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Functional rearrangement of polychlorinated pyrrolidin-2-ones to 5-imino-lactams promoted by *n*-propylamine

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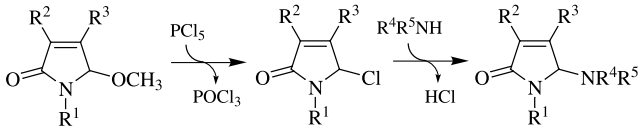
Abstract—The reaction of 4-methyl-pyrrolidin-2-ones, chlorinated at the C(3) and C(6) positions, with *n*-propylamine constitutes a new method for the preparation of 5-propylimino-pyrrolidin-2-ones or 3-pyrrolin-2-ones in generally good yields. The transformation involves a series of eliminations, substitutions and double bond shifts. This constitutes a remarkable example of a functional rearrangement.

1. Introduction

Pyrrolidin-2-ones (γ-lactams) and 3-pyrrolin-2-ones incorporating a nitrogen substituent at the C(5) carbon are important structural motifs, which are found in numerous biologically active compounds. This includes herbicides and plant growth regulators,[1–10] nootropic agents,[11] cognition enhancing pharmaceuticals,[12] antidepressants[13,14] and azamitosane systems.[15,16] Moreover, some γ-lactams have found application in the assembly of polymers with semiconducting properties.[17]

In spite of the current interest in these types of compounds, only a few preparative routes have been described in the literature. The most common method exploits the cyclization of succinic or maleic acid derivatives, typically succinic or maleic monoamides,[18–20] β-cyanoamides,[21] succinic diamides or amidines,[22,23] succinonitriles,[24,25] 3-cyanopropanoates[26] and, for analogy, 4-oxobutanoate esters.[11] Other interesting approaches to these compounds involve a three-component reaction using α-aminoalkenes, isonitriles and isocyanates,[27] and the rearrangement of *N*-acyl-*N*′-enylhydrazines.[28] Alternatively, the nitrogen appendage can be introduced at the C(5) position through the manipulation of preexisting functional groups, as in the case of alkylimino-de-oxo-bisubstitution of succinic or maleic imides,[13,15] and autoxidation of pyrrole systems.[29] Of particular promise, in this context, is the nitrogenation of γ-lactams that carry a C(5)-halogen atom by reaction with *N*-nucleophiles. This approach was originally investigated by Foucaud[30,31] and has recently been re-evaluated by Nikitin and Andryukhova.[32] Interestingly, the Russian researchers obtained 5-amino-1,5-dihydro-2*H*-pyrrol-2-ones in only two steps from the 5-methoxy analogues. This involved conversion of the 5-methoxy analogues into the corresponding 5-chloro intermediates (Scheme 1).[33]



Scheme 1.

During our recent studies on the synthesis and reactivity of 4-methyl-pyrrolidin-2-ones (**A**) chlorinated at the C(3) and C(6) positions, we disclosed that when treated with a solution of alkaline methoxide (in methanol under mild conditions), these compounds were converted into the corresponding *N*-substituted 5-methoxy or 5,5-dimethoxy-4-methyl-3-pyrrolin-2-ones (**B**) (Scheme 2).[34] The transformation involves a series of eliminations/substitutions that give rise to a remarkable functional rearrangement (FR) in which the oxidation state of the starting molecule is preserved and the functionalities repositioned. In practice, two or three of the C–Cl groups at the C(3) and C(6) positions of **A** are replaced by a double bond at C(3)–C(4) and, respectively, one or two methoxy groups at C(5). The

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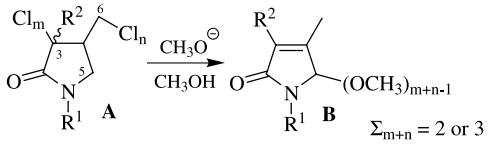
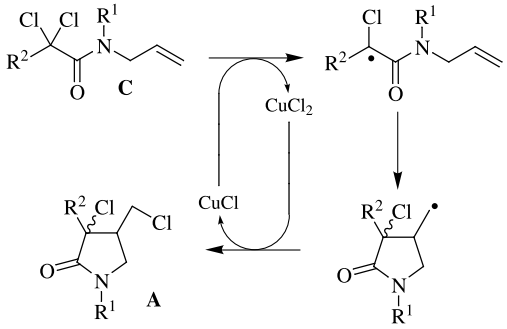


Scheme 2.

starting polyhalogenated pyrrolidin-2-ones **A** can be easily prepared, as a mixture of *cis*- and *trans*-isomers, by the atom transfer radical cyclization (ATRC) of *N*-allyl α-perchloro amides **C** (Scheme 3).[35] This reaction is typically mediated by redox catalysts, such as the complex between CuCl and *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA).[36,37] The C(3) stereocentre of the lactams is configurationally unstable under the reaction conditions and the thermodynamically more stable diastereoisomer predominates. This diastereoisomer has the larger substituents at the C(3) and C(4) positions on the opposite faces of the ring.[35]



Scheme 3.

The effectiveness and generality of the FR of polychlorinated pyrrolidin-2-ones with alkaline alcoholates prompted us to investigate if alternative nucleophilic/basic systems could be equally effective. Of particular interest was the incorporation of nitrogen nucleophiles in the functional rearrangement as this could allow the direct introduction of a nitrogen atom at the unfunctionalized C(5) position. This would avoid the need to start from C(5)-oxygen substituted γ-lactams.[13,15,30–32] Previous studies of alcohols with polychlorinated pyrrolidinones showed the importance of the alcohol structure (on increasing the size of the alkyl group in the alcohol from methyl to ethyl, yields decrease to some extent) and reaction conditions in the FR (e.g., no FR occurred when methanol was combined with a weak base, like carbonate).[34] Based on this work, amines appeared to be the most appropriate nitrogen nucleophiles with which to study the functional rearrangement of polychlorinated pyrrolidin-2-ones.

Herein we report, for the first time, our findings on the reaction of various chlorinated γ-lactams with *n*-propylamine (PA). The choice of PA was made on the basis of the low boiling point (48 °C) of this amine. It can easily be evaporated from reaction mixtures and so can play a combined role as reagent and solvent. As a consequence of the FR using PA, the 5-imino functional group was, in each case considered, introduced on the γ-lactam ring in generally good yield.

2. Results and discussion

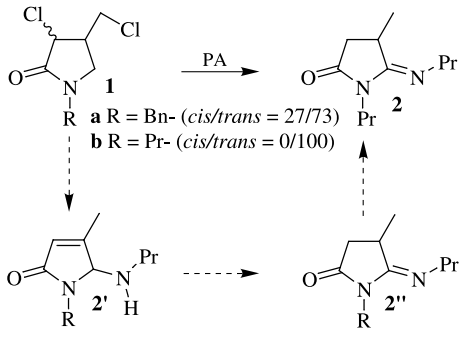
Our preliminary studies on the viability of the FR involved reaction of *N*-benzyl-3-chloro-4-chloromethyl-pyrrolidin-2-one (**1a**) with PA at different temperatures and concentrations (Table 1). Unexpectedly, in all cases, *N*-propyl-4-methyl-5-propylimino-pyrrolidin-2-one (**2**) was recovered as the main product (Scheme 4). This result contrasts with the reaction of **1a** with sodium methoxide in methanol, which led to 5-methoxy-4-methyl-3-pyrrolin-2-one.[34] For reaction with PA, the double bond of the FR product is located between C(5) and the exocyclic nitrogen and not, as foreseen, between the C(3) and C(4) positions.

The discrepancy may be explained by the higher valency of nitrogen compared to oxygen which, when an NHPr group residues at C(5), should permit the double bond to move from C(3)–C(4) to form an imine bond at C(5). We believe that FR of **1a** with PA should then provide the predicted *N*-benzyl-4-methyl-5-propylamino-3-pyrrolin-2-one (**2′a**), but as a transient product, which immediately undergoes double bond isomerisation. Indeed, when **1a** was reacted with $(CH_3CH_2)_2NH$ (DEA), a secondary amine, *N*-benzyl-4-methyl-5-diethylamino-3-pyrrolin-2-one (**3**) was obtained

Table 1. Reaction of **1a** with PA[a]

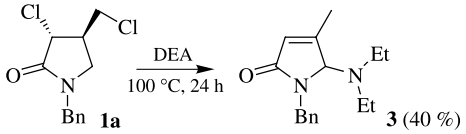
Entry	PA (mL)	*T* (°C)	Conv. (%)[b]	**2** (%)[c]
1	2.5	60	100	28
2	2.5	80	100	40
3	2.5	120	100	47
4	2.5	140	100	48
5	5	140	100	54

[a] 1 mmol of substrate was used; reaction time 24 h.
[b] GC values.
[c] Yield determined on isolated material.

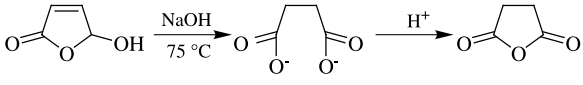


Scheme 4.

as the main product (Scheme 5). In this case, as the exocyclic nitrogen in the intermediate pyrrolin-2-one is unable to form a double bond at C(5), so the unsaturation has to remain inside the ring. Further evidence that the FR of **1a** with PA involves intermediate **2′a** comes from the related, and recently observed, rearrangement of 5-hydroxy-2(5H)-furanone to succinic anhydride under basic conditions (Scheme 6).[38] In this reaction, double bond isomerisation was observed to form an intermediate dicarboxylate.



Scheme 5.



Scheme 6.

Another remarkable feature of this reaction is replacement of the *N*-benzyl group in **1a** with a propyl appendage in product **2**. Evidently, during the course of the reaction, most likely following formation of the 5-imino lactam **2″a**, substitution of the benzylamine moiety with *n*-propylamine takes place (Scheme 4).[39,40] As a consequence, two different primary amines come to share the same reaction mixture. This resulted in the formation of a variety of byproducts that contained the benzylic group (as indicated by GC-MS), unless forcing conditions, such as high temperature (140 °C) and relatively large volumes of *n*-propylamine (5 mL/mmol) were employed.

As a consequence of the facile substitution of the *N*-benzyl group in **1a**, we decided to study the FR of polychlorinated pyrrolidin-2-ones bearing an *N*-propyl chain. In this way, any exchange of the *N*-substituent with PA would not generate a new product. This tactic allowed us to investigate the FR under mild reaction conditions. Indeed, the FR of pyrrolidin-2-one **1b** with PA (Scheme 4) was observed at temperatures as low as 40 °C (Table 2). Moreover, when using 2 mL of PA to 1 mmol of **1b**, the 5-imino pyrrolidin-2-one **2** was isolated in a respectable 57% yield (Table 2, entry 7).

Gratified by these preliminary results and with a view to assessing the scope of the method, the four chlorinated pyrrolidin-2-ones **4**–**7** were prepared in high yield through the HATRC of the respective *N*-allyl amides with CuCl/TMEDA.

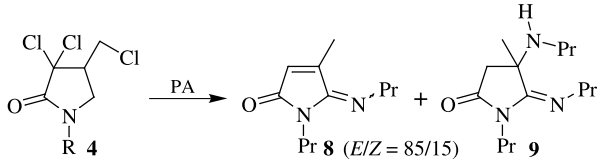
The FR of pyrrolidin-2-one **4** at 40 °C with 2 mL of *n*-propylamine per mmol of substrate, gave the 5-imino pyrrolidin-2-one **9** as the main product together with a small amount of the expected γ-lactam **8** (Scheme 7; Table 3, entry 5). It is likely that lactam **9** is formed by a highly regioselective Michael-type addition of PA onto the C=C bond of **8**. When the temperature of the reaction was raised, and the mixture heated at 80 °C, only the Michael-type adduct was isolated (Table 3, entry 6). In order to avoid the Michael-type addition, the reaction was carried out at lower temperatures. Pleasingly, following reaction of **4** with PA at −13 °C for 4 h, only the 3-pyrrolin-2-one **8** was isolated in a respectable yield of 63% (Table 3, entry 1).

When substrate **5** was heated with PA (2 mL/mmol of substrate) for 16 h at 40 °C, some starting material remained and a variety of products were formed. From the crude reaction mixture we isolated the FR adduct **10**, in low yield (6%), and *N*-propyl-3-methyl-4-(propylamino)methyl-3-pyrrolin-2-one (**11**) as the main product (Scheme 8; Table 3, entry 7). On increasing the reaction temperature to 80–100 °C, it was possible to obtain complete conversion of starting material and to improve the yield of **10** to 29% (Table 3, entry 8 and 9), whereas the yield of **11** remained well above 50%. The unwanted product **11** could derive from one, or more, of the three possible paths outlined in Scheme 9, wherein an amino-de-halogenation step is variously combined with a dehydrohalogenation step.

Table 2. Reaction of **1b** with PA[a]

Entry	PA (mL)	*t* (h)	*T* (°C)	Conv. (%)[b]	**2** (%)[c]
1	1	24	20	73	28
2	1	24	40	100	48
3	1	16	40	97	45
4	1	24	60	100	42
5	1	24	80	100	38
6	1	24	100	100	43
7	2	24	40	99	57

[a] 1 mmol of **1b** was used.
[b] GC values.
[c] Yield determined on isolated material.



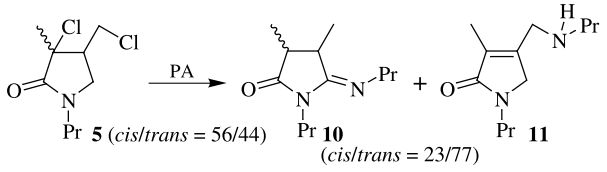
Scheme 7.

As far as the γ-lactam **6** is concerned, the FR with *n*-propylamine (2 mL/mmol of substrate) at 40 °C was disappointing. The rearranged product, *N*-propyl-3,4-dimethyl-5-propylimino-3-pyrrolin-2-one (**12**), was isolated

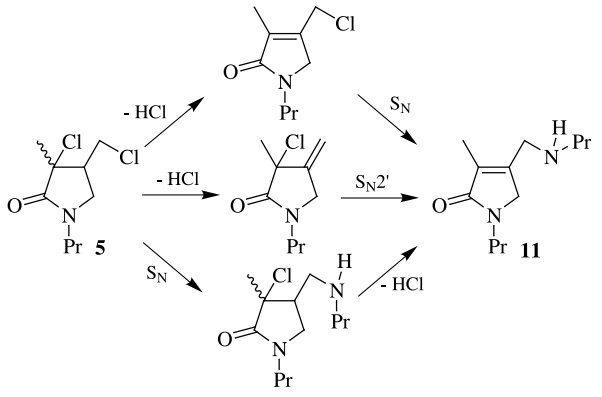
Table 3. Reaction of pyrrolidin-2-ones **4–7** with PA[a]

Entry	Substrate	*t* (h)	*T* (°C)	Conv. (%)[b]	Products (%)[c]
1[d]	**4**	4	−13	100	**8** (63); **9** (0)
2	**4**	16	−13	100	**8** (63); **9** (6)
3	**4**	16	0	100	**8** (61); **9** (15)
4	**4**	16	20	100	**8** (53); **9** (41)
5	**4**	16	40	100	**8** (7); **9** (59)
6	**4**	16	60	100	**9** (56)
7	**5**	16	40	85	**10** (6); **11** (64)
8	**5**	16	80	100	**10** (28); **11** (68)
9	**5**	16	100	100	**10** (29); **11** (59)
10	**6**	16	40	100	**12** (5)
11	**6**	16	60	100	**12** (9)
12	**6**	16	80	100	**12** (22)
13	**6**	16	100	100	**12** (25)
14	**6**	16	120	100	**12** (15)
15[e]	**7**	0.5	−13	100	**13** (68); **14** (0)
16[e]	**7**	1	−13	100	**13** (63); **14** (0)
17	**7**	16	−13	100	**13** (13); **14** (0)
18	**7**	16	0	100	**13** (7); **14** (0)
19	**7**	16	40	100	**13** (0); **14** (23)
20	**7**	16	60	100	**13** (0); **14** (37)
21	**7**	16	80	100	**13** (0); **14** (44)

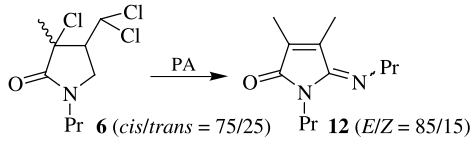
[a] Substrate (1 mmol), PA (2 mL).
[b] GC values.
[c] Yield determined on isolated material.
[d] The substrate was thermostated at −13 °C before addition of PA.
[e] The substrate was thermostated at −13 °C before addition of PA and 1 mL of diethyl ether was added to prevent its solidification.



Scheme 8.



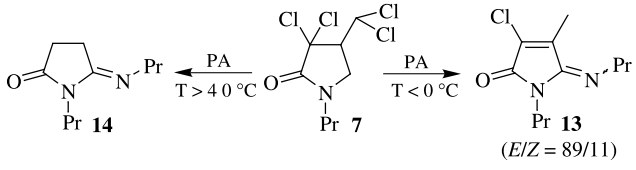
Scheme 9.



Scheme 10.

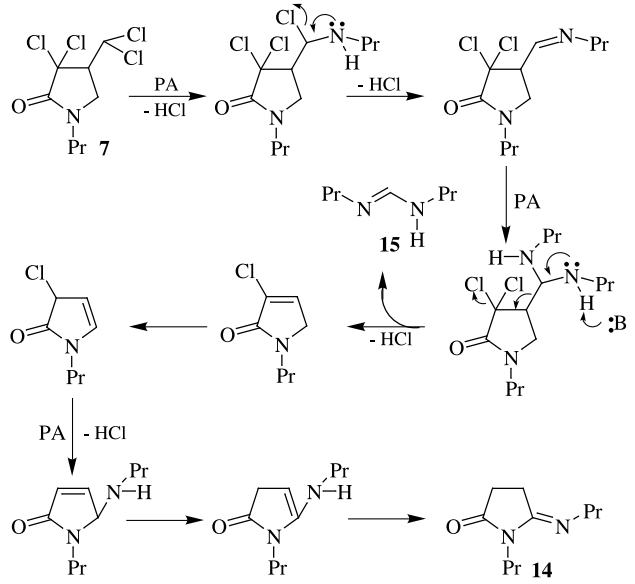
in only 5% yield (Scheme 10; Table 3, entry 10). In this case, heating the reaction mixture to 100 °C was also beneficial and the yield of **12** increased to 25% (Table 3, entry 13).

Finally, treatment of the polychlorinated pyrrolidin-2-one **7** with PA (at 40 °C) surprisingly afforded the degradation product **14** as the main component of the reaction crude (23%). No trace of the rearranged lactam **13** was detected (Scheme 11; Table 3, entry 19). As observed for the previous rearrangements, temperature proved to be a critical reaction parameter. In fact, on mixing the reagents at −13 °C for no more than 0.5 h (Scheme 11; Table 3, entry 15), the FR proceeded efficiently, providing the rearranged lactam **13** in good yield (68%). Temperatures higher than 40 °C caused, on the contrary, a progressive increase in the amount of imine **14**. Interestingly, from the MS analysis of the crude reaction mixtures containing *N*-propyl-5-propylimino-pyrrolidin-2-one (**14**) it was possible to detect a peak, which can be assigned to *N*,*N*′-dipropylformamidine (**15**). This was confirmed after comparison of the spectrum with an authentic sample of **15**, synthesized by a literature procedure.[41] The simultaneous formation of amidine **15** together with lactam **14** sheds some light on the mechanism of degradation of substrate **7**. The degradation is likely to start by substitution of the two *exo*-Cl atoms in **7** by two PA units. Then, from the resulting *N*,*N*-acetal, a base catalyzed fragmentation should afford amidine **15** and the intermediate *N*-propyl-3-chloro-3-pyrrolin-2-one, which in



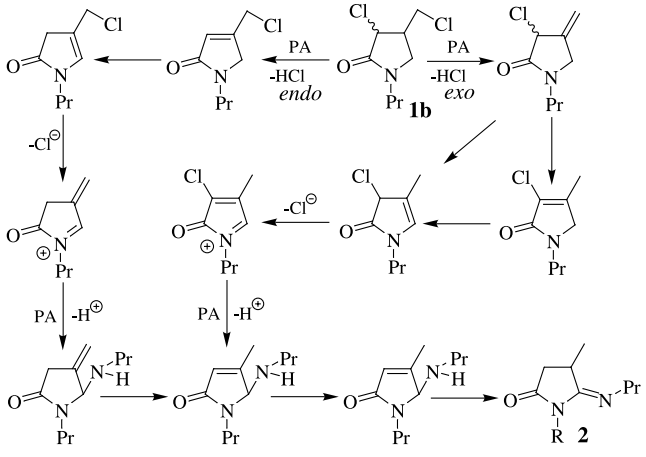
Scheme 11.

a few further steps could be transformed into **14** (Scheme 12).



Scheme 12.

The results from all these experiments clearly show that similarities can be drawn between the FR of polychlorinated pyrrolidin-2-ones using PA or CH_3OH/CH_3ONa. Therefore, it is reasonable to assume that the same type of mechanism is occurring in both transformations. In agreement with our previous proposal[34] and taking **1b** as a model pyrrolidin-2-one, we believe that the reaction starts with a base-promoted dehydrohalogention. This is an *exo* or *endo* elimination according to the ease with which the required *anti-periplanar* conformation is attained. The double bond then shifts from the C(4)–C(5) position to afford an intermediate Δ^4-pyrrolin-2-one. This can react further to afford, via a solvolysis step, a stable *N*-acyliminium cation that, after condensation with PA, is converted into the final product **2** (Scheme 13).



Scheme 13.

A few years ago we reported that *N*-substituted-3-benzyl-imino-pyrrolidin-2-ones could be prepared by heating *N*-substituted-3-chloro-4-chloromethyl-pyrrolidin-2-ones with benzylamine (3 equiv) and NaI in THF at reflux.[42] Given that these are similar reaction conditions to the ones described for the FR, it is surprising that different products are formed. Consequently, the reaction with the *N*-benzyl-3-chloro-4-chloromethyl-pyrrolidin-2-one was repeated and, as expected from the results of the present work, the structure of the reaction product was, without doubt, defined as *N*-benzyl-5-benzylimino-4-methyl-pyrrolidin-2-ones. This means that our former product characterization was erroneous and that the same functional rearrangement is operative.

3. Structural characterizations of the (*E*)- and (*Z*)-5-iminolactams 2, 8–10, 12–14

For all the 5-iminolactams, the (*E*) configuration largely or exclusively prevails. For adducts **2**, **9**, **10** and **14** only the (*E*)-isomer was isolated, while for products **8**, **12** and **13**, 11–15% of the minor (*Z*)-isomer (in equilibrium with the (*E*)-counterpart) was observed.

The stereochemistry of the 5-propylimino group was derived from ^{1}H NMR two-dimensional nuclear Overhauser enhancement experiments in the phase sensitive mode (NOESY-TPPI),[43] that were run after a complete assignment of the ^{1}H and ^{13}C NMR spectra, through inverse detection techniques (HMQC).[44] This was used in order to unambiguously assign all proton and carbon signals, in particular, those of the different propyl chains. NOESY-TPPI experiments permit the detection of protons close to one another in space and, at the same time, to evidence exchange processes which are slow enough on the NMR timescale.[45] The two situations can be distinguished from the sign of the relevant cross-peaks with respect to that of diagonal peaks: cross-peaks denoting proximity of two protons have opposite sign, whereas cross-peaks deriving from exchange phenomena have the same sign with respect to the diagonal ones (which are set as negative). From NOESY-TPPI spectra it was readily seen that the signals of methylene protons bonded to the imino moiety share positive cross-peaks with the signals of groups at the C(4) position in derivatives **2**, **9**, **10** and **14**, and this indicates an (*E*)-type configuration. In the case of compounds **8**, **12** and **13**, ^{1}H NMR spectra showed the presence of two sets of signals, and negative correlations were found between the corresponding signals of the two forms in NOESY-TPPI spectra, evidencing that an exchange process between two isomeric species is present.[42] Moreover, positive cross-peaks were found, for the major isomer only, among the signals of the iminopropyl appendage and those of the groups at the C(4) position, indicating that the (*E*)-type configuration also prevails in these products. It is interesting to note that the tendency to have a small amount of the (*Z*)-isomer of the iminopropyl group (in equilibrium with the prevailing (*E*)-isomer) is only observed for the γ-lactams with a $C(4)_{sp2}$ carbon. The (*Z*)-isomer is not observed for those compounds with a $C(4)_{sp3}$ carbon, even when two substituents are present, for example, as in the case of the pyrrolidin-2-one **9**. The preponderance of the (*E*)-isomers, then, is attributed to the higher thermodynamic stability of these frameworks.

4. Conclusion

The reaction of 4-methyl-pyrrolidin-2-ones chlorinated at the C(3) and C(6) positions with PA establishes a new method for the preparation, generally in good yield, of 5-propylimino pyrrolidin-2-ones or 3-pyrrolin-2-ones. This FR is similar to that observed when the same substrates are treated with CH_3OH/CH_3ONa. In order to obviate the problem of substitution of the *N*-substituent on the γ-lactam ring, the FR with PA requires the use of polychlorinated pyrrolidin-2-ones bearing an *N*-propyl group. In this way, notwithstanding that the exchange still occurs, it cannot be noticed owing to the degeneracy of the phenomenon. This structural prerequisite, however, restricts the versatility of the method. Current studies are investigating the application of the methodology to the synthesis of roccellic acid[46] and the results will be reported in due course.

5. Experimental

5.1. General

^1H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ solutions with a Bruker Avance 400 Spectrometer and a Bruker DPX 200 spectrometer, and the chemical shifts are reported in ppm relative to tetramethylsilane as external standard. Conditions for HMQC spectra were: evolution delay = 50 ms, spectral width = 10 ppm with 2048 complex points in *f*2; 256 *t*1 values and 64 scans for *t*1 value. A squared sine function (SSB = 2) in *f*2 and *f*1 was applied before Fourier transformation. Conditions for NOESY phase-sensitive spectra by time-proportional phase incrementation (TPPI) were: mixing time of 600 ms, spectral width 8.16 ppm with 2048 complex points in *f*2; 128 *t*1 values and 64 scans for *t*1 value. A squared sine function (SSB = 2) in *f*2 and gaussian multiplication (LB = −1, GB = 0.01) in *f*1 were applied before Fourier transformation. IR spectra were obtained with a Perkin–Elmer 1600 Series FTIR. Mass spectra were acquired with a combined HP 5890 GC/HP 5989A MS Engine. Reagents and solvents were standard grade commercial products, purchased from Acros, Aldrich or Fluka, and used without further purification. Acetonitrile (for the radical cyclizations) was dried over three batches of 3 Å sieves (5% w/v, 12 h). The silica gel used for flash chromatography was 60 Merck (0.040–0.063 mm). *N*-propyl-2-propenylamine and *N*-propyl-3-chloro-2-propenylamine were prepared for *N*-alkylation of *n*-propylamine with allyl bromide or 1,3-dichloropropene. The *N*-allyl-*N*-propyl α-perchloro amide precursors of polychlorinated pyrrolidin-2-ones **1b** and **4**–**7** were obtained by amino-de-chlorination of the appropriate acyl chlorides.[35] *N*-Benzyl-3-chloro-4-chloromethyl-pyrrolidin-2-one (**1a**) was prepared according to the literature.[47]

5.2. Preparation of polychlorinated pyrrolidin-2-ones

5.2.1. Typical procedure for the preparation of polychlorinated pyrrolidin-2-ones: *N*-propyl-3-chloro-4-chloromethyl-pyrrolidin-2-one (1b). CuCl (0.20 g, 2 mmol) and the *N*-allyl-*N*-propyl-dichloroacetamide (4.20 g, 20 mmol) were weighted in a Schlenk tube, then dry acetonitrile (10 mL) and TMEDA (0.6 mL, 4 mmol) were added under argon. The mixture was stirred at 80 °C and after 24 h diluted with HCl (5% w/v, 20 mL) and extracted with CH_2Cl_2 (3×10 mL). The combined organic layers were dried with toluene (10 mL) through azeotropic distillation. Flash-chromatography of the crude product on silica, eluting with a petroleum ether (bp 40/60 °C)/diethyl ether gradient, afforded the pyrrolidin-2-one **1b** (3.40 g, 81%) as an unseparable mixture of *cis*/*trans* diastereoisomers (27/73); orange oil; [found: C, 45.59; H, 6.31; N, 6.76. $C_8H_{13}Cl_2NO$ requires C, 45.73; H, 6.24; N, 6.67]; IR (liquid film) 1707 (C=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): *trans* diastereoisomer (73%) δ 0.91 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.57 (2H, m, $CH_2CH_2CH_3$), 2.65–3.05 (1H, m, C(4)*H*), 3.05–3.91 (6H, m, CH_2NCH_2-C(4)HCH_2), 4.33 (1H, d, *J* = 7.6 Hz, C(3)*H*); *cis* diastereoisomer (27%) δ 0.91 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.57 (2H, m, $CH_2CH_2CH_3$), 2.65–3.05 (1H, m, C(4)*H*), 3.05–3.91 (6H, m, $CH_2NCH_2C(4)HCH_2$), 4.44 (1H, d, *J* = 7.6 Hz, C(3)*H*); MS (EI, 70 eV) *m*/*z*: 209 (17, M^+), 194 (35), 180 (100), 174 (52), 152 (22), 42 (17).

5.2.2. *N*-Propyl-3,3-dichloro-4-chloromethyl-pyrrolidin-2-one (4). According to the general procedure, cyclization of *N*-allyl-*N*-propyl-trichloroacetamide (4.90 g, 20 mmol) at 25 °C for 20 h gave the pyrrolidin-2-one **4** (4.35 g, 89%) as yellow oil; [found: C, 39.41; H, 5.01; N, 5.86. $C_8H_{12}Cl_3NO$ requires C, 39.29; H, 4.95; N, 5.73]; IR (liquid film) 1729 (C=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 0.92 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.61 (2H, m, $CH_2CH_2CH_3$), 2.87–4.17 (7H, m, $CH_2NCH_2C(4)HCH_2$); MS (EI, 70 eV) *m*/*z*: 243 (13, M^+), 228 (47), 214 (100), 208 (55), 180 (28), 42 (47).

5.2.3. *N*-Propyl-3-chloro-4-chloromethyl-3-methyl-pyrrolidin-2-one (5). According to the general procedure, cyclization of *N*-allyl-*N*-propyl-2,2-dichloropropanamide (4.48 g, 20 mmol) at 25 °C for 20 h gave the pyrrolidin-2-one **5** (4.30 g, 96%) as an unseparable mixture of *cis*/*trans* diastereoisomers (56/44); orange oil; [found: C, 48.34; H, 6.68; N, 6.12. $C_9H_{15}Cl_2NO$ requires C, 48.23; H, 6.75; N, 6.25]; IR (liquid film) 1706 (C=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): *cis* diastereoisomer (56%) δ 0.91 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.58 (2H, m, $CH_2CH_2CH_3$), 1.76 (3H, s, C(3)CH_3), 2.36–2.68 (1H, m, C(4)*H*), 3.04–4.00 (6H, m, $CH_2NCH_2C(4)HCH_2$); *trans* diastereoisomer (44%) δ 0.91 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.58 (2H, m, $CH_2CH_2CH_3$), 1.63 (3H, s, C(3)CH_3), 2.80–3.04 (1H, m, C(4)*H*), 3.04–4.00 (6H, m, $CH_2NCH_2C(4)HCH_2$); MS (EI, 70 eV) *m*/*z*: 223 (17, M^+), 208 (25), 194 (100), 188 (48), 160 (18), 42 (22).

5.2.4. *N*-Propyl-3-chloro-4-dichloromethyl-3-methyl-pyrrolidin-2-one (6). According to the general procedure, cyclization of *N*-(3-chloroallyl)-*N*-propyl-2,2-dichloropropanamide (5.17 g, 20 mmol) at 25 °C for 20 h gave the pyrrolidin-2-one **6** (4.71 g, 91%) as an unseparable mixture of *cis*/*trans* diastereoisomers (75/25); light yellow oil; [found: C, 41.84; H, 5.39; N, 5.36. $C_9H_{14}Cl_3NO$ requires C, 41.81; H, 5.46; N, 5.42]; IR (liquid film) 1711 (C=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): *cis* diastereoisomer (75%) δ 0.92 (3H, t, *J* = 7.4 Hz, $CH_2CH_2CH_3$), 1.59 (2H, m, $CH_2CH_2CH_3$), 1.91 (3H, s, C(3)CH_3), 2.89 (1H, td, *J* = 7.4, 9.5 Hz, C(4)*H*), 3.03–3.56 (4H, m, C(5)$H_2NCH_2CH_2$), 6.04

(1H, d, J=9.5 Hz, C(4)C*H*); *trans* diastereoisomer (25%) δ 0.94 (3H, t, J=7.4 Hz, $CH_2CH_2CH_3$), 1.59 (2H, m, $CH_2CH_2CH_3$), 1.78 (3H, s, C(3)CH_3), 3.03–3.56 (4H, m, CH_2NC(5)*H*C(4)*H*), 3.77 (1H, dd, J=7.6, 11.4 Hz, C(5)*H*), 5.93 (1H, d, J=4.5 Hz, C(4)C*H*); MS (EI, 70 eV) *m/z*: 257 (15, M^+), 242 (33), 228 (100), 222 (52), 194 (23), 42 (25).

5.2.5. *N*-Propyl-3,3-dichloro-4-dichloromethyl-pyrrolidin-2-one (7). According to the general procedure, cyclization of *N*-(3-chlorallyl)-*N*-propyl-trichloroacetamide (5.58 g, 20 mmol) at 25 °C for 20 h gave the pyrrolidin-2-one **7** (5.08 g, 91%) as pale yellow oil; [found: C, 34.53; H, 4.04; N, 5.09. $C_8H_{11}Cl_4NO$ requires C, 34.44; H, 3.97; N, 5.02]; IR (liquid film) 1733 (C=O) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ 0.94 (3H, t, J=7.4 Hz, $CH_2CH_2CH_3$), 1.62 (2H, m, $CH_2CH_2CH_3$), 3.22–3.51 (4H, m, CH_2-NC(5)*H*C(4)*H*), 3.64 (1H, dd, J=6.8, 9.6 Hz, C(5)*H*), 6.09 (1H, d, J=7.9 Hz, C(4)C*H*); MS (EI, 70 eV) *m/z*: 277 (10, M^+), 264 (58), 250 (100), 242 (48), 214 (27), 159 (20), 130 (47), 109 (20), 42 (30).

5.3. Functional rearrangement of polychlorinated pyrrolidin-2-ones

5.3.1. Preparation of (*E*)-*N*-propyl-4-methyl-5-propylimino-pyrrolidin-2-one (2). The polychlorinated pyrrolidin-2-one **1a** (0.26 g, 1 mmol) was weighted in a Schlenk tube, then *n*-propylamine (5 mL) was added under argon. The mixture was stirred at 140 °C for 24 h, then evaporated under vacuum to remove *n*-propylamine, and finally diluted with H_2O (4 mL) and extracted with CH_2Cl_2 (2×5 mL). Flash-chromatography of the crude product on silica, eluting with a petroleum ether (bp 40/60 °C)/diethyl ether gradient, afforded **2** (106 mg, 54%) as an orange yellow oil; [found: C, 67.40; H, 10.21; N, 14.19. $C_{11}H_{20}N_2O$ requires C, 67.31; H, 10.27; N, 14.27]; IR (liquid film) 1660 cm^{-1} (C=N), 1737 cm^{-1} (C=O); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.94 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.21 (3H, d, J=7.2 Hz, C(4)CH_3), 1.58 (2H, m, C=NCH_2CH_2), 1.61 (2H, m, N(1)CH_2CH_2), 2.15 (1H, dd, J=1.9, 17.5 Hz, C(3)*H*), 2.76 (1H, dd, J=8.8, 17.5 Hz, C(3)*H*), 3.09 (1H, m, C(4)*H*), 3.28 (1H, m, C=NC*H*), 3.35 (1H, m, C=NC*H*), 3.50 (2H, m, N(1)CH_2); ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.27 (N(1)$CH_2CH_2CH_3$), 11.84 (C=N$CH_2CH_2CH_3$), 19.28 (C(4)CH_3), 20.46 (N(1)CH_2CH_2), 24.87 (C=NCH_2CH_2), 29.01 (*C*(4)), 37.88 (*C*(3)), 40.47 (N(1)CH_2), 50.97 (C=NCH_2), 161.80 (*C*(5)), 175.64 (*C*(2)); MS (EI, 70 eV) *m/z*: 196 (100, M^+), 181 (40), 167 (68), 153 (40), 139 (83), 126 (57), 113 (25), 97 (20), 41 (22).

5.3.2. Preparation of *N*-benzyl-5-diethylamino-4-methyl-3-pyrrolin-2-one (3). According to the general procedure, the rearrangement of **1a** (0.26 g, 1 mmol) with diethylamine (2.5 mL) at 100 °C for 24 h gave **3** (0.10 g, 40%) as a yellowish oil; [found: C, 74.34; H, 8.62; N, 10.77. $C_{16}H_{22}N_2O$ requires C, 74.38; H, 8.58; N, 10.84]; IR (liquid film) 1696 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.97 (6H, t, J=7.1 Hz, N(CH_2CH_3)$_2$), 1.93 (3H, d, J=1.4 Hz, C(4)CH_3), 2.60 (4H, broad m, N(CH_2CH_3)$_2$), 4.02 (1H, d, J=15.1 Hz, N(1)C*H*Ar), 4.53 (1H, s, C(5)*H*), 5.07 (1H, d, J=15.1 Hz, N(1)C*H*Ar), 5.88 (1H, q, J=1.4 Hz, C(3)*H*), 7.19–7.30 (5H, m, Ar(*H*)); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.91 (C(4)CH_3), 15.04 (N(CH_2CH_3)$_2$), 43.0 (br, N(CH_2CH_3)$_2$), 43.27 (CH_2Ar), 79.15 (*C*(5)N), 123.36 (*C*(3)), 127.07 (*Ar*), 127.75 (*Ar*), 128.44 (*Ar*), 138.18 (*Ar*), 158.55 (*C*(4)), 170.29 (*C*=O); MS (EI, 70 eV) *m/z*: 258 (5, M^+), 186 (67), 91 (100).

5.3.3. Preparation of *N*-propyl-4-methyl-5-propylimino-3-pyrrolin-2-one (8). According to the general procedure, the rearrangement of **4** (0.24 g, 1 mmol) with *n*-propylamine (2 mL) at −13 °C for 4 h gave **8** (0.12 g, 63%) as an unseparable mixture of *E*/*Z* diastereoisomers (85/15); yellow oil; [found: C, 68.10; H, 9.41; N, 14.47. $C_{11}H_{18}N_2O$ requires C, 68.01; H, 9.34; N, 14.42]; IR (liquid film) 1654 cm^{-1} (C=N), 1724 cm^{-1} (C=N); ^{1}H NMR (400 MHz, $CDCl_3$): (*E*)-diastereoisomer (85%) δ 0.84 (3H, t, J=7.5 Hz, N(1)$CH_2CH_2CH_3$), 0.96 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.55 (2H, m, N(1)CH_2CH_2), 1.67 (2H, m, C=NCH_2CH_2), 2.26 (3H, d, J=1.6 Hz, C(4)CH_3), 3.50 (2H, t, J=7.3 Hz, N(1)CH_2), 3.71 (2H, t, J=6.8 Hz, C=NCH_2), 6.13 (1H, q, J=1.6 Hz, C(3)*H*); (*Z*)-diastereoisomer (15%) δ 0.87 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.98 (3H, t, J=7.2 Hz, C=N$CH_2CH_2CH_3$), 1.55 (2H, m, N(1)CH_2CH_2), 1.67 (2H, m, C=NCH_2CH_2), 2.01 (3H, d, J=1.5 Hz, C(4)CH_3), 3.66 (2H, t, J=7.6 Hz, N(1)CH_2), 3.67 (2H, t, J=6.8 Hz, C=NCH_2), 6.06 (1H, q, J=1.5 Hz, C(3)*H*); ^{13}C NMR (100 MHz, $CDCl_3$): (*E*)-diastereoisomer (85%) δ 11.27 (N(1)$CH_2CH_2CH_3$), 11.72 (C=N$CH_2CH_2CH_3$), 17.43 (C(4)CH_3), 21.77 (N(1)CH_2CH_2), 25.31 (C=NCH_2CH_2), 39.61 (N(1)CH_2), 51.08 (C=NCH_2), 129.09 (*C*(3)), 140.63 (*C*(4)), 152.76 (*C*(5)), 169.96 (*C*(2)); (*Z*)-diastereoisomer (15%) δ 10.97 (N(1)$CH_2CH_2CH_3$), 11.72 (C=N$CH_2CH_2CH_3$), 11.99 (C(4)CH_3), 23.76 (N(1)CH_2CH_2), 25.20 (C=NCH_2CH_2), 42.79 (N(1)CH_2), 50.27 (C=NCH_2), 122.78 (*C*(3)), 150.40 (*C*(4)), 150.72 (*C*(5)), 172.54 (*C*(2)); MS (EI, 70 eV) *m/z*: 194 (100, M^+), 179 (28), 165 (58), 151 (58), 137 (37), 123 (35), 111 (22), 94 (67), 41 (22).

5.3.4. Preparation of (*E*)-*N*-propyl-4-methyl-4-propylamino-5-propylimino-pyrrolidin-2-one (9). According to the general procedure, the rearrangement of **4** (0.24 g, 1 mmol) with *n*-propylamine (2 mL) at 40 °C for 16 h gave **9** (0.15 g, 59%) as a yellowish oil; [found: C, 66.45; H, 10.76; N, 16.48. $C_{14}H_{27}N_3O$ requires C, 66.36; H, 10.74; N, 16.58]; IR (liquid film) 1668 cm^{-1} (C=N), 1733 cm^{-1} (C=O); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.84 (3H, t, J=7.5 Hz, N(1)$CH_2CH_2CH_3$), 0.89 (3H, t, J=7.4 Hz, NH$CH_2CH_2CH_3$), 0.93 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.40–1.50 (2H, m, NHCH_2CH_2), 1.46 (3H, s, C(4)CH_3), 1.55 (2H, m, N(1)CH_2CH_2), 1.58 (2H, m, C=NCH_2CH_2), 2.26 (1H, dt, J=7.1, 10.5 Hz, NHC*H*), 2.34 (1H, d, J=18.0 Hz, C(3)H_2), 2.43 (1H, dt, J=7.1, 10.5 Hz, NHC*H*), 2.74 (1H, d, J=18.0 Hz, C(3)H_2), 3.48 (2H, t, J=7.3 Hz, N(1)CH_2), 3.59 (2H, t, J=6.8 Hz, C=NCH_2); ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.30 (N(1)$CH_2CH_2CH_3$), 11.75 (NH$CH_2CH_2CH_3$), 11.82 (C=N$CH_2CH_2CH_3$), 20.44 (N(1)CH_2CH_2), 23.54 (NHCH_2CH_2), 25.22 (C=NCH_2CH_2), 26.60 (C(4)CH_3), 40.38 (N(1)CH_2), 42.77 (*C*(3)), 45.34 (NHCH_2), 48.58 (C=NCH_2), 59.77 (*C*(4)), 157.68 (*C*(5)), 173.69 (*C*(2)); MS (EI, 70 eV) *m/z*: 253 (1, M^+), 238 (3), 224 (8), 194 (100), 179 (22), 126 (45), 84 (23), 42 (15).

5.3.5. Preparation of (*E*)-*N*-propyl-3,4-dimethyl-5-propylimino-pyrrolidin-2-one (10). According to the general procedure, the rearrangement of **5** (0.22 g, 1 mmol) with *n*-propylamine (2 mL) at 100 °C for 16 h gave **10** (61 mg, 29%) as an unseparable mixture of *cis*/*trans* diastereoisomers (23/77); yellow oil; [found: C, 68.64; H, 10.59; N, 13.33. $C_{12}H_{22}N_2O$ requires C, 68.53; H, 10.54; N, 13.32]; IR (liquid film) 1671 cm^{-1} (C=N), 1736 cm^{-1} (C=O); ^1H NMR (400 MHz, $CDCl_3$): *trans* diastereoisomer (77%) δ 0.84 (3H, t, J=7.5 Hz, N(1)$CH_2CH_2CH_3$), 0.90 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.18 (3H, d, J=7.2 Hz, C(4)CH_3), 1.19 (3H, d, J=7.4 Hz, C(3)CH_3), 1.56 (2H, m, N(1)CH_2CH_2), 1.58 (2H, m, C=NCH_2CH_2), 2.22 (1H, m, J=1.9, 7.4 Hz, C(3)*H*), 2.61 (1H, m, J=1.9, 7.2 Hz, C(4)*H*), 3.20–3.53 (4H, m, CH_2NC=NCH_2); *cis* diastereoisomer (23%) δ 0.83 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.91 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.02 (3H, d, J=7.3 Hz, C(4)CH_3), 1.15 (3H, d, J=7.4 Hz, C(3)CH_3), 1.55 (2H, m, N(1)CH_2CH_2), 1.57 (2H, m, C=NCH_2CH_2), 2.71 (1H, m, J=7.8 Hz, C(3)*H*), 3.12 (1H, m, J=7.7 Hz, C(4)*H*), 3.20–3.53 (4H, m, CH_2-NC=NCH_2); ^{13}C NMR (100 MHz, $CDCl_3$): *trans* diastereoisomer (77%) δ 11.18 (N(1)$CH_2CH_2CH_3$), 11.77 (C=N$CH_2CH_2CH_3$), 17.57 (C(3)CH_3), 18.57 (C(4)CH_3), 20.43 (N(1)CH_2CH_2), 24.85 (C=NCH_2CH_2), 37.67 (*C*(4)), 40.32 (N(1)CH_2), 44.50 (*C*(3)), 50.96 (C=NCH_2), 161.03 (*C*(5)), 179.06 (*C*(2)); *cis* diastereoisomer (23%) δ 9.44 (C(3)CH_3), 11.23 (N(1)$CH_2CH_2CH_3$), 11.82 (C=NCH_2-CH_2CH_3), 13.27 (C(4)CH_3), 20.47 (N(1)CH_2CH_2), 24.83 (C=NCH_2CH_2), 33.11 (*C*(4)), 38.89 (*C*(3)), 40.36 (N(1)CH_2), 51.05 (C=NCH_2), 161.63 (*C*(5)), 178.35 (*C*(2)); MS (EI, 70 eV) *m*/*z*: 210 (65, M^+), 195 (43), 181 (45), 167 (35), 153 (100), 140 (52), 111 (32), 55 (20), 41 (18).

5.3.6. Preparation of *N*-propyl-3-methyl-4-(propylamino)methyl-3-pyrrolin-2-one (11). According to the general procedure, the rearrangement of **5** (0.22 g, 1 mmol) with *n*-propylamine (2 mL) at 80 °C for 16 h gave **11** (0.14 g, 68%) as a pale yellow oil; [found: C, 68.51; H, 10.58; N, 13.40. $C_{12}H_{22}N_2O$ requires C, 68.53; H, 10.54; N, 13.32]; IR (liquid film) 1681 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 0.80 (3H, t, J=7.5 Hz, N(1)$CH_2CH_2CH_3$), 0.81 (3H, t, J=7.5 Hz, NH$CH_2CH_2CH_3$), 1.40 (2H, m, NHCH_2-CH_2), 1.48 (2H, m, N(1)CH_2CH_2), 1.73 (3H, s, C(3)CH_3), 2.45 (2H, m, NHCH_2), 3.29 (2H, t, J=7.3 Hz, N(1)CH_2), 3.47 (2H, s, C(4)CH_2), 3.77 (2H, d, J=1.4 Hz, C(5)H_2); ^{13}C NMR (100 MHz, $CDCl_3$): δ 8.79 (C(3)CH_3), 11.18 (N(1)$CH_2CH_2CH_3$), 11.58 (NH$CH_2CH_2CH_3$), 21.78 (N(1)CH_2CH_2), 22.96 (NHCH_2CH_2), 43.72 (N(1)CH_2), 46.08 (C(3)CH_2), 51.58 (NHCH_2), 52.01 (*C*(5)), 130.08 (*C*(3)), 147.63 (*C*(4)), 172.18 (*C*(2)); MS (EI, 70 eV) *m*/*z*: 210 (1, M^+), 181 (4), 151 (100).

5.3.7. Preparation of *N*-propyl-3,4-dimethyl-5-propylimino-3-pyrrolin-2-one (12). According to the general procedure, the rearrangement of **6** (0.26 g, 1 mmol) with *n*-propylamine (2 mL) at 100 °C for 16 h gave **12** (52 mg, 25%) as an unseparable mixture of *E*/*Z* diastereoisomers (85/15); yellow oil; [found: C, 69.08; H, 9.71; N, 13.40. $C_{12}H_{20}N_2O$ requires C, 69.19; H, 9.68; N, 13.45]; IR (liquid film) 1656 cm^{-1} (C=N), 1718 cm^{-1} (C=O); ^1H NMR (400 MHz, $CDCl_3$): (*E*)-diastereoisomer (85%) δ 0.85 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.97 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.55 (2H, m, N(1)CH_2CH_2), 1.68 (2H, m, C=NCH_2CH_2), 1.89 (3H, q, J=1.1 Hz, C(3)CH_3), 2.16 (3H, q, J=1.1 Hz, C(4)CH_3), 3.52 (2H, t, J=7.2 Hz, N(1)CH_2), 3.72 (2H, t, J=6.8 Hz, C=NCH_2); (*Z*)-diastereoisomer (15%) δ 0.88 (3H, t, J=7.4 Hz, N(1)CH_2CH_2-CH_3), 0.98 (3H, t, J=7.3 Hz, C=N$CH_2CH_2CH_3$), 1.57 (2H, m, N(1)CH_2CH_2), 1.70 (2H, m, C=NCH_2CH_2), 1.87 (3H, m, C(3)CH_3), 1.93 (3H, q, J=1.1 Hz, C(4)CH_3), 3.66 (2H, m, C=NCH_2), 3.67 (2H, m, N(1)CH_2); ^{13}C NMR (100 MHz, $CDCl_3$): (*E*)-diastereoisomer (85%) δ 8.18 (C(3)CH_3), 11.33 (N(1)$CH_2CH_2CH_3$), 11.76 (C=NCH_2-CH_2CH_3), 14.40 (C(4)CH_3), 21.87 (N(1)CH_2CH_2), 25.45 (C=NCH_2CH_2), 39.70 (N(1)CH_2), 51.05 (C=NCH_2), 132.53 (*C*(3)), 136.65 (*C*(4)), 152.93 (*C*(5)), 171.01 (*C*(2)); (*Z*)-diastereoisomer (15%) δ 8.70 (C(3)CH_3), 9.51 (C(4)CH_3), 11.33 (N(1)$CH_2CH_2CH_3$), 11.76 (C=NCH_2-CH_2CH_3), 22.66 (N(1)CH_2CH_2), 25.35 (C=NCH_2CH_2), 43.11 (N(1)CH_2), 50.25 (C=NCH_2), 130.55 (*C*(3)), 139.42 (*C*(4)), 151.02 (*C*(5)), 170.81 (*C*(2)); MS (EI, 70 eV) *m*/*z*: 208 (100, M^+), 193 (43), 179 (73), 165 (53), 151 (83), 138 (48), 123 (22), 108 (48).

5.3.8. Preparation of *N*-propyl-3-chloro-4-methyl-5-propylimino-3-pyrrolin-2-one (13). According to the general procedure, the rearrangement of **7** (0.28 g, 1 mmol) with *n*-propylamine (2 mL) at −13 °C for 0.5 h gave **13** (0.15 g, 68%) as an unseparable mixture of *E*/*Z* diastereoisomers (89/11); orange oil; [found: C, 57.64; H, 7.56; N, 12.17. $C_{11}H_{17}ClN_2O$ requires C, 57.77; H, 7.49; N, 12.25]; IR (liquid film) 1657 cm^{-1} (C=N), 1734 cm^{-1} (C=O); ^1H NMR (400 MHz, $CDCl_3$): (*E*)-diastereoisomer (89%) δ 0.84 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.96 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.56 (2H, m, N(1)CH_2CH_2), 1.68 (2H, m, C=NCH_2CH_2), 2.27 (3H, s, C(4)CH_3), 3.56 (2H, t, J=7.2 Hz, N(1)CH_2), 3.72 (2H, t, J=6.8 Hz, C=NCH_2); (*Z*)-diastereoisomer (11%) δ 0.88 (3H, t, J=7.4 Hz, N(1)$CH_2CH_2CH_3$), 0.97 (3H, t, J=7.3 Hz, C=N$CH_2CH_2CH_3$), 1.56 (2H, m, N(1)CH_2CH_2), 1.68 (2H, m, C=NCH_2CH_2), 2.01 (3H, s, C(4)CH_3), 3.67 (2H, t, J=6.8 Hz, C=NCH_2), 3.70 (2H, t, J=7.7 Hz, N(1)CH_2); ^{13}C NMR (100 MHz, $CDCl_3$): (*E*)-diastereoisomer (89%) δ 11.18 (N(1)$CH_2CH_2CH_3$), 11.66 (C=N$CH_2CH_2CH_3$), 14.40 (C(4)CH_3), 21.72 (N(1)CH_2CH_2), 25.15 (C=NCH_2CH_2), 40.22 (N(1)CH_2), 51.31 (C=NCH_2), 132.55 (*C*(3)), 134.22 (*C*(4)), 149.71 (*C*(5)), 164.20 (*C*(2)); (*Z*)-diastereoisomer (11%) δ 9.89 (C(4)CH_3), 10.89 (N(1)$CH_2CH_2CH_3$), 11.66 (C=N$CH_2CH_2CH_3$), 23.56 (N(1)CH_2CH_2), 25.09 (C=NCH_2CH_2), 43.81 (N(1)CH_2), 50.58 (C=NCH_2), 127.0 (*C*(3)), 143.5 (*C*(4)), 147.5 (*C*(5)), 164.20 (*C*(2)); MS (EI, 70 eV) *m*/*z*: 228 (100, M^+), 213 (20), 199 (77), 185 (47), 171 (35), 158 (42), 151 (72), 145 (27), 128 (53).

5.3.9. Preparation of (*E*)-*N*-propyl-5-propylimino-pyrrolidin-2-one (14). According to the general procedure, the rearrangement of **7** (0.28 g, 1 mmol) with *n*-propylamine (2 mL) at 80 °C for 16 h gave **14** (80 mg, 44%) as an orange-yellow oil; [found: C, 65.78; H, 9.88; N, 15.41. $C_{10}H_{18}N_2O$ requires C, 65.90; H, 9.95; N, 15.37]; IR (liquid film) 1671 cm^{-1} (C=N), 1739 cm^{-1} (C=O); ^1H NMR (400 MHz, $CDCl_3$): δ 0.88 (3H, t, J=7.4 Hz, N(1)CH_2-CH_2CH_3), 0.92 (3H, t, J=7.4 Hz, C=N$CH_2CH_2CH_3$), 1.59

(2H, m, N(1)CH_2CH_2), 1.60 (2H, m, C=NCH_2CH_2), 2.53–2.57 (2H, m, C(3)H_2), 2.60–2.65 (2H, m, C(4)H_2), 3.22 (2H, t, J=6.9 Hz, C=NCH_2), 3.52 (2H, t, J=7.4 Hz, N(1)CH_2); ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.29 (N(1)$CH_2CH_2CH_3$), 11.83 (C=N$CH_2CH_2CH_3$), 20.45 (N(1)CH_2CH_2), 21.80 (*C*(4)), 24.27 (C=NCH_2CH_2), 28.29 (*C*(3)), 40.79 (N(1)CH_2), 51.47 (C=NCH_2), 158.73 (*C*(5)), 176.47 (*C*(2)); MS (EI, 70 eV) *m/z*: 182 (78, M^+), 167 (48), 153 (100), 139 (73), 125 (92), 112 (62), 99 (30), 83 (47), 68 (45), 54 (63), 41 (83).

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