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Combination of hydrazine polyanion strategy and ring-closing metathesis in the synthesis of heterocycles

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ABSTRACT

An efficient method for the synthesis of cyclic hydrazine derivatives starting from disubstituted hydrazines is reported. The method is based on the selective alkylation of hydrazine dianions with bromoalkenes and subsequent cyclization using Grubbs' catalysts. The described method provides fast and easy access to the substrates for ring-closing metathesis and the corresponding heterocycles containing a hydrazine moiety. The scope and limitations of the new method are also demonstrated.

1. Introduction

Hydrazine derivatives are well-known compounds used as pesticides, dyes, drugs and building blocks in organic synthesis. Currently known hydrazine-based drugs are used for the treatment of tuberculosis, hypertension and Parkinson's disease.[1] Some hydrazines demonstrate neuroprotective properties and are used as antidepressants.[2] Also, hydrazine-based peptidomimetics were shown to be potent agents against hepatitis[3] and AIDS.[4] In recent years, great interest in the synthesis of heterocyclic hydrazine derivatives has emerged since certain compounds were proven to show remarkable biological activities.[5–7]

A number of methods for the synthesis of heterocycles containing endocyclic N–N bond have been developed. Mainly these compounds are prepared by direct alkylation of hydrazines with dihalides,[8–10] however, Diels–Alder[11,12] and Mitsunobu[13] transformations are also utilized. These methods are good for the synthesis of particular molecules, but the scope is limited to five-, six- and seven-membered rings. The scope may be significantly expanded by applying a ring-closing metathesis (RCM) strategy, however, it requires efficient methods for the synthesis of the corresponding dienes, which is an additional challenge. Synthesis of cyclic hydrazines by the RCM reaction was first mentioned by Tae.[14,15] At the same time, the problem of efficient synthesis of alkene-bearing hydrazines was not solved, which still hampers the development of effective hydrazine-based RCM platform.

In our current work we provide an efficient one-pot method for the synthesis of the corresponding dienes based on a hydrazine polyanion strategy, the advantages of which have been shown in our previous works.[16–19] The dienes were further converted to the corresponding heterocycles via the RCM reaction.

2. Results and discussion

We started with symmetrical dialkylation of dianions with bromoalkenes (Scheme 1). The dianions from PhNHNHBoc, EtNHNHBoc and BocNHNHBoc were generated by treatment with 2 equiv of BuLi in THF at −78 °C with subsequent addition of the alkylating agent. The reaction progress was monitored by TLC. The addition of 2 equiv of allyl bromide to the dianions lead to the rapid formation of the monoalkylated products (1 h) and the slow formation of the dialkylated products (1–3 days) even at 40 °C. At room temperature the reactions were incomplete. Unfortunately, we failed to introduce the alkenyl groups with longer chain in the similar manner obtaining the monoalkylated products with a small amount of the dialkylated species. We propose the different reasons for the alkylation reactions with 4-bromobutene and 5-bromopentene. The dianion being also a strong base may promote elimination of 4-bromobutene with formation of butadiene. We suppose the dialkylation with 5-bromopentene was incomplete because of steric problems as similar behaviour has been previously observed.[16]

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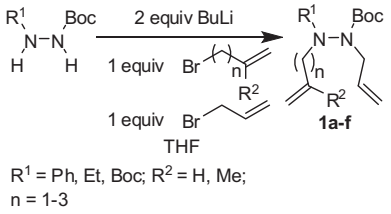
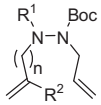


Scheme 1. Direct dialkylation of dianions.

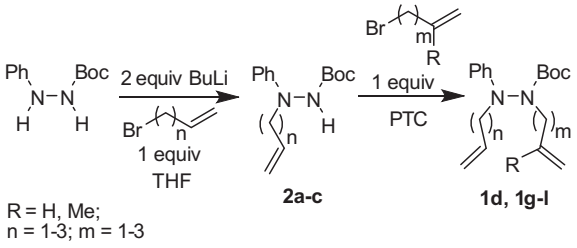
Considering these limitations next we tried the consecutive one-pot monoalkylation of both nitrogens of the PhNHNHBoc dianion to introduce the alkenyl groups with longer or branched chain onto the Ph nitrogen and smaller allyl group onto the Boc nitrogen (Scheme 1). The corresponding products were obtained in good yields (Table 1). Again, the formation of the dialkylated products took 1–2 days at 40 °C.

Table 1
Products of direct alkylation of dianions



	R^1	R^2	*n*	Conditions	Yield, %
1a[16]	Ph	H	1	2 equiv of AllBr, −78 °C to 40 °C, 1 day	77
1b	Et	H	1	2 equiv of AllBr, −78 °C to 40 °C, 1 day	49
1c[20]	Boc	H	1	2 equiv of AllBr, −78 °C to 40 °C, 3 days	81
1d	Ph	H	2	CH_2=$CH(CH_2)_2$Br, −78 °C, 1 h; AllBr, 40 °C, 2 days	60
1e	Ph	H	3	CH_2=$CH(CH_2)_3$Br, −78 °C, 1 h; AllBr, 40 °C, 2 days	81
1f	Ph	Me	1	CH_2=$C(CH_3)CH_2$Br, −78 °C, 1 h; AllBr, 40 °C, 1 day	80

To synthesize the dienes containing substituents with a longer chain on the Boc nitrogen we worked out another methodology. At first we performed monoalkylation of the PhNHNHBoc dianion with 1 equiv of the alkylating agent. The monoalkylated derivatives formed within 1 h and were obtained in very good yields. Further alkylation was performed under PTC conditions (K_2CO_3/NaOH/TBAHS/toluene) at room temperature (Scheme 2).

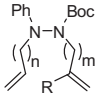


Scheme 2. Monoalkylation of dianions and further alkylation under PTC conditions.

Generally 1 equiv of the alkylating agent was used and the reaction was complete after 1 day. However, in some cases (entries **1j** and **1l**) 2 equiv of 4-bromobutene and longer reaction times were required. The corresponding dienes were obtained in good or excellent yields (Table 2). As both alkylation reactions were very clean we decided to make this approach easier and to perform the same reaction sequence in a one-pot fashion without separation of the monoalkylated product. We found that such way has the same efficiency and may be successfully used (entry **1k**). To the best of our knowledge, this one-pot method for the synthesis of alkene-bearing hydrazines has not been previously reported.

RCM studies started with the cyclization of **1a** using Grubbs' first generation catalyst (Scheme 3). We found that the use of 5 mol % of the catalyst seemed to be optimal for the cyclization. For example,

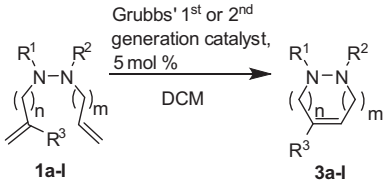
Table 2
Products of mono- and double alkylation



R		*n*	*m*	Conditions	Yield, %
2a[16]		1		AllBr, −78 °C, 1 h;	90
2b		2		CH_2=$CH(CH_2)_2$Br, −78 °C, 1 h	80
2c		3		CH_2=$CH(CH_2)_3$Br, −78 °C, 1 h	75
1d	H	2	1	1 equiv AllBr, rt, 1day	81[a]
1g	H	1	2	1 equiv CH_2=$CH(CH_2)_2$Br, rt, 1 day	93[a]
1h	H	1	3	1 equiv CH_2=$CH(CH_2)_3$Br, rt, 1 day	91[a]
1i	Me	1	1	1 equiv CH_2=$C(CH_3)CH_2$Br, rt, 1 day	61[a]
1j	H	2	2	2 equiv CH_2=$CH(CH_2)_2$Br, rt, 2 days	71[a]
1k	H	2	3	1 equiv CH_2=$CH(CH_2)_2$Br, rt, 1 day	79[a]
1k	H	2	3	1 equiv CH_2=$CH(CH_2)_2$Br, −78 °C, 1 h; 1 equiv CH_2=$CH(CH_2)_3$Br, rt, 1 day	65[b]
1l	H	3	2	2 equiv CH_2=$CH(CH_2)_2$Br, rt, 2 days	71[a]

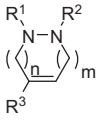
[a] Synthesized from the corresponding monoalkylated derivative.
[b] One-pot synthesis starting from PhNHNHBoc.

using 2 and 5 mol % of the catalyst the corresponding six-membered ring **3a** was obtained in 39% and 89% yields, respectively. All other dienes containing unsubstituted double bonds except **1b** were cyclized under the same conditions (Table 3). Compound **1b** did not react at all in the presence of Grubbs' first generation catalyst, so, the corresponding cycle was obtained by employing Grubbs' second generation catalyst. A possible reason for such behaviour is that **1b** may also act as a ligand interacting and deactivating the catalyst. The interaction with the second generation catalyst must be much weaker because of higher electron density on the Ru atom and hence the ring-closed product **3b** may be obtained. Prochiral cycles **3f** and **3i** were also synthesized utilizing Grubbs' second generation catalyst.



Scheme 3. Ring-closing metathesis of dienes.

Table 3
Products of ring-closing metathesis



	R^1	R^2	R^3	*n*	*m*	Conditions	Yield, %
3a	Ph	Boc	H	1	1	GI, 5 mol %, rt, 30 min[a]	89
3b	Et	Boc	H	1	1	GII, 5 mol %, rt, 1 day[b]	71
3c[21]	Boc	Boc	H	1	1	GI, 5 mol %, rt, 2 h[a]	87
3d	Ph	Boc	H	2	1	GI, 5 mol %, rt, 1 day[a]	88
3e	Ph	Boc	H	3	1	GI, 5 mol %, rt, 1 day[a]	94
3f	Ph	Boc	Me	1	1	GII, 5 mol %, rt, 1 day[b]	80
3g	Ph	Boc	H	1	2	GI, 5 mol %, rt, 1 day[a]	86
3h	Ph	Boc	H	1	3	GI, 5 mol %, rt, 1 day[a]	81
3i	Boc	Ph	Me	1	1	GII, 5 mol %, rt, 1 day[b]	82
3j	Ph	Boc	H	2	2	GI, 5 mol %, rt, 2 h[a]	77
3k	Ph	Boc	H	2	3	GI, 5 mol %, rt, 1 day[a]	54
3l	Ph	Boc	H	3	2	GI, 5 mol %, rt, 1 day[a]	51

[a] GI=Grubbs' first generation catalyst.
[b] GII=Grubbs' second generation catalyst.

All six-, seven- and eight-membered rings including prochiral cycles were obtained in good to excellent yields. Some decrease of yields for nine-membered heterocycles **3k** and **3l** was observed even when lower substrate concentrations were used for more efficient cyclization. The use of Grubbs' second generation catalyst did not improve the yields. We also noticed that the cyclization of the substrates with identical alkenyl groups proceeded much faster. To the best of our knowledge, RCM studies with different alkene-bearing hydrazines and synthesis of the corresponding prochiral heterocycles have not been previously described in the literature.

3. Conclusion

In summary, we have demonstrated a fast and convenient synthetic route to cyclic hydrazines. The key step of the method is the efficient one-pot double alkylation of disubstituted hydrazines. During the study heterocycles of different size and structure were synthesized which demonstrates the wide scope of the method. This approach can be easily utilized in the systematic synthesis of hydrazine derivatives.

4. Experimental section

4.1. General

All polyanion alkylation and ring-closing metathesis reactions were performed under argon atmosphere in oven-dried glassware. THF was freshly distilled from Na/benzophenone, DCM was freshly distilled from calcium hydride. PhNHNHBoc, BocNHNHBoc and EtNHNHBoc were prepared by known methods.[18,22] All other reagents were obtained from commercial sources and used without further purification. TLC was performed using Macherey–Nagel silica gel TLC plates, Alugram® SIL G/UV 254. Spots were visualized by UV light at 254 nm or by ~1% ethanolic solution of phosphomolybdic acid with subsequent heating. Column chromatography was carried out on a Merck Kieselgel 70–230 mesh. ^{1}H and ^{13}C spectra were recorded at 200 MHz and 50 MHz, respectively, on a AVANCE II 200 spectrometer (Spektrospin AG, Switzerland). Deuteroform was used as a solvent. The chemical shifts are reported in parts per million scale relative to the singlet (7.26 for ^{1}H) and triplet (77.0 for ^{13}C). Coupling constants are reported in hertz. IR spectra were measured on a Perkin–Elmer Spectrum BXII FTIR spectrometer using ATR technique with ZnSe. Melting points were determined on a Gallenkamp melting point apparatus. HRMS spectra were measured on a Thermo Electron LTQ Orbitrap ESI spectrometer. Compounds **3c**, **3j**, **3k** and **3l** are crystalline solids, others are oils.

4.2. Typical procedure for symmetrical diallylation of dianions (1a–c)

*4.2.1. tert-Butyl 1,2-diallyl-2-phenylhydrazinecarboxylate (**1a**)[16].* An oven-dried flask was charged with PhNHNHBoc (1.00 mmol, 208 mg), evacuated and backfilled with argon. Thereafter THF (5 mL) was added to dissolve the solid. The reaction mixture was cooled down to −78 °C and 1.6 M *n*-BuLi solution in hexane (2.10 mmol, 1.30 mL) was added dropwise. The reaction mixture was allowed to warm up to −40 °C for 15 min and allyl bromide (2.10 mmol, 0.185 mL) was added. The reaction mixture was allowed to warm up to room temperature for 1 h, then heated to 40 °C and stirred overnight. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). When the reaction was complete the volatiles were removed under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). The *title compound* **1a** (222 mg, 77%) was obtained as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.67; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.82 (t, 1H, J=7.3 Hz, Ph), 6.68 (d, 2H, J=8.0 Hz, Ph), 5.89–6.09 (m, 2H, C*H*=CH_2), 5.13–5.36 (m, 4H, CH=CH_2), 3.92–4.39 (m, 4H, NCH_2), 1.30/1.48 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.5, 148.7, 135.0, 134.1, 129.0, 119.0, 118.1, 117.0, 112.6, 81.0, 57.3, 53.0, 28.4. FTIR ν (cm^{-1}): 3079, 2979, 2929, 1702, 1599, 1499, 1367, 1241, 1145, 921, 748, 693.

*4.2.2. tert-Butyl 1,2-diallyl-2-ethylhydrazinecarboxylate (**1b**).* The reaction was carried out following the typical procedure in Section 4.2 to afford the *title compound* **1b** (49% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.65; ^{1}H NMR (200 MHz, $CDCl_3$): δ=5.67–5.91 (m, 2H, C*H*=CH_2), 4.98–5.13 (m, 4H, CH=CH_2), 3.78 (br s, 2H, NCH_2), 3.40 (br s, 2H, NCH_2), 2.61–3.03 (m, 2H, CH_2), 1.40 (s, 9H, C(CH_3)$_3$), 0.91–0.98 (m, 3H, CH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.6, 136.0, 135.2, 117.1, 116.5, 80.0, 58.8, 54.9, 48.6, 28.7, 13.5; FTIR ν (cm^{-1}): 3081, 2975, 2932, 2868, 1694, 1374, 1366, 1244, 1170, 1142, 918; HRMS (ESI): m/z calcd for $C_{13}H_{25}N_2O_2$ (MH$^+$): 241.1911; found: 241.1908.

*4.2.3. Di-tert-butyl 1,2-diallylhydrazine-1,2-dicarboxylate (**1c**)[20].* The reaction was carried out following the typical procedure in Section 4.2 to afford the *title compound* **1c** (81% yield) as colourless liquid. R_f (petroleum ether/EtOAc 5:1)=0.68; ^{1}H NMR (200 MHz, $CDCl_3$): δ=5.77–5.97 (m, 2H, C*H*=CH_2), 5.09–5.20 (m, 4H, CH=CH_2), 3.90–4.21 (m, 4H, NCH_2), 1.44 (s, 18H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.5/154.8/154.4, 134.1/134.0/133.6, 118.2/117.9/117.3, 81.1/81.0/80.9, 54.8, 52.7, 28.3 (the product was isolated as a 2.9:1 ratio of rotamers); FTIR ν (cm^{-1}): 3082, 2978, 2930, 1709, 1392, 1367, 1246, 1142.

4.3. Typical procedure for selective one-pot dialkylation of dianions (1e–f)

*4.3.1. tert-Butyl 1-allyl-2-(pent-4-enyl)-2-phenylhydrazinecarboxylate (**1e**).* An oven-dried flask was charged with PhNHNHBoc (1.00 mmol, 208 mg), evacuated and backfilled with argon. Thereafter THF (5 mL) was added to dissolve the solid. The reaction mixture was cooled down to −78 °C and 1.6 M *n*-BuLi solution in hexane (2.10 mmol, 1.30 mL) was added dropwise. The reaction mixture was allowed to warm up to −40 °C for 15 min and 5-bromopentene (1.00 mmol, 0.12 mL) was added. The reaction mixture was allowed to warm up to room temperature for 1 h, then allyl bromide (1.10 mmol, 0.10 mL) was added and the reaction mixture was heated to 40 °C and stirred overnight. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). When the reaction was complete the volatiles were removed under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). The *title compound* **1e** (256 mg, 81%) was obtained as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.70; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.18–7.26 (m, 2H, Ph), 6.75–6.82 (m, 1H, Ph), 6.64 (d, 2H, J=8.0 Hz, Ph), 5.75–6.08 (m, 2H, C*H*=CH_2), 4.99–5.24 (m, 4H, CH=CH_2), 3.30–4.35 (m, 4H, NCH_2), 2.09–2.19 (m, 2H, CH_2), 1.71–1.86 (m, 2H, CH_2), 1.29/1.49 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.6, 148.7, 138.1, 134.2, 129.1, 118.7, 117.9, 115.1, 112.5, 80.9, 53.0, 31.4, 28.4, 27.2; FTIR ν (cm^{-1}): 3079, 2976, 2929, 1699, 1599, 1499, 1366, 1149, 914, 746, 692; HRMS (ESI): m/z calcd for $C_{19}H_{29}N_2O_2$ (MH$^+$): 317.2224; found: 317.2226.

*4.3.2. tert-Butyl 1-allyl-2-(2-methylallyl)-2-phenylhydrazinecarboxylate (**1f**).* The reaction was carried out following the typical procedure in Section 4.3 to afford the *title compound* **1f** (80% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.74; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.21–7.29 (m, 2H, Ph), 6.85 (t, 1H, J=7.3 Hz, Ph), 6.69 (d, 2H, J=8.0 Hz, Ph), 5.93–6.13 (m, 1H, C*H*=CH_2),

4.94–5.30 (m, 4H, CH=CH_2), 3.78–4.37 (m, 4H, NCH_2), 1.84 (s, 3H, CH_3), 1.32/1.51 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.5, 149.0, 141.4, 134.0, 128.8, 119.0, 118.0, 112.6, 111.7, 81.0, 61.9, 52.7, 28.3, 20.5; FTIR ν (cm^{-1}): 3064, 2975, 2937, 1701, 1600, 1499, 1366, 1235, 1147, 899, 748, 692; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{26}N_2NaO_2$ (MNa^+): 325.1887; found: 325.1887.

4.4. Typical procedure for monoalkylation of dianions (2a–c)

*4.4.1. tert-Butyl 2-allyl-2-phenylhydrazinecarboxylate (**2a**)*[16]. An oven-dried flask was charged with PhNHNHBoc (3.17 mmol, 660 mg), evacuated and backfilled with argon. Thereafter THF (16 mL) was added to dissolve the solid. The reaction mixture was cooled down to −78 °C and 1.6 M *n*-BuLi solution in hexane (6.34 mmol, 3.96 mL) was added dropwise. The reaction mixture was allowed to warm up to −40 °C for 15 min and allyl bromide (3.20 mmol, 0.29 mL) was added. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 1 h the reaction was complete. The volatiles were removed under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). The *title compound* **2a** (704 mg, 90%) was obtained as colourless liquid. R_f (petroleum ether/EtOAc 5:1)=0.52; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.25–7.33 (m, 2H, Ph), 6.85–6.92 (m, 3H, Ph), 6.55 (br s, 1H, N*H*), 5.87–6.07 (m, 1H, C*H*=CH$_2$), 5.25–5.37 (m, 2H, CH=CH_2), 4.14 (s, 2H, NCH_2), 1.53 (s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.2, 149.1, 133.0, 129.2, 119.5, 118.4, 113.1, 80.9, 55.8, 28.4; FTIR ν (cm^{-1}): 3296, 3070, 2979, 2933, 1705, 1599, 1499, 1366, 1247, 1158, 746, 690.

*4.4.2. tert-Butyl 2-(but-3-enyl)-2-phenylhydrazinecarboxylate (**2b**).* The reaction was carried out following the typical procedure in Section 4.4 to afford the *title compound* **2b** (80% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.49; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.25–7.33 (m, 2H, Ph), 6.84–6.88 (m, 3H, Ph), 6.33/6.50 (br s/s, 1H, N*H*), 5.86–6.00 (m, 1H, C*H*=CH$_2$), 5.09–5.22 (m, 2H, CH=CH_2), 3.58–3.61 (m, 2H, NCH_2), 2.47 (q, 2H, *J*=7.1 Hz, CH_2), 1.41/1.55 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.2, 149.2, 136.0, 129.2, 119.2, 116.6, 112.8, 81.0, 52.0, 31.3, 28.4; FTIR ν (cm^{-1}): 3287, 3071, 2977, 2937, 1703, 1599, 1498, 1366, 1247, 1159, 911, 745, 690; HRMS (ESI): *m*/*z* calcd for $C_{15}H_{23}N_2O_2$ (MH^+): 263.1754; found: 263.1750.

*4.4.3. tert-Butyl 2-(pent-4-enyl)-2-phenylhydrazinecarboxylate (**2c**).* The reaction was carried out following the typical procedure in Section 4.4 to afford the *title compound* **2c** (75% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.53; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.25–7.33 (m, 2H, Ph), 6.83–6.88 (m, 3H, Ph), 6.22/6.42 (br s/s, 1H, N*H*), 5.82–5.96 (m, 1H, C*H*=CH$_2$), 5.03–5.15 (m, 2H, CH=CH_2), 3.48–3.55 (m, 2H, NCH_2), 2.20 (q, 2H, *J*=7.1 Hz, CH_2), 1.76–1.87 (m, 2H, CH_2), 1.41/1.54 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.0, 149.5, 138.2, 129.2, 119.3, 115.2, 112.9, 81.0, 52.3, 31.3, 28.4, 26.0; FTIR ν (cm^{-1}): 3295, 3071, 2977, 2929, 1702, 1599, 1498, 1366, 1249, 1158, 745, 690; HRMS (ESI): *m*/*z* calcd for $C_{16}H_{25}N_2O_2$ (MH^+): 277.1911; found: 277.1905.

4.5. Typical procedure for alkylation of trisubstituted hydrazines under PTC conditions (1d, g–l)

*4.5.1. tert-Butyl 1-allyl-2-(but-3-enyl)-2-phenylhydrazinecarboxylate (**1d**).* Compound **2b** (0.57 mmol, 150 mg) was dissolved in toluene (0.6 mL) and allyl bromide (0.60 mmol, 0.053 mL) was added. The reaction was performed at room temperature under PTC conditions by adding K_2CO_3 (1.14 mmol, 158 mg), NaOH (1.99 mmol, 76 mg) and TBAHS (0.06 mmol, 20 mg) to the reaction mixture. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 1 day the reaction was complete. H_2O (3 mL) was added and the mixture was extracted with diethyl ether (3×3 mL). Combined diethyl ether solutions were evaporated under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). The *title compound* **1d** (140 mg, 81%) was obtained as a yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.70; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.20–7.28 (m, 2H, Ph), 6.80 (t, 1H, *J*=7.3 Hz, Ph), 6.65 (d, 2H, *J*=8.2 Hz, Ph), 5.77–6.11 (m, 2H, C*H*=CH$_2$), 5.05–5.26 (m, 4H, CH=CH_2), 3.30–4.37 (m, 4H, NCH_2), 2.46 (q, 2H, *J*=7.4 Hz, CH_2), 1.29/1.48 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.8, 148.3, 135.8, 134.1, 129.1, 118.8, 118.1, 116.5, 112.3, 80.9, 53.2, 52.9, 32.5, 28.4; FTIR ν (cm^{-1}): 3075, 2976, 2925, 1699, 1598, 1498, 1381, 1366, 1248, 1150, 915, 746, 692; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{27}N_2O_2$ (MH^+): 303.2067; found: 303.2063.

*4.5.2. tert-Butyl 2-allyl-1-(but-3-enyl)-2-phenylhydrazinecarboxylate (**1g**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1g** (93% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.68; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.82 (t, 1H, *J*=7.3 Hz, Ph), 6.68 (d, 2H, *J*=8.2 Hz, Ph), 5.71–6.12 (m, 2H, C*H*=CH$_2$), 5.03–5.37 (m, 4H, CH=CH_2), 3.36–4.25 (m, 4H, NCH_2), 2.37–2.50 (m, 2H, CH_2), 1.28/1.50 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.8, 148.8, 135.7, 135.0, 129.0, 119.0, 116.7, 116.6, 112.5, 80.8, 58.0, 49.3, 32.9, 28.4; FTIR ν (cm^{-1}): 3079, 2977, 2929, 1701, 1599, 1499, 1389, 1366, 1150, 916, 747, 692; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{27}N_2O_2$ (MH^+): 303.2067; found: 303.2062.

*4.5.3. tert-Butyl 2-allyl-1-(pent-4-enyl)-2-phenylhydrazinecarboxylate (**1h**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1h** (91% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.74; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.82 (t, 1H, *J*=7.3 Hz, Ph), 6.68 (d, 2H, *J*=7.8 Hz, Ph), 5.72–6.11 (m, 2H, C*H*=CH$_2$), 4.96–5.37 (m, 4H, CH=CH_2), 3.31–4.26 (m, 4H, NCH_2), 2.04–2.15 (m, 2H, CH_2), 1.71–1.86 (m, 2H, CH_2), 1.29/1.49 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.7, 148.8, 137.9, 134.9, 129.0, 118.9, 116.7, 115.1, 112.4, 80.7, 57.9, 49.6, 31.3, 28.3, 27.7; FTIR ν (cm^{-1}): 3075, 2976, 2925, 1701, 1598, 1498, 1390, 1366, 1300, 1151, 913, 746, 692; HRMS (ESI): *m*/*z* calcd for $C_{19}H_{29}N_2O_2$ (MH^+): 317.2224; found: 317.2223.

*4.5.4. tert-Butyl 2-allyl-1-(2-methylallyl)-2-phenylhydrazinecarboxylate (**1i**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1i** (61% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.77; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.22–7.30 (m, 2H, Ph), 6.85 (t, 1H, *J*=7.3 Hz, Ph), 6.68 (d, 2H, *J*=8.0 Hz, Ph), 5.92–6.11 (m, 1H, C*H*=CH$_2$), 4.94–5.37 (m, 4H, CH=CH_2), 3.68–4.53 (m, 4H, NCH_2), 1.85 (s, 3H, CH_3), 1.35 (s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.3, 141.8, 135.5, 129.0, 118.9, 116.4, 114.2, 112.5, 81.0, 58.0, 56.2, 28.3, 20.7; FTIR ν (cm^{-1}): 3075, 2973, 2929, 1702, 1599, 1499, 1366, 1234, 1165, 1140, 747, 692; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{27}N_2O_2$ (MH^+): 303.2067; found: 303.2062.

*4.5.5. tert-Butyl 1,2-di(but-3-enyl)-2-phenylhydrazinecarboxylate (**1j**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1j** (71% yield) as colourless oil. R_f (petroleum ether/EtOAc 5:1)=0.73; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.23–7.31 (m, 2H, Ph), 6.84 (t, 1H, *J*=7.2 Hz, Ph), 6.70 (d, 2H, *J*=8.0 Hz, Ph), 5.74–6.01 (m, 2H, C*H*=CH$_2$), 5.06–5.23 (m, 4H, CH=CH_2), 3.34–3.82 (m, 4H, NCH_2), 2.43–2.58 (m, 4H, CH_2), 1.32/1.54 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.8, 148.5, 135.6, 135.4, 129.0, 118.7, 116.5, 112.3, 80.7, 53.6, 49.4, 32.8, 32.5, 28.2; FTIR ν (cm^{-1}): 3067, 2977, 2929, 1699,

1598, 1498, 1366, 1151, 913, 746, 693; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{29}N_2O_2$ (MH^+): 317.2224; found: 317.2228.

*4.5.6. tert-Butyl 2-(but-3-enyl)-1-(pent-4-enyl)-2-phenylhydrazinecarboxylate (**1k**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1k** (79% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.70; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.80 (t, 1H, *J*=7.3 Hz, Ph), 6.66 (d, 2H, *J*=8.0 Hz, Ph), 5.70–5.98 (m, 2H, C*H*=CH_2), 4.95–5.19 (m, 4H, CH=CH_2), 3.29–3.68 (m, 4H, NCH_2), 2.47 (q, 1H, *J*=7.3 Hz, CH_2), 2.03–2.14 (m, 2H, CH_2), 1.74–1.86 (m, 2H, CH_2), 1.27/1.50 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.6, 137.9, 135.7, 129.1, 118.7, 116.6, 115.2, 112.4, 80.7, 53.7, 49.8, 32.6, 31.4, 28.4, 27.8; FTIR ν (cm^{-1}): 2970, 2929, 1702, 1599, 1498, 1392, 1367, 1163, 914, 748, 694; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{31}N_2O_2$ (MH^+): 331.2380; found: 331.2372.

*4.5.7. tert-Butyl 1-(but-3-enyl)-2-(pent-4-enyl)-2-phenylhydrazinecarboxylate (**1l**).* The reaction was carried out following the typical procedure in Section 4.5 to afford the *title compound* **1l** (71% yield) as colourless oil. R_f (petroleum ether/EtOAc 5:1)=0.72; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.22–7.30 (m, 2H, Ph), 6.83 (t, 1H, *J*=7.3 Hz, Ph), 6.69 (d, 2H, *J*=8.0 Hz, Ph), 5.73–6.01 (m, 2H, C*H*=CH_2), 5.05–5.17 (m, 4H, CH=CH_2), 3.32–3.80 (m, 4H, NCH_2), 2.48 (q, 1H, *J*=7.3 Hz, CH_2), 2.15–2.25 (m, 2H, CH_2), 1.78–1.94 (m, 2H, CH_2), 1.31/1.52 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.8, 138.0, 135.6, 129.1, 118.7, 116.6, 115.3, 112.5, 80.8, 53.5, 49.5, 32.9, 31.4, 28.4, 27.3; FTIR ν (cm^{-1}): 3075, 2976, 2929, 1700, 1598, 1499, 1366, 1163, 1132, 902, 745, 692; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{31}N_2O_2$ (MH^+): 331.2380; found: 317.2376.

*4.5.8. Demonstrative procedure for one-pot dialkylation of disubstituted hydrazines (**1k**).* An oven-dried flask was charged with PhNHNHBoc (1.5 mmol, 312 mg), evacuated and backfilled with argon. Thereafter THF (7.5 mL) was added to dissolve the solid. The reaction mixture was cooled down to −78 °C and 1.6 M *n*-BuLi solution in hexane (3.10 mmol, 1.90 mL) was added dropwise. The reaction mixture was allowed to warm up to −40 °C for 15 min and 4-bromobutene (1.50 mmol, 0.15 mL) was added. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 1 h the reaction was complete. The volatiles were removed under reduced pressure. The residue was dissolved in toluene (1.5 mL) and 5-bromopentene (1.6 mmol, 0.19 mL) was added. The second alkylation was performed at room temperature under PTC conditions by adding K_2CO_3 (3 mmol, 414 mg), NaOH (5.25 mmol, 210 mg) and TBAHS (0.15 mmol, 49.5 mg) to the reaction mixture. The reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 1 day the reaction was complete. H_2O (7.5 mL) was added and the mixture was extracted with diethyl ether (3×7.5 mL). Combined diethyl ether solutions were evaporated under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). Compound **1k** (320 mg, 65%) was obtained as yellowish oil.

4.6. Typical procedure for ring-closing metathesis for six-, seven- and eight-membered rings (3a–j)

*4.6.1. tert-Butyl 2-phenyl-2,3-dihydropyridazine-1(6H)-carboxylate (**3a**).* An oven-dried flask was charged with **1a** (0.35 mmol, 100 mg), evacuated and backfilled with argon. Thereafter freshly distilled DCM (17 mL) was added. A solution of Grubbs' first generation catalyst (0.05 equiv, 14.4 mg) in freshly distilled DCM (1 mL) was added to the reaction mixture. The reaction was performed at room temperature and the reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 30 min the reaction was complete. The volatiles were removed under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether/EtOAc 5:1). The *title compound* **3a** (80 mg, 89%) was obtained as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.41. ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.79–6.84 (m, 3H, Ph), 5.79–5.86 (m, 2H, C*H*=C*H*), 3.81–4.39 (m, 4H, NCH_2), 1.38 (s, 9H, C(CH_3)$_3$). ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.3, 129.2, 125.1, 124.2, 119.5, 113.4, 81.0, 45.2, 43.1, 28.4. FTIR ν (cm^{-1}): 3067, 2972, 2929, 1697, 1599, 1497, 1366, 1250, 1228, 1162, 1142, 749, 690. HRMS (ESI): *m*/*z* calcd for $C_{15}H_{21}N_2O_2$ (MH^+): 261.1598; found: 261.1597.

*4.6.2. tert-Butyl 2-ethyl-2,3-dihydropyridazine-1(6H)-carboxylate (**3b**).* The reaction was carried out following the typical procedure in Section 4.7 using Grubbs' second generation catalyst to afford the *title compound* **3b** (71% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.53; ^{1}H NMR (200 MHz, $CDCl_3$): δ=5.70 (s, 2H, C*H*=C*H*), 3.66 (br s, 4H, NCH_2), 2.79 (s, 2H, CH_2), 1.44 (s, 9H, C(CH_3)$_3$), 1.02 (t, 3H, *J*=7.1 Hz, CH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.8, 122.9, 122.7, 79.9, 51.2, 46.9, 37.3, 28.5, 12.6; FTIR ν (cm^{-1}): 3039, 2974, 2932, 2848, 1687, 1408, 1377, 1364, 1232, 1174, 1123; HRMS (ESI): *m*/*z* calcd for $C_{11}H_{21}N_2O_2$ (MH^+): 213.1598; found: 213.1598.

*4.6.3. Di-tert-butyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate (**3c**)*[21]. The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3c** (87% yield) as a white solid. R_f (petroleum ether/EtOAc 5:1)=0.41; mp=67–69 °C (lit.[22] 75 °C); ^{1}H NMR (200 MHz, $CDCl_3$): δ=5.74 (s, 2H, C*H*=C*H*), 4.17–4.40 (m, 2H, NCH_2), 3.62–3.79 (m, 2H, NCH_2), 1.44 (s, 18H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=154.7, 124.0, 81.0, 43.3, 28.4; FTIR ν (cm^{-1}): 2980, 2935, 1695, 1388, 1367, 1226, 1166, 1142, 1120, 1074.

*4.6.4. tert-Butyl 2-phenyl-2,3,4,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (**3d**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3d** (88% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.52; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.25–7.33 (m, 2H, Ph), 6.70–6.87 (m, 3H, Ph), 5.47–5.94 (m, 2H, C*H*=C*H*), 4.62–4.97/3.60–3.88 (m/m, 4H, NCH_2), 2.25–2.71 (m, 2H, CH_2), 1.36/1.55 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.3/155.8, 148.2/147.8, 129.4/129.2, 128.3/128.0, 127.4/126.2/125.4, 118.6/118.3, 111.6/111.2, 81.1/80.7, 50.7, 49.7/48.8, 28.4, 24.1/23.7 (the product was isolated as a 2.2:1 ratio of rotamers); FTIR ν (cm^{-1}): 3061, 2975, 2925, 1702, 1599, 1499, 1366, 1238, 1165, 1138, 747, 690; HRMS (ESI): *m*/*z* calcd for $C_{16}H_{23}N_2O_2$ (MH^+): 275.1754; found: 275.1751.

*4.6.5. tert-Butyl 2-phenyl-2,3,4,5-tetrahydro-1,2-diazocine-1(8H)-carboxylate (**3e**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3e** (94% yield) as brownish oil. R_f (petroleum ether/EtOAc 5:1)=0.53; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.23–7.31 (m, 2H, Ph), 6.65–6.82 (m, 3H, Ph), 5.87–6.12 (m, 2H, C*H*=C*H*), 3.16–4.51 (m, 4H, NCH_2), 2.05–2.47 (m, 2H, CH_2CH_2), 1.36/1.54 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=155.9, 147.3, 134.8, 129.4, 127.6, 117.5, 110.3, 80.5, 51.5, 43.2, 28.4, 27.3, 23.9; FTIR ν (cm^{-1}): 3064, 2975, 2931, 1700, 1598, 1500, 1366, 1342, 1274, 1232, 1160, 1135, 745, 692; HRMS (ESI): *m*/*z* calcd for $C_{17}H_{25}N_2O_2$ (MH^+): 289.1911; found: 289.1914.

*4.6.6. tert-Butyl 4-methyl-2-phenyl-2,3-dihydropyridazine-1(6H)-carboxylate (**3f**).* The reaction was carried out following the typical procedure in Section 4.7 using Grubbs' second generation catalyst to afford the *title compound* **3f** (80% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.53; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.24–7.32 (m, 2H, Ph), 6.83–6.87 (m, 3H, Ph), 5.50 (s, 1H, C=C*H*), 3.68–4.39 (m, 4H, NCH_2), 1.79 (s, 3H, CH_3), 1.43–1.58 (m, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.1, 131.3, 129.2, 119.5, 118.7, 113.5, 81.0, 49.1, 42.2, 28.4, 20.5; FTIR ν (cm^{-1}): 3066,

2974, 2932, 1702, 1599, 1497, 1392, 1367, 1248, 1159, 1135, 748, 730, 690; HRMS (ESI): *m*/*z* calcd for $C_{16}H_{23}N_2O_2$ (MH^+): 275.1754; found: 275.1752.

*4.6.7. tert-Butyl 2-phenyl-2,3,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (**3g**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3g** (86% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.47; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.20–7.28 (m, 2H, Ph), 6.69–6.83 (m, 3H, Ph), 5.63–5.84 (m, 2H, C*H*=C*H*), 3.50–4.38 (m, 4H, NCH_2), 2.07–2.56 (m, 2H, CH_2), 1.33 (s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.8, 129.3, 127.9, 127.2, 118.8, 112.2, 80.6, 50.3, 47.9, 28.5, 25.1; FTIR ν (cm^{-1}): 3067, 2977, 2931, 1698, 1599, 1499, 1366, 1241, 1226, 1168, 1141, 748, 691; HRMS (ESI): *m*/*z* calcd for $C_{16}H_{23}N_2O_2$ (MH^+): 275.1754; found: 275.1750.

*4.6.8. tert-Butyl 2-phenyl-2,3,7,8-tetrahydro-1,2-diazocine-1(6H)-carboxylate (**3h**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3h** (81% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.56; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.21–7.29 (m, 2H, Ph), 6.69–6.84 (m, 3H, Ph), 5.91–6.04 (m, 2H, C*H*=C*H*), 3.84–4.10/2.36–2.90 (m/m, 4H, NCH_2), 2.08–2.36/1.52/1.39 (m/s/s, 13H, CH_2CH_2, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0/155.4, 147.5, 136.0/135.3, 129.3, 125.8/124.7, 118.7, 112.5/112.2, 80.1, 48.6/48.1, 46.1/45.6, 28.4, 27.1/25.7, 25.0/24.7 (the product was isolated as a 1:1 ratio of rotamers); FTIR ν (cm^{-1}): 3075, 2977, 2941, 1698, 1598, 1498, 1387, 1366, 1150, 917, 746, 692; HRMS (ESI): *m*/*z* calcd for $C_{17}H_{25}N_2O_2$ (MH^+): 289.1911; found: 289.1904.

*4.6.9. tert-Butyl 5-methyl-2-phenyl-2,3-dihydropyridazine-1(6H)-carboxylate (**3i**).* The reaction was carried out following the typical procedure in Section 4.7 using Grubbs' second generation catalyst to afford the *title compound* **3i** (82% yield) as yellowish oil. R_f (petroleum ether/EtOAc 5:1)=0.58; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.24–7.32 (m, 2H, Ph), 6.84–6.88 (m, 3H, Ph), 5.61 (s, 1H, C=C*H*), 3.62–4.43 (m, 4H, NCH_2), 1.69 (s, 3H, CH_3), 1.44 (s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.0, 148.3, 132.3, 129.2, 119.5, 117.9, 113.5, 81.0, 46.1, 45.1, 28.4, 20.1; FTIR ν (cm^{-1}): 3064, 2974, 2930, 1702, 1599, 1498, 1391, 1366, 1250, 1163, 1138, 751, 691; HRMS (ESI): *m*/*z* calcd for $C_{16}H_{23}N_2O_2$ (MH^+): 275.1754; found: 275.1749.

*4.6.10. tert-Butyl 2-phenyl-3,4,7,8-tetrahydro-1,2-diazocine-1(2H)-carboxylate (**3j**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3j** (77% yield) as a white solid. Mp=85–87 °C. R_f (petroleum ether/EtOAc 5:1)=0.52; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.23–7.31 (m, 2H, Ph), 6.67–6.90 (m, 3H, Ph), 5.75–5.98 (m, 2H, C*H*=C*H*), 2.92–4.37 (m, 4H, NCH_2), 2.10–2.50 (m, 4H, CH_2), 1.30/1.54 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.9/154.4, 149.3/148.8, 130.5/130.2, 130.0/129.7, 129.4/129.2, 119.0/118.8, 112.0, 81.0/80.6, 51.2/51.0, 50.2/49.9, 28.6/28.4, 26.6/26.4, 25.7/25.5 (the product was isolated as a 2.8:1 ratio of rotamers); FTIR ν (cm^{-1}): 3063, 2974, 2934, 1696, 1598, 1498, 1385, 1366, 1318, 1161, 1140, 747, 734, 690; HRMS (ESI): *m*/*z* calcd for $C_{17}H_{25}N_2O_2$ (MH^+): 289.1911; found: 289.1912.

4.7. Typical procedure for ring-closing metathesis for nine-membered rings (3k–l)

*4.7.1. tert-Butyl 2-phenyl-2,3,4,7,8,9-hexahydro-1H-1,2-diazonine-1-carboxylate (**3k**).* An oven-dried flask was charged with **1k** (0.30 mmol, 100 mg), evacuated and backfilled with argon. Thereafter freshly distilled DCM (24 mL) was added. A solution of Grubbs' first generation catalyst (0.05 equiv, 12.5 mg) in freshly distilled DCM (1 mL) was added to the reaction mixture. The reaction was performed at room temperature and the reaction progress was monitored by TLC (petroleum ether/EtOAc 5:1). After 1 day the reaction was complete. The volatiles were removed under reduced pressure and the residue was purified by column chromatography on silica (petroleum ether → chloroform) to yield the *title compound* **3k** (49 mg, 54%) as a white solid. Mp=82–83 °C; R_f (petroleum ether/EtOAc 5:1)=0.63; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.18–7.26 (m, 2H, Ph), 6.80 (t, 1H, *J*=7.3 Hz, Ph), 6.63 (d, 2H, *J*=8.0 Hz, Ph), 1.59–4.10 (m, 10H, NCH_2, CH_2), 1.22/1.50 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=157.2, 150.6, 129.8, 129.5, 129.2, 119.0, 112.4, 80.4, 53.9, 50.7, 28.4, 25.3, 24.4, 22.9; FTIR ν (cm^{-1}): 2972, 2913, 1701, 1598, 1498, 1392, 1366, 1324, 1281, 1162, 1141, 747, 725, 690; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{27}N_2O_2$ (MH^+): 303.3067; found: 303.3068.

*4.7.2. tert-Butyl 2-phenyl-2,3,4,5,8,9-hexahydro-1H-1,2-diazonine-1-carboxylate (**3l**).* The reaction was carried out following the typical procedure in Section 4.7 to afford the *title compound* **3l** (51% yield) as a white solid. Mp=81–83 °C; R_f (petroleum ether/EtOAc 5:1)=0.64; ^{1}H NMR (200 MHz, $CDCl_3$): δ=7.19–7.27 (m, 2H, Ph), 6.83 (t, 1H, *J*=7.3 Hz, Ph), 6.64 (d, 2H, *J*=7.8 Hz, Ph), 5.47–5.68 (m, 2H, C*H*=C*H*), 3.13–4.03 (m, 4H, NCH_2), 1.52–2.92 (m, 6H, CH_2), 1.19/1.46 (s/s, 9H, C(CH_3)$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ=156.6, 151.0/150.2, 130.5, 129.9/129.8, 129.3/129.1, 119.2, 112.6/112.4, 80.9/80.4, 56.0/55.6, 49.3/48.6, 28.6/28.3, 26.4/26.1, 24.4/23.8, 23.3/23.0 (the product was isolated as a 4.1:1 ratio of rotamers); FTIR ν (cm^{-1}): 2977, 2925, 1698, 1600, 1497, 1358, 1165, 1138, 748, 730, 692; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{27}N_2O_2$ (MH^+): 303.3067; found: 303.3061.

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Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.tet.2011.11.091.

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