in the presence of catalytic amount of complex **2a** and **2b** and the best ratio was observed in the presence of complex **2a** bearing two sterically hindered benzylic side arms (Table 2, entries 4 compared to 5). The chemical characterizations of the products were made by NMR spectroscopy. The conversions were based on the *N*-methylpiperidine by GC. We our best reaction conditions in hands, we next evaluated the scope of the transformation with various aldehydes.

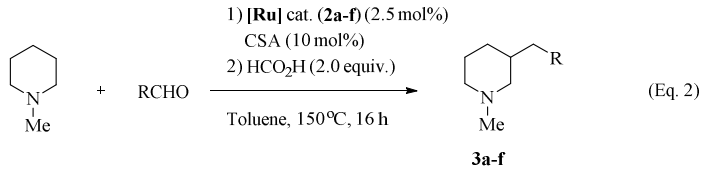
2.4. β-Alkylation of N-Methylpiperidine with Various Aldehydes

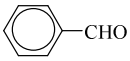
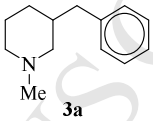
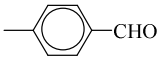
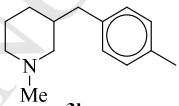
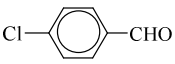
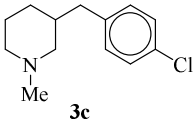
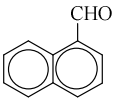
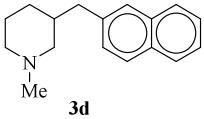
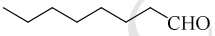
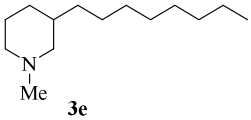
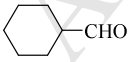
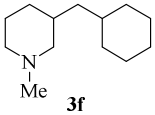
The scope of the selective C(3) alkylation reaction, starting from various aldehydes and *N*-methylpiperidine has been examined (Table 3, Eq. 2). *N*-Methylpiperidine was smoothly converted to the desired products with various aliphatic and aromatic aldehydes between 59-85% isolated yield (Table 3, entries 1-36). Indifferently aldehydes bearing electron-withdrawing such as chloro group or electron-releasing such as methyl group were successfully engaged in this reaction. The reaction appeared to be quite general and good results were obtained from the reaction of *N*-methylpiperidine with *p*-methylbenzaldehyde yielding up to 87% of product **3b**. The coupling of *N*-methylpiperidine with an electron-poor aromatic aldehydes such as 4-chlorobenzaldehyde and α-naphthaldehyde also nicely, yields at between 65–78% and 55-75% (Table 3, entries 13–18 and 19-24). More importantly, the reaction was not limited to aromatic aldehydes, and aliphatic aldehydes such as octanal and cyclohekzanal provided good yields (Table 3, entries 25-36). When the reaction of *N*-methylpiperidine with an electron-rich aliphatic aldehydes such as octanal and cyclohexyl aldehyde was investigated, yields at between 80–95% and 90-100% (Table 3, entries 25–30 and 31-36).

In conclusion, selective C(3) alkylation of *N*-methylpiperidine involving activation of C(sp^3)-H bond via hydrogen transfer was efficiently catalyzed by ruthenium complex **2f**. We attributed these performance differences to well-accordance electronic and steric properties of the NHC ligands. We believe that in the presence of electron-donor and sterically hindered NHC ligands bearing 3,5-di-*tert*-butylbenzyl substituent, hydrogen transfer step more readily takes place and this is might be a key step.

Table 3

Ruthenium(II) catalyzed β-alkylation of *N*-methylpiperidine by using various aldehydes.[a]



Entry	RCHO	[Ru]	Product	Yield[b] (%)
1		**2a**	 **3a**	88
2		**2b**		85
3		**2c**		80
4		**2d**		76
5		**2e**		90
6		**2f**		92 (85)[c]
7		**2a**	 **3b**	87 (76)[c]
8		**2b**		80
9		**2c**		75
10		**2d**		70
11		**2e**		82
12		**2f**		84
13		**2a**	 **3c**	76
14		**2b**		75
15		**2c**		68
16		**2d**		65
17		**2e**		70
18		**2f**		78 (69)[c]
19		**2a**	 **3d**	70
20		**2b**		65
21		**2c**		62
22		**2d**		55
23		**2e**		69
24		**2f**		75 (59)[c]
25		**2a**	 **3e**	89
26		**2b**		86
27		**2c**		80
28		**2d**		82
29		**2e**		90
30		**2f**		95 (75)[c]
31		**2a**	 **3f**	99
32		**2b**		95
33		**2c**		90
34		**2d**		91
35		**2e**		95
36		**2f**		100 (85)[c]

[a] Reaction conditions: **[Ru]** cat. (**2a-f**) (2.5 mol%), *N*-methylpiperidine (1.5 mmol), aldehyde (1.0 mmol), toluene (1 mL), 150 °C, 16 h.
[b] GC yields were calculated with respect to aldehyde from the results of GC spectrometry.
[c] Isolated yields were shown in parentheses.

3. Conclusion

In summary, we have prepared a series of new benzimidazolium halides and their corresponding new ruthenium(II) complexes. All new compounds were characterized using different spectroscopic and analytical techniques. Ruthenium complexes were tested as promising catalyst for selective β-C(sp^3)-H functionalization of *N*-methylpiperidine with various aldehydes as electrophile in the presence of external acidic additive based on hydrogen transfers. The catalytic systems generated from ruthenium complexes were very efficient at 2.5 mol% catalyst loading for selective β-C(sp^3)-H functionalization of *N*-methylpiperidine with various aldehydes. The ruthenium complexes were all found to be suitable catalysts for this study. This catalytic reaction makes possible the selective introduction of a variety of substituents arising from aldehydes at the C(3) position. Further studies to extend this methodology and effort to establish the detailed mechanism are in progress.

4. Experimental

4.1. General Methods

All reactions performed to prepare the benzimidazolium halides and their ruthenium complexes were carried out under argon in flame-dried glassware using standard Schlenk techniques. Chemicals and solvents were purchased from Sigma-Aldrich and Merck. Dichloromethane, dimethylformamide, toluene and diethyl ether were of anhydrous quality and were used as received. The solvents used were purified by distillation over the drying agents indicated and were transferred under argon. All reagents were purchased from commercial sources and used without further purification. Microanalyses were performed by İnönü University Scientific and Technological Research Center (Malatya, Turkey). IR spectra were recorded on ATR (Attenuated Total Reflection) sampling accessory in the range of 400-4000 cm^{-1} with Perkin Elmer Spectrum 100 Spectrophotometer. Melting points were measures in open capillary tubes with an Electrothermal-9200 melting points apparatus. Routine ^{1}H NMR and ^{13}C NMR spectra were recorded using a Bruker UltraShield 300, Bruker Ascend™ 400 Avance III HD and Bruker Avance 600 AMX spectrometer operating at 300, 400 and 600 MHz for ^{1}H NMR, and at 75, 100 and 150 MHz for ^{13}C NMR in $CDCl_3$ with tetramethylsilane (TMS) as an internal reference. The NMR studies were carried out in high-quality 5 mm NMR tubes. Chemical shifts (δ) and coupling constants (J) are reported in ppm and in Hz, respectively. NMR multiplicities are abbreviated as follows: s = singlet, d = doublet, t = triplet, q = quartet, pent = pentet, hext = hextet, m = multiplet. ^{1}H NMR spectra are referenced to residual protiated solvents (δ = 7.26 ppm for $CDCl_3$), ^{13}C chemical shifts are reported relative to deuteriated solvents (δ = 77.16 ppm for $CDCl_3$). The catalytic solutions were analysed with an Agilent 6890N GC and Schimadzu 2010 Plus GC-MS system by GC-FID (Flame Ionization Dedector) with an HP-5 column of 30 m length, 0.32 mm diameter, and 0.25 μm film thickness.

*4.2. General Procedure for the Preparation of Benzimidazolium Halides (**1a-f**)*

A dimethylformamide (5 mL) solution of *N*-(alkyl)-benzimidazole (5.0 mmol) and alkyl halide (5.0 mmol) was stirred at 80 °C for 24 h. After completion of the reaction, the solvent was removed by vacuum and Et_2O (15 mL) was added to obtain a white crystalline solid, which was filtered off. The solid was washed with Et_2O (3×10 mL) and dried under vacuum. The crude product was recrystallized from EtOH/Et_2O mixture (1:2, *v/v*) and dried under vacuum.

*4.2.1. 1-(n-Butyl)-3-(3,4,5-trimethoxybenzyl)benzimidazolium chloride (**1a**)*

This benzimidazolium chloride was synthesized according to published procedure.[33]

*4.2.2. 1-(4-Methoxybenzyl)-3-(benzyl)benzimidazolium chloride (**1b**)*

(1.42 g, yield 78%); ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 3.68 (s, 3H, $CH_2C_6H_4(OCH_3)$-4); 5.74 (s, 2H, $CH_2C_6H_5$); 5.80 (s, 2H, $CH_2C_6H_4(OCH_3)$-4); 6.79 and 7.27 (d, J = 7.3 Hz, 4H, arom. C*H*, $CH_2C_6H_4(OCH_3)$-4); 7.40-7.56 (m, 9H, arom. C*H*, NC_6H_4N and $CH_2C_6H_5$); 12.12 (s, 1H, NC*H*N). ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 51.1 ($CH_2C_6H_5$); 51.5 ($CH_2C_6H_4(OCH_3)$-4); 55.3 ($CH_2C_6H_4(OCH_3)$-4); 113.7, 113.8, 114.7, 124.7, 126.9, 127.0, 128.3, 129.2, 129.4, 130.0, 131.3, 160.1 (arom. *C*s, NC_6H_4N, $CH_2C_6H_5$ and $CH_2C_6H_4(OCH_3)$-4); 143.7 (N*C*HN). Elemental analysis calcd. (%) for $C_{22}H_{21}ClN_2O$ (Mr = 364.87 $g.mol^{-1}$): C 72.42, H 5.80, N 7.68; found (%): C 72.42, H 5.81, N 7.69.

*4.2.3. 1-(3-Methoxybenzyl)-3-(4-methylbenzyl)benzimidazolium chloride (**1c**)*

(1.64 g, yield 87%); ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 2.30 (s, 3H, $CH_2C_6H_4(CH_3)$-4); 3.79 (s, 3H, $CH_2C_6H_4(OCH_3)$-3); 5.84 (s, 2H, $CH_2C_6H_4(CH_3)$-4); 5.86 (s, 2H, $CH_2C_6H_4(OCH_3)$-3); 6.86 and 7.04 (d, J = 6.6 Hz, 2H, arom. C*H*, $CH_2C_6H_4(OCH_3)$-3); 7.10 (s, 1H, arom. C*H*, $CH_2C_6H_4(OCH_3)$-3); 7.16 and 7.40 (d, J = 7.8 Hz, 4H, arom. C*H*, $CH_2C_6H_4(CH_3)$-4); 7.27 (dd, J = 14.5, 6.6 Hz, 1H, arom. C*H*, $CH_2C_6H_4(OCH_3)$-3); 7.47-7.60 (m, 4H, arom. C*H*, NC_6H_4N); 11.88 (s, 1H, NC*H*N). ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 21.2 ($CH_2C_6H_4(CH_3)$-4); 51.4 ($CH_2C_6H_4(CH_3)$-4); 51.5 ($CH_2C_6H_4(OCH_3)$-3); 55.6 ($CH_2C_6H_4(OCH_3)$-3); 113.8, 113.9, 114.9, 120.3, 127.0, 127.1, 128.3, 129.7, 130.0, 130.4, 131.4, 131.5, 134.3, 139.2, 160.3 (arom. *C*s, NC_6H_4N, $CH_2C_6H_4(CH_3)$-4 and $CH_2C_6H_4(OCH_3)$-3); 143.7 (N*C*HN). Elemental analysis calcd. (%) for $C_{23}H_{23}N_2OCl$ (Mr = 378.90 $g.mol^{-1}$): C 72.91, H 6.12, N 7.39; found (%): C 72.98, H 6.20, N 7.47.

*4.2.4. 1-(3-Methoxybenzyl)-3-(4-methoxybenzyl)benzimidazolium chloride (**1d**)*

This benzimidazolium chloride was synthesized according to published procedure.[34]

*4.2.5. 1-(4-Methoxybenzyl)-3-(4-tert-butylbenzyl)benzimidazolium bromide (**1e**)*

(2.11 g, yield 91%); ^{1}H NMR (400 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.18 (s, 9H, $CH_2C_6H_4(C(CH_3)_3)$-4); 3.68 (s, 3H, $CH_2C_6H_4(OCH_3)$-4); 5.75 (s, 4H, $CH_2C_6H_4(C(CH_3)_3)$-4 and $CH_2C_6H_4(OCH_3)$-4); 6.80 and 7.29 (d, J = 8.3 Hz, 4H, arom. CH, $CH_2C_6H_4(OCH_3)$-4); 7.36 (d, J = 8.2 Hz, 2H, arom. C*H*, $CH_2C_6H_2(C(CH_3)_3)$-4); 7.40-7.44 and 7.52-7.55 (m, 6H, arom. C*H*, NC_6H_4N and $CH_2C_6H_2(C(CH_3)_3)$-4); 11.72 (s, 1H, NC*H*N). ^{13}C NMR (100 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 31.2 ($CH_2C_6H_4(C(CH_3)_3)$-4); 34.6 ($CH_2C_6H_4(C(CH_3)_3)$-4); 51.1 ($CH_2C_6H_4(C(CH_3)_3)$-4); 51.2 ($CH_2C_6H_4(OCH_3)$-4); 55.3 ($CH_2C_6H_4(OCH_3)$-4); 113.8, 114.7, 124.8, 126.3, 127.0, 128.1, 129.8, 130.0, 130.1, 131.3, 131.4, 152.3, 160.1 (arom. *C*s, NC_6H_4N, $CH_2C_6H_4(C(CH_3)_3)$-4 and $CH_2C_6H_4(OCH_3)$-4); 143.4 (N*C*HN). Elemental analysis calcd. (%) for $C_{26}H_{29}BrN_2O$ (Mr = 465.44 g.mol^{-1}): C 67.10, H 6.28, N 6.02; found (%): C 67.12, H 6.31, N 6.04.

*4.2.6. 1-(2,3,4,5,6-Pentamethylbenzyl)-3-(3,5-di-tert-butylbenzyl) benzimidazolium bromide (**1f**)*

(2.527 g, yield 90%) ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.26 (s, 18H, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 2.25, 2.29 and 2.31 (s, 15H, $CH_2C_6(CH_3)_5$-2,3,4,5,6); 5.85 (s, 2H, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 5.90 (s, 2H, $CH_2C_6(CH_3)_5$-2,3,4,5,6); 7.15 (d, J = 1.6 Hz, 1H, arom. C*H*, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 7.37 (d, J = 1.5 Hz, 2H, arom. C*H*, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 7.46-7.57 (m, 3H, arom. C*H* of benzimidazole, NC_6H_4N); 7.61-7.64 (m, 1H, arom. C*H* of benzimidazole, NC_6H_4N); 10.53 (s, 1H, NC*H*N) ppm. ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ = 17.0, 17.1 and 17.3 ($CH_2C_6(CH_3)_5$-2,3,4,5,6); 31.3 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 34.9 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 48.2 ($CH_2C_6(CH_3)_5$-2,3,4,5,6); 52.1 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 113.6, 113.7, 121.9, 122.9, 125.1, 126.8, 127.0, 131.6, 131.7, 132.7, 133.5, 134.0, 152.0 (arom. *C*s, NC_6H_4N, $CH_2C_6(CH_3)_5$-2,3,4,5,6 and $CH_2C_6H_3(C(CH_3)_3)$-3,5); 143.3 (N*C*HN). Elemental analysis calcd (%) for $C_{34}H_{45}BrN_2$ (Mr = 561.65 g.mol^{-1}): C 72.71, H 8.08, N 4.99; found (%): C 72.84, H 8.11, N 5.04.

*4.3. General Procedure for the Preparation of the Ruthenium Complexes (**2a-f**)*

A solution of benzimidazolium halide (1.0 mmol), Ag_2O (0.5 mmol), and activated 4 Å molecular sieves in anhydrous CH_2Cl_2 (20 mL) was stirred room temperature for 20 h in the dark conditions. The reaction mixture was filtered through Celite, and the solvent was removed under reduced pressure. The *in situ* prepared silver(I)-NHC complex was reacted with $[RuCl_2(p\text{-cymene})]_2$ dimer (0.5 mmol), and the mixture was allowed to stir for 4 h at room temperature. The solution was filtered through Celite, and the solvent was removed under vacuum to afford the product as a red-brown powder. The crude product was washed with Et_2O (3×5 mL), dried under vacuum and recrystallized from CH_2Cl_2/Et_2O (1:2, *v/v*).

*4.3.1. Dichloro-[1-(n-butyl)-3-(3,4,5-trimethoxybenzyl)benzimidazol-2-ylidene](p-cymene)ruthenium(II) (**2a**)*

(0.482 g, yield 73%) ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.04 (t, J = 7.3 Hz, 3H, $CH_2CH_2CH_2CH_3$); 1.28 (d, J = 6.9 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 1.65 (m, 2H, $CH_2CH_2CH_2CH_3$); 2.02 (s, 3H, CH_3 of *p*-cymene); 1.92-1.94 and 2.23-2.25 (m, 2H, $CH_2CH_2CH_2CH_3$); 2.98 (hept, J = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 3.73 and 3.85 (s, 9H, $CH_2C_6H_2(OCH_3)_3$-3,4,5); 4.39-4.41 and 5.00-5.02 (m, 2H, $CH_2CH_2CH_2CH_3$); 5.05-5.09 (m, 2H, $CH_2C_6H_2(OCH_3)_3$-3,4,5); 5.38-5.48, 5.83-5.89 and 6.16-6.29 (m, 4H, arom. C*H* of *p*-cymene); 6.40 (s, 2H, arom. C*H*, $CH_2C_6H_2(OCH_3)_3$-3,4,5); 7.10-7.20 (m, 2H, arom. C*H* of benzimidazole, NC_6H_4N); 7.26-7.31 (m, 1H, arom. C*H* of benzimidazole, NC_6H_4N); 7.49 (d, J = 8.1 Hz, 1H, arom. C*H* of benzimidazole, NC_6H_4N); 7.26-7.31 (m, 1H, arom. C*H* of benzimidazole, NC_6H_4N) ppm. ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ = 14.0 ($CH_2CH_2CH_2CH_3$); 18.7 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 20.4 ($CH_2CH_2CH_2CH_3$); 21.6 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 30.7 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 32.4 ($CH_2CH_2CH_2CH_3$); 50.2 ($CH_2CH_2CH_2CH_3$); 53.0 and 53.5 ($CH_2C_6H_2(OCH_3)_3$-3,4,5); 56.3 and 61.0 ($CH_2C_6H_2(OCH_3)_3$-3,4,5); 83.5, 84.4, 85.2 and 86.9 (s, arom *C*s of *p*-cymene); 99.2, 103.7, 109.2, 110.9, 111.8, 122.9, 123.0, 133.1, 135.1, 135.8, 153.6 (arom. *C*s, NC_6H_4N and $CH_2C_6H_2(OCH_3)_3$-3,4,5); 189.8 (Ru-$C_{carbene}$). Elemental analysis calcd (%) for $C_{31}H_{40}Cl_2N_2O_3Ru$ (Mr = 660.64 g.mol^{-1}): C 56.36, H 6.10, N 4.24; found (%): C 56.40, H 6.12, N 4.25.

*4.3.2. Dichloro-[1-(4-methoxybenzyl)-3-(benzyl)benzimidazole-2-ylidene](p-cymene)ruthenium(II) (**2b**)*

(0.545 g, yield 86%); ^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.20 (d, J = 6.9 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 1.91 (s, 3H, CH_3 of *p*-cymene); 2.77 (h, J = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 3.80 (s, 3H, $CH_2C_6H_4(OCH_3)$-4); 5.07 (d, J = 5.9 Hz, 2H, $CH_2C_6H_5$); 5.37 (d, J = 5.8 Hz, 2H, $CH_2C_6H_4(OCH_3)$-4); 5.85 (t, J = 14.7 Hz, 2H, arom. C*H* of *p*-cymene); 6.35 and 6.55 (d, J = 16.8 Hz, 2H, arom. C*H* of *p*-cymene); 6.87-7.37 (m, 13H, arom. C*H*, NC_6H_4N, $CH_2C_6H_5$ and $CH_2C_6H_4(OCH_3)$-4). ^{3}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 18.4 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 22.6 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 31,0 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 52.7 ($CH_2C_6H_5$); 53.0 ($CH_2C_6H_4(OCH_3)$-4); 55.4 ($CH_2C_6H_4(OCH_3)$-4); 84.3, 84.4, 85.6, 85.7 (arom *C*s of *p*-cymene); 97.3, 108.4, 111.6, 111.7, 111.8, 114.3, 123.0, 123.1, 126.0, 127.3, 129.4, 135.5, 135.6, 137.5, 158.9 (arom. *C*s, NC_6H_4N, $CH_2C_6H_5$ and $CH_2C_6H_4(OCH_3)$-4); 191.5 (Ru-$C_{carbene}$). Elemental analysis calcd. (%) for $C_{32}H_{34}Cl_2N_2ORu$ (Mr = 634.61 g.mol^{-1}): C 60.56, H 5.40, N 4.41; found (%): C 60.59, H 5.46, N 4.47.

*4.3.3. Dichloro-[1-(3-methoxybenzyl)-3-(4-methylbenzyl)benzimidazole-2-ylidene](p-cymene)ruthenium(II) (**2c**)*

(0.486 g, yield 75%); ^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.11 (d, J = 6.9 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 1.83 (s, 3H, CH_3 of *p*-cymene); 2.27 (s, 3H, $CH_2C_6H_4(CH_3)$-4); 2.66 (h, J = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 3.70 (s, 3H, $CH_2C_6H_4(OCH_3)$-3); 5.03 (d, J = 5.2 Hz, 2H, $CH_2C_6H_4(CH_3)$-4); 5.29 (d, J = 5.6 Hz, 2H, $CH_2C_6H_4(OCH_3)$-3); 5.68 (t, J = 19.2 Hz, 2H, arom. C*H* of *p*-cymene); 6.42 and 6.51 (d, J = 16.8 Hz, 2H, arom. C*H* of *p*-cymene); 6.58-7.21 (m, 12H, arom. C*H*, NC_6H_4N,

$CH_2C_6H_4(CH_3)$-4 and $CH_2C_6H_4(OCH_3)$-3). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 17.3 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 20.8 ($CH_2C_6H_4(CH_3)$-4); 21.5 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 29,6 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 51.8 ($CH_2C_6H_4(CH_3)$-4) and ($CH_2C_6H_4(OCH_3)$-3); 54.3 ($CH_2C_6H_4(OCH_3)$-3); 83.9, 84.0, 84.2, 84.4 (arom *C*s of *p*-cymene); 95.9, 107.0, 110.6, 110.7, 110.8, 111.7, 117.1, 121.1, 122.2, 124.8, 128.6, 129.0, 133.4, 134.5, 134.6, 136.1, 138.2, 158.1 (arom. *C*s, NC_6H_4N, $CH_2C_6H_4(CH_3)$-4 and $CH_2C_6H_4(OCH_3)$-3); 190.6 (Ru-$C_{carbene}$). Elemental analysis calcd. (%) for $C_{33}H_{36}Cl_2N_2ORu$ (Mr = 648.63 g.mol^{-1}): C 61.11, H 5.59, N 4.32; found (%): C 61.19, H 5.66, N 4.37.

*4.3.4. Dichloro-[1-(3-methoxybenzyl)-3-(4-methoxybenzyl)benzimidazole-2-ylidene](p-cymene)ruthenium(II) (**2d**)*

(0.445 g, yield 67%); ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.13 (d, *J* = 6.6 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 1.87 (s, 3H, CH_3 of *p*-cymene); 2.73 (h, *J* = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 3.71 (s, 6H, $CH_2C_6H_4(OCH_3)$-3 and $CH_2C_6H_4(OCH_3)$-4); 4.98 (d, *J* = 5.9 Hz, 2H, $CH_2C_6H_4(OCH_3)$-3); 5.31 (d, *J* = 5.9 Hz, 2H, $CH_2C_6H_4(OCH_3)$-4); 5.61-6.57 (m, 4H, arom. C*H* of *p*-cymene); 6.60-7.25 (m, 12H, arom. C*H*, NC_6H_4N, $CH_2C_6H_4(OCH_3)$-3 and $CH_2C_6H_4(OCH_3)$-4). ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 18.5 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 22.5 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 30,7 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 52.9 ($CH_2C_6H_4(OCH_3)$-3 and $CH_2C_6H_4(OCH_3)$-4); 55.3 ($CH_2C_6H_4(OCH_3)$-3 and $CH_2C_6H_4(OCH_3)$-4); 83.6, 84.0, 85.8, 86.1 (arom *C*s of *p*-cymene); 97.5, 108.6, 111.6, 112.0, 112.6, 118.0, 123.2, 123.4, 127.8, 129.0, 130.1, 133.3, 133.4, 135.2, 135.4, 135.8, 139.2, 160.1 (arom. *C*s, NC_6H_4N, $CH_2C_6H_4(OCH_3)$-3 and $CH_2C_6H_4(OCH_3)$-4); 191.9 (Ru-$C_{carbene}$). Elemental analysis calcd. (%) for $C_{33}H_{36}Cl_2N_2O_2Ru$ (Mr = 664.63 g.mol^{-1}): C 59.64, H 5.46, N 4.21; found (%): C 59.67, H 5.48, N 4.26.

*4.3.5. Dichloro-[1-(4-methoxybenzyl)-3-(4-tert-butylbenzyl)benzimidazole-2-ylidene](p-cymene)ruthenium(II) (**2e**)*

(0.283 g, yield 41%); ^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.18 (d, *J* = 6.9 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 1.31 (s, 9H, $CH_2C_6H_4(C(CH_3)_3)$-4); 1.90 (s, 3H, CH_3 of *p*-cymene); 2.72 (h, *J* = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 3.80 (s, 3H, $CH_2C_6H_4(OCH_3)$-4); 5.07 (d, *J* = 19.3 Hz, 2H, $CH_2C_6H_4(C(CH_3)_3)$-4); 5.36 (d, *J* = 19.2 Hz, 2H, $CH_2C_6H_4(OCH_3)$-4); 5.72, 5.85, 6.36 and 6.59 (d, *J* = 16.2 Hz, 4H, arom. C*H* of *p*-cymene); 7.06-7.37 (m, 12H, arom. C*H*, NC_6H_4N, $CH_2C_6H_2(C(CH_3)_3)$-4 and $CH_2C_6H_4(OCH_3)$-4). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 18.4 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 22.8 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 31,0 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 31.4 ($CH_2C_6H_4(C(CH_3)_3)$-4); 34.6 ($CH_2C_6H_4(C(CH_3)_3)$-4); 52.5 ($CH_2C_6H_4(C(CH_3)_3)$-4); 52.6 ($CH_2C_6H_4(OCH_3)$-4); 55.4 ($CH_2C_6H_4(OCH_3)$-4); 84.4, 84.6, 85.9, 86.0 (arom *C*s of *p*-cymene); 97.4, 107.8, 111.7, 111.8, 114.3, 123.0, 123.1, 125.5, 125.8, 127.3, 129.4, 134.4, 135.5, 135.7, 150.5, 158.9 (arom. *C*s, NC_6H_4N, $CH_2C_6H_4(C(CH_3)_3)$-4 and $CH_2C_6H_4(OCH_3)$-4); 191.3 (Ru-$C_{carbene}$). Elemental analysis calcd. (%) for $C_{36}H_{42}Cl_2N_2ORu$ (Mr = 690.72 g.mol^{-1}): C 62.60, H 6.13, N 4.06; found (%): C 62.63, H 6.15, N 4.06.

*4.3.6. Dichloro-[1-(2,3,4,5,6-pentamethylbenzyl)-3-(3,5-di-tert-butylbenzyl)benzimidazol-2-ylidene](p-cymene)ruthenium(II) (**2f**)*

(0.582 g, yield 74%) ^{1}H NMR (300 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 1.26 (s, 18H, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 1.28 (d, *J* = 6.9 Hz, 6H, $CH(CH_3)_2$ of *p*-cymene); 2.07 (s, 3H, CH_3 of *p*-cymene); 2.20, 2.30 and 2.34 (s, 15H, $CH_2C_6(CH_3)_5$-2,3,4,5,6); 2.82 (hept, *J* = 6.9 Hz, 1H, $CH(CH_3)_2$ of *p*-cymene); 5.32 (d, *J* = 5.2 Hz, 2H, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 5.38 (d, *J* = 5.3 Hz, 2H, $CH_2C_6(CH_3)_5$-2,3,4,5,6); 5.30-5.72 (m, 3H, arom. C*H* of *p*-cymene); 6.19 (d, *J* = 8.4 Hz, 1H, arom. C*H* of *p*-cymene); 6.86 and 7.31 (s, 3H, arom. C*H*, $CH_2C_6H_3(C(CH_3)_3)$-3,5); 6.76-6.81 (m, 2H, arom. C*H* of benzimidazole, NC_6H_4N); 6.94-7.04 (m, 2H, arom. C*H* of benzimidazole, NC_6H_4N) ppm. ^{13}C NMR (75 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ = 16.7, 17.1 and 17.3 ($CH_2C_6(CH_3)_5$-2,3,4,5,6); 18.5 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 22.3 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 30.9 ($CH_3C_6H_4(CH(CH_3)_2)$-4); 31.4 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 34.9 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 52.6 ($CH_2C_6(CH_3)_5$-2,3,4,5,6); 53.5 ($CH_2C_6H_3(C(CH_3)_3)$-3,5); 84.5, 85.4, 85.5 and 86.0 (arom *C*s of *p*-cymene); 96.0, 107.0, 111.2, 111.8, 119.7, 120.8, 122.3, 122.6, 129.4, 135.5, 135.6, 136.9, 151.4 (arom. *C*s, NC_6H_4N, $CH_2C_6(CH_3)_5$-2,3,4,5,6 and $CH_2C_6H_3(C(CH_3)_3)$-3,5); 189.9 (s, Ru-$C_{carbene}$). Elemental analysis calcd (%) for $C_{44}H_{58}Cl_2N_2Ru$ (Mr = 786.93 g.mol^{-1}): C 67.16, H 7.43, N 3.56; found (%): C 67.24, H 7.47, N 3.57.

*4.4. General Procedure for the Preparation of Cyclic Amines (**3a-f**)*

To a stirred solution of *N*-methylpiperidine (1.5 mmol) was added aldehyde derivatives (1.0 mmol). Subsequently ruthenium complexes **2a-f** (2.5 mol%) were added and then sealed Schlenk tube was stirred in at 150 ^{o}C (oil bath temperature) for 16 h. After the reaction mixture was cooled down and then HCO_2H (2.0 eq.) was added and stirring continued at 140 ^{o}C for 1 h. The crude mixture was directly taken for GC analysis and purified by column chromatography ($CHCl_3$/MeOH) to afford the C(3)-alkylated *N*-methylpiperidine derivatives **3a-f**.

*4.4.1. 3-Benzyl-N-methylpiperidine (**3a**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 7.38-7.12 (m, 5H); 2.87 (t, 2H, *J* = 7.0 Hz); 2.54 (d, 2H, *J* = 7.1 Hz); 2.31 (s, 3H); 1.99-1.95 (m, 2H); 1.97-1.90 (m, 1H); 1.76-1.62 (m, 2H); 1.02-0.85 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 24.6, 29.5, 36.9, 40.7, 45.6, 55.7, 61.1, 126.1, 128.4, 129.1, 139.4. Elemental analysis calcd. (%) for $C_{13}H_{19}N$ (Mr = 189.20 g.mol^{-1}): C 82.48, H 10.12, N 7.40; found (%): C 82.50, H 10.13, N 7.41.

*4.4.2. 3-(4-Methyl)benzyl-N-methylpiperidine (**3b**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 7.15-7.03 (s, 4H); 2.87 (t, 2H, *J* = 7.2 Hz); 2.50 (d, 2H, *J* = 7.2 Hz); 2.34 (s, 3H); 2.33 (s, 3H); 2.08-1.93 (m, 2H); 1.83-1.71 (m, 2H); 1.70-1.63 (m, 2H); 1.01-0.86 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25

^{o}C, TMS): δ (ppm) = 21.0, 24.1, 29.3, 36.7, 40.2, 45.5, 55.7, 61.0, 128.9, 129.0, 135.7, 135.9. Elemental analysis calcd. (%) for $C_{14}H_{21}N$ (Mr = 203.20 g.mol^{-1}): C 82.70, H 10.41, N 6.89; found (%): C 82.71, H 10.43, N 6.88.

*4.4.3. 3-(4-Chloro)benzyl-N-methylpiperidine (**3c**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 7.28 (dd, 2H, *J* = 11.6 Hz); 7.08 (d, 2H, *J* = 8.1 Hz); 2.85 (t, 2H, *J* = 7.8 Hz); 2.50 (d, 2H, *J* = 7.1 Hz); 2.34 (s, 3H); 2.04-1.83 (m, 2H); 1.81-1.66 (m, 1H); 1.65-1.56 (m, 2H); 1.04-0.92 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 24.8, 29.8, 37.4, 40.2, 46.1, 56.0, 61.4, 128.3, 130.3, 131.7, 138.3 (arom. *C*s of $CH_2CH_2CH_2CHCH_2N(CH_3)$-3-$CH_2(C_6H_4)$-4-(Cl)). Elemental analysis calcd. (%) for $C_{13}H_{18}NCl$ (Mr = 223.10 g.mol^{-1}): C 69.79, H 8.11, N 6.26; found (%): C 69.81, H 8.13, N 6.28.

*4.4.4. 3-(Naphtholen-3-yl)methyl-N-methylpiperidine (**3d**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS) δ 7.90–7.25 (m, 7H), 5.32 (s, 1H), 2.91 (t, *J* = 7.0 Hz, 2H), 2.72 (d, *J* = 6.9 Hz, 2H), 2.34 (s, 3H), 2.10-2.0 (m, 2H), 1.92–1.60 (m, 3H), 1.05-1.01 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS) δ 136.2, 133.4, 132.2, 128.1, 127.6, 127.4, 127.3, 126.0, 125.4, 60.6, 55.5, 45.1, 40.6, 36.1, 29.1, 23.7. Elemental analysis calcd. (%) for $C_{19}H_{21}N$ (Mr = 263.20 g.mol^{-1}): C 86.64, H 8.04, N 5.32; found (%): C 86.65, H 8.06, N 5.33.

*4.4.5. 3-(Octyl)-N-methylpiperidine (**3e**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 2.89 (d, *J* = 8.0 Hz, 2H), 2.33 (s, 3H), 1.99-1.65 (m, 7H), 1.29-1.18 (m, 12H), 0.87 (t, 3H, *J* = 8.0 Hz); 0.85–0.78 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 14.0, 22.6, 24.1, 26.4, 35.0, 55.8, 29.2, 29.4, 29.5, 29.7, 31.8, 34.2, 45.4, 61.4. Elemental analysis calcd. (%) for $C_{14}H_{29}N$ (Mr = 211.20 g.mol^{-1}): C 79.55, H 13.83, N 6.63; found (%): C 79.57, H 13.85, N 6.65.

*4.4.6. 3-(Cyclohexyl)-N-methylpiperidine (**3f**)*

^{1}H NMR (600 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 2.91 (t, *J* = 7.2 Hz, 2H), 2.36 (s, 3H), 1.82-1.64 (m, 11H), 1.06 (t, 2H, *J* = 7.0 Hz); 1.34-1.13 (m, 5H), 0.93-0.77 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$, 25 ^{o}C, TMS): δ (ppm) = 24.3, 26.2, 26.3, 26.5, 30.0, 32.1, 33.4, 33.7, 34.2, 42.2, 45.6, 55.8, 61.8. Elemental analysis calcd. (%) for $C_{13}H_{25}N$ (Mr = 195.20 g.mol^{-1}): C 79.93, H 12.90, N 7.17; found (%): C 79.94, H 12.92, N 7.18.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://

References

1. Rubiralta M, Giralt E, Diez A, *in Piperidine: Structure, Preparation, Reactivity and Synthetic Applications of Piperidine and its Derivatives.* vol. 43, 1st ed. Amsterdam; Elsevier; 1991.
2. Struntz GM, Findlay JA, *in The Alkaloids*, ed. A. Brossi, vol. 26, New York; Academic, 1985, pp. 89-183.
3. Vitaku E, Smith DT, Njardarson JT, *J Med Chem.* 2014;57:10257-10274.
4. Lawrence SA, *Amines: Synthesis, Properties and Applications*. New York; Cambridge University Press, 2004.
5. Nugent, TC, *Chiral Amine Synthesis: Methods, Development and Applications*. Weinheim; Wiley-VCH Verlag, 2010.
6. (a) Seayad J, Tillack A, Hartung CG, Beller M, *Adv Synth Catal*. 2002;344:795-813;
   (b) Müller TE, Hultzsch KC, Yus M, Foubelo F, Tada M, *Chem Rev*. 2008;108:3795-3892;
   (c) Andrews I, Cui J, DaSilva J, Dudin L, Dunn P, Hayler J, Hinkley B, Hughes D, Kaptein B, Kolis S, Lorenz K, Mathew S, Rammeloo T, Wang L, Wells A, White T, Xie C, Zhang F, *Org. Process Res Dev*. 2009;13:397-408;
   (d) Xie J-H, Zhu S-F, Zhou Q-L, *Chem Rev*. 2011;111:1713-1760.
7. Garattini S, Valzelli L, *Serotonin*. Amsterdam; Elsevier; 1965.
8. (a) Schwartz RE, Liesch J, Hensens O, Zitano L, Honeycutt S, Garrity G, Fromtling RA, Onishi J, Monaghan R, *J Antibiot*. 1988;41:1774-1779;
   (b) Csatayová K, Špánik I, Ďurišová V, Szolcsányi P, *Tetrahedron Lett*. 2010;51:6611-6614;
   (c) Lesma G, Sacchetti A, Silvani A, *Tetrahedron Asymmetry* 2010;21:2329-2333;
   (d) Zheng G, Dwoskin LP, Deaciuc AG, Crooks PA, *Bioorg Med Chem Lett*. 2008;18:6509-6512;
   (e) Horton DB, Nickell JR, Zheng G, Crooks PA, Dwoskin LP, *J Neurochem*. 2013;127:177-186;
   (f) Patel L, Lindley C, *Expert Opin Pharmacother*. 2003;4:2279-2296;
   (g) Giardina GAM, Gagliardi S, Martinelli M, *IDrugs* 2003;6:758-772;
   (h) Gerspacher M, *Prog Med Chem*. 2005;43:49-103;
   (i) Watson PS, et al. *Bioorg Med Chem Lett*. 2006;16:5695-5699;
9. (a) Taylor RD, MacCoss M, Lawson ADG, *J Med Chem*. 2014;57:5845-5859;
   (b) Scott JD, Weinstein J, Miller MW, Stamford AW, Gilbert EJ, Xia Y, Greenlee WJ, Li W, *PCT Int Appl*. WO2007084319 (A2), 2007;
   (c) Ackermann J, Bleicher K, Ceccarelli G, Simona M, Chomienne O, Mattei P, Schulz-Gasch T, *PCT Int Appl*. WO2007063012 (A1), 2007;
   (d) Michael JP, *Nat Prod Rep*. 2008;25:139-165;
   (e) Rachel HF, Karen LG, *CNS Drugs*, 1997;8(2):163-188;
   (f) Santella JB-III, Gardner DS, Yao W, Shi C, Reddy P, Tebben AJ, Delucca GV, Wacker DS, Watson PS, Welch PK, Wadman ES, Davies P, Solomon KA, Graden DM, Yeleswaram S, Mandlekar S, Kariv I, Decicco CP, Ko SS, Carter P, Duncia JV, *Bioorg. Med. Chem. Lett*. 2008;18:576-585.
10. Romera JL, Cid JM, Trabanco AA, *Tetrahedron Lett.* 2004;45:8797-8800.
11. Salvatore RN, Nagle AS, Jung KW, *J Org Chem*. 2002;67:674-683.
12. Salvatore RN, Yoon CH, Jung KW, *Tetrahedron* 2001;57:7785-7811.
13. Singh CB, Kavala V, Samal AK, Patel BK, *Eur J Org Chem*. 2007;2007:1369-1377.
14. Storer R I, Carrera DE, Ni Y, MacMillan DWC, *J Am Chem Soc*. 2006;128:84-86.
15. Tararov VI, Borner A, *Synlett* 2005;2:203-211.
16. (a) Xie Z, Zan X, Sun S, Pan X, Liu L, *Org Lett*. 2016;18:3944-3947;
   (b) Sahli Z, Sundararaju B, Achard M, Bruneau C, *Green Chem*. 2013;15:775-779;
   (c) Murugesh V, Bruneau C, Achard M, Ranjan AS, Sharma GVM, Suresh S, *Chem Commun*. 2017;53:10448-10451;
   (d) Yuan K, Jiang F, Sahli Z, Achard M, Roisnel T, Bruneau C, *Angew Chem., Int Ed*. 2012;51:8876-8880;
   (e) Rösler S, Ertl M, Irrgang T, Kempe R, *Angew Chem., Int Ed*. 2015;54:15046-15050;
   (f) Cabrero-Antonino JR, Alberico E, Junge K, Junge H, Beller M, *Chem Sci*. 2016;7:3432-3442;
   (g) Sundararaju B, Tang Z, Achard M, Sharma GVM, Toupet L, Bruneau C, *Adv Synth Catal*. 2010;352:3141-3146;
   (h) Yang Q, Wang Q, Yu Z, *Chem Soc Rev*. 2015;44:2305-2329;
   (i) Enyong AB, Moasser B, *J Org Chem*. 2014:79;7553-7563;
   (j) Mahato S, Jana CK, *Org Biomol Chem*. 2017;15:1655-1660;

(k) Kaloğlu M, Gürbüz N, Sémeril D, Özdemir İ, *Eur J Inorg Chem*. 2018;10:1236-1243.

17. (a) Jazzar R, Hitce J, Renaudat A, Sofack-Kreutzer J, Baudoin O, *Chem Eur J*. 2010;16:2654-2672;
(b) Bellina F, Rossi R, *Chem Rev*. 2010;110:1082-1146.
18. (a) Chatani N, Asaumi T, Ikeda T, Yorimitsu S, Ishii Y, Kakiuchi F, Murai S, *J Am Chem Soc*. 2000;122: 12882-12883;
(b) DeBoef B, Pastine SJ, Sames D, *J Am Chem Soc*. 2004;126:6556-6557;
(c) Yi CS, Yun SY, *Organometallics* 2004;23:5392-5395.
19. (a) Wilson RB Jr., Laine RM, *J Am Chem Soc*. 1985;107:361-369;
(b) Murahashi S-I, Komiya N, Terai H, Nakae T, *J Am Chem Soc*. 2003;125:15312-15313;
(c) Li Z, Li C-J, *Org Lett*. 2004;6:4997-4999;
(d) Li Z, Li C-J, *J Am Chem Soc*. 2005;127:3672-3673;
(e) Catino AJ, Nichols JM, Nettles BJ, Doyle MP, *J Am Chem Soc*. 2006;128:5648-5649;
(f) Murahashi S-I, Nakae T, Terai H, Komiya N, *J Am Chem Soc*. 2008;130:11005-11012;
(g) Volla CMR, Vogel P, *Org Lett*. 2009;11:1701-1704;
(h) Wang S-J, Wangdfbv Z-Y, Zheng X-Q, *Chem Commun*. 2009;47:7372-7374;
(i) Louafi F, Hurvois J-P, Chibani A, Roisnel T, *J Org Chem*. 2010;75:5721-5724;
(j) Shu X-Z, Yang Y-F, Xia X-F, Ji K-G, Liu X-Y, Liang Y-M, *Org Biomol Chem*. 2010;8:4077-4079;
(k) Rueping M, Vila C, Koenigs RM, Poscharny K, Fabry DC, *Chem Commun*. 2011;47:2360-2362.
20. (a) Horwell DC, Howson W, Naylor D, Willems HMG, *Bioorg Med Chem Lett*. 1995;5:1445-1450;
(b) Thomas C, Ohnmacht U, Niger M, Gmeiner P, *Bioorg Med Chem Lett*. 1998;8:2885-2890;
(c) Zhou Z-L, Keana JFW, *J Org Chem*. 1999;64:3763-3766;
(d) Yamada S, Jahan I, *Tetrahedron Lett*. 2005;46:8673-8676;
(e) Fleck TJ, McWorther WWJ, DeKam RN, Pearlman BA, *J Org Chem*. 2003;68:9612-9617;
(f) Hunter RA, Macfarlane DPS, Whitby RJ, *Synlett* 2006;19:3314-3318.
21. (a)Xia X-F, Shu X-Z, Ji K-G, Yang Y-F, Shaukat A, Liu X-Y, Liang Y-M, *J Org Chem*. 2010;75:2893-2002.
(b) Takasu N, Oisaki K, Kanai M, *Org Lett*. 2013;15:1918-1921.
22. Zhang X, Fried A, Knapp S, Goldman AS, *Chem Commun*. 2003;16:2060-2061.
23. Bolig AD, Brookhart M, *J Am Chem Soc*. 2007;129:14544-14545.
24. Sundararaju B, Achard M, Sharma GVM, Bruneau C, *J Am Chem Soc*. 2011;133:10340-10343.
25. Willcox D, Chappell BGN, Hogg KF, Calleja J, Smalley AP, Gaunt MJ, *Science* 2016;354:851-857.
26. Ye S, Yang W, Coon T, Fanning D, Neubert T, Stamos D, Yu J-Q, *Chem Eur J*. 2016;22:4748-4752.
27. (a) Arduengo AJ, Dias HVR, Harlow RL, Kline M, *J Am Chem Soc*. 1992;114:5530-5534;
(b) Herrmann WA, Kocher C, *Angew Chem., Int Ed*. 1997;36:2162-2187;
(c) Sanford MS, Love JA, Grubbs RH, *Organometallics* 2001;20:5314-5318;
(d) Scott NM, Nolan SP, *Eur J Inorg Chem*. 2005;10:1815-1828;
(e) Hopkinson MN, Richter C, Schedler M, Glorius F, *Nature* 2014;510:485-496.
28. (a) Torres O, Martin M, Sola E, *Organometallics* 2009;28:863-870;
(b) Stringer BD, Quan LM, Barnard PJ, Wilson DJD, Hogan CF, *Organometallics* 2014;33:4860-4872;
(c) Chen C, Lu C, Zheng Q, Ni S, Zhang M, Chen W, *Beilstein J Org Chem*. 2015;11:1786-1795;
(d) Li W, Wiesenfeldt MP, Glorius F, *J Am Chem Soc*. 2017;139:2585-2588.
29. (a) Tan Z, Jiang H, Zhang M, *Org Lett*. 2016;18:3174-3177;
(b) Shen J, Cai D, Kuai C, Liu Y, Wei M, Cheng G, Cui X, *J Org Chem*. 2015;80:6584-6589;
(c) Li J, Sarkar SD, Ackermann L, *Top Organomet Chem*. 2016;55:217-257.
30. (a) Boudiar T, Sahli Z, Sundararaju B, Achard M, Kabouche Z, Doucet H, Bruneau C, *J Org Chem*. 2012;77:3674-3678;
(b) Jiang F, Achard M, Bruneau C, *Chem Eur J*. 2015;21:14319-14323.
31. Şahin Z, Gürbüz N, Özdemir İ, Şahin O, Büyükgüngör O, Achard M, Bruneau C, *Organometallics* 2015;34(11):2296-2304.
32. Özdemir İ, Düşünceli SD, Kaloğlu N, Achard M, Bruneau C, *J Organomet Chem*. 2015;799-800:311-315.
33. Günal S, Kaloğlu N, Özdemir İ, Demir S, Özdemir İ, *Inorg Chem Commun*. 2012;21:142-146.
34. Kaloğlu M, Özdemir İ, *Tetrahedron* 2018;74:2837-2845.
35. (a) Kaloğlu M, Kaloğlu N, Özdemir İ, *ChemistrySelect* 201;3:5600-5607;
(b) Kaloğlu M, Özdemir İ, *Appl Organomet Chem*. 2018;32:e4399;
(c) Kaloğlu M, Kaloğlu N, Özdemir İ, *Chin J Chem*. 2018;36:837-844.
36. (a) Çetinkaya B, Demir S, Özdemir İ, Toupet L, Sémeril D, Bruneau C, Dixneuf PH, *New J Chem*. 2001;25:519-521;
(b) Çetinkaya B, Demir S, Özdemir İ, Toupet L, Sémeril D, Bruneau C, Dixneuf PH, *Chem Eur J*. 2003;9:2323-2330;
(c) Demir S, Özdemir İ, Şahin O, Çetinkaya B, Büyükgüngör O, *Synlett* 2010;3:496-500.

- A series of new benzimidazolium halides (**1a-f**) as *N*-heterocyclic carbene (NHC) ligand precursors and their corresponding new ruthenium(II) complexes (**2a-f**) with general formula [$RuCl_2$(arene)(NHC)], (arene = η^6-*p*-cymene) were synthesized.

- All new compounds were fully characterized by analytical and spectral methods.

- Ruthenium(II) complexes were tested as promising catalyst for selective β-C(sp^3)-H functionalization of *N*-methylpiperidine with various aldehydes through hydrogen transfers in presence of external acidic additive.