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3-Alkenyl-5-chloropyrazoles: expedient synthesis via heterocyclization of 1,1-dichloro-4-halo-1-alken-3-ones with hydrazines

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ABSTRACT

Synthesis of hard-to-reach 5-chloro-3-alkenylpyrazoles was developed via heterocyclization of alkyl-, benzyl- or dialkylhydrazines with 1,1-dichloro-4-halo-1-alken-3-ones obtained from haloacyl chlorides and vinylidene chloride. The reaction process includes the formation of intermediate 5-chloro-3-(1-haloalkyl)pyrazoles followed by dehydrohalogenation.

1. Introduction

Pyrazoles are widely applicable as building blocks in novel syntheses of analgesic, antiphlogistic, antibacterial and antidepressant drugs,[1] insectoacaricides,[2] dyes, luminophores, ligands,[3] etc. Among the pyrazole functional derivatives, ethenylpyrazoles are of the utmost significance. Due to the presence of ethenyl moiety they can be successfully transformed into diverse representatives of pyrazoles, including polymers, polynuclear and annulated cycles. The known synthetic protocols for preparation of pyrazole derivatives are numerous and mainly based on the reactions of hydrazines with 1,3-dicarbonyl compounds, electron-deficient alkynes, functionally-substituted enones.[4] However, these methods are impracticable for the syntheses of alkenylpyrazoles. Thus, the development of methods for the expedient synthesis of alkenylpyrazoles is a problem of today.

The known approaches to 1-alkenylpyrazoles involve the direct vinylation of NH–pyrazoles with acetylenes in superbase systems[5,6] or in the presence of Lewis acids[7] and the alkylation reactions with dihaloalkanes followed by dehydrohalogenation.[8,9] The transformations of 4-chloroalkyl-, acyl- or formylpyrazoles are found to be the most appropriate methods to obtain 4-alkenylpyrazoles.[10] The syntheses of 3- and 5-alkenylpyrazoles are limited by the availability of the starting alkenyl- or haloalkyl 1,3-dicarbonyl compounds whose reactions with hydrazines give either the target structures or the 3(5)-haloalkylpyrazoles as their precursors.[11] Anyway, these processes are not chemoselective and mainly result in a mixture of 3- and 5-substituted products. As for 3- and 5-vinylpyrazoles, the cross-coupling reactions of 5-halopyrazoles with ethenes[12] or the reactions of 5-metallated pyrazoles with vinylhalogenides[13] are very promising approaches. These methods are of limited utility in the synthesis of 3-alkenylpyrazoles due to the less availability of corresponding 3-halo- and 3-metallated pyrazoles.[12,13] That is why the synthesis of 3-vinylpyrazoles from sydnones[14,15] is still a significant method though the target compounds are obtained in low yield (~21%) as a mixture with an unidentified hydrocarbon. The synthesis of 3-vinylpyrazole by thermal decomposition of polycyclic pyrazoline is also known.[16]

Reactivity of alkenylpyrazoles has not thoroughly been investigated though some reactions of polymerization,[17] complexing,[18] cycloaddition[19] and amidoalkylation[14] have been described. It should be particularly emphasized that 3-alkenylpyrazoles are both hard-to-synthesized and poorly studied.

2. Results and discussion

Herein we report on a convenient approach to 3-alkenylpyrazoles based on dehydrohalogenation of 3-haloalkyl-pyrazoles obtained from 1,1-dichloro-4-halo-1-alken-3-ones and alkyl-,

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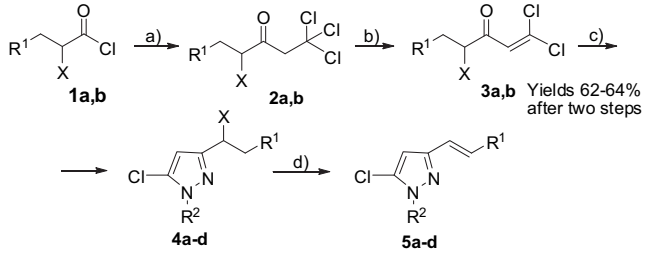
benzyl- or dialkylhydrazines. Before our investigations this methodology of 3-alkenylpyrazole synthesis has not been discussed. Probably, the reasons are a scarce information on 1,4-polyhalo-1-en-3-ones (only chloromethyl, chloroethyl, dichloroethyl and trifluoromethyl derivatives are known[20,21]) and the lack of systematic studies upon the reactions of 2,2-dihaloenones with hydrazines except our publications.[22]

We carried out the reactions of corresponding acylchlorides **1a**–**d** with vinylidene chloride using conditions[23,24] to synthesize earlier unknown 1,1,1-trichloro-4-haloalkane-3-ones **2** and 1,1-dichloro-4-haloalk-1-en-3-ones **3** as precursors of the target pyrazoles (Schemes 1–3).

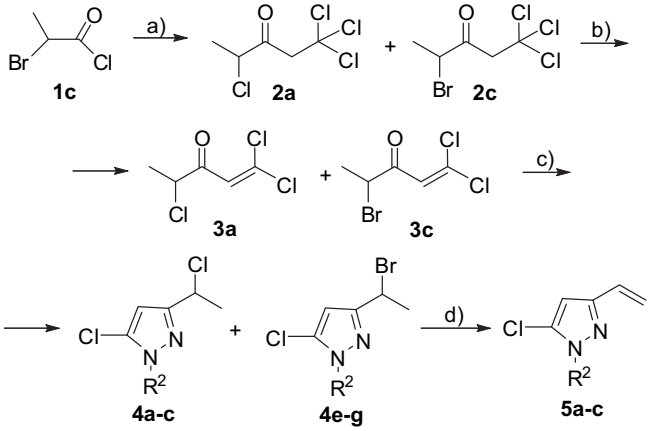


1-3: X = Cl, R^1 = H (**a**), X = Br, R^1 = Me (**b**)

4: X = Cl, R^1 = H, R^2 = Me (**a**), Et (**b**), Bn (**c**), X = Br, R^1 = Me, R^2 = Bn (**d**)

5: R^1 = H, R^2 = Me (**a**), Et (**b**), Bn (**c**), R^1 = Me, R^2 = Bn (**d**)

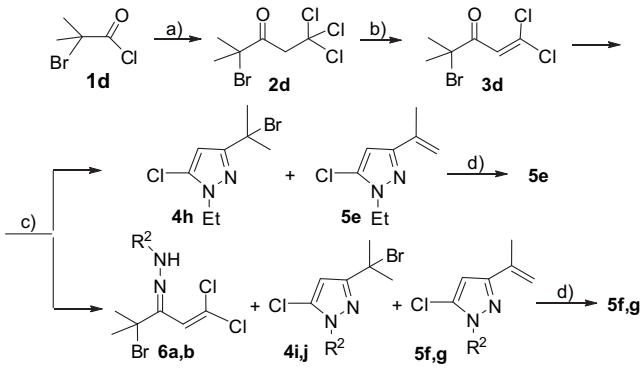
Scheme 1. Synthesis of pyrazoles **5a**–**d** from acylchlorides **1a**,**b**. Reaction conditions: (a) **1a**,**b** (100 mmol), vinylidene chloride (120 mmol), $AlCl_3$ (100 mmol), CH_2Cl_2 (250 mL), from −5 °C to rt for 10 h; (b) **2a**,**b** (100 mmol), Et_3N (100 mmol), Et_2O (200 mL), from −5 °C to rt, for 20 min at rt; (c) **3a**,**b** (50 mmol), H_2N–NMe_2 (100 mmol) or H_2N–NHR^2 (50 mmol), Et_3N (50 mmol), Et_2O (150 mL), rt, 5 h; (d) pyrazole **4** (50 mmol), DMF (20 mL), MW (800 W), 10–30 min.



R^2 = Me (**4a,e,5a**),E t (**4b,f,5b**),Bn (**4c,g,5c**)

Scheme 2. Synthesis of pyrazoles **5a**–**c** from 2-bromopropanoyl chloride **1c**. Reaction conditions: (a) **1c** (100 mmol), vinylidene chloride (120 mmol), $AlCl_3$ (100 mmol), CH_2Cl_2 (200 mL), from −5 °C to rt for 10 h; (b) mixture of **2a** and **2c**, obtained from (a), Et_3N (100 mmol), Et_2O (200 mL), from −5 °C to rt, 20 min at rt; (c) mixture of **3a** and **3c**, obtained from (b), H_2N–NMe_2 (200 mmol) or H_2N–NHR^2 (100 mmol), Et_3N (100 mmol), Et_2O (200 mL), rt, 5 h; (d) mixture of **4a**–**c** and **4e**–**g**, obtained from (c), DMF (20 mL), MW (800 W), 10 min.

Intermediate ketones **2** were shown to be unstable under storage or distillation. So, to increase yield and to simplify the experiment ketones **2a**,**b** (see Scheme 1) or the mixtures of **2a** and **2c** obtained (see Scheme 2) were subjected to dehydrochlorination with triethylamine without separation and isolation in a pure form. It must be emphasized that selective dehydrohalogenation of the trichloroethyl moiety was achieved only in the presence of



R^2 = Pr (**4i, 5f, 6a**), Bn (**4j, 5g, 6b**)

Scheme 3. Synthesis of pyrazoles **5e**–**g** from 2-bromo-2-methylpropanoyl chloride **1d**. Reaction conditions: (a) **1d** (100 mmol), vinylidene chloride (120 mmol), $AlCl_3$ (100 mmol), CH_2Cl_2 (200 mL), from −5 °C to rt for 10 h; (b) **2d** (100 mmol), Et_3N (100 mmol), Et_2O (200 mL), from −5 °C to rt, 20 min at rt; (c) **3d** (100 mmol), H_2N–NHR^2 (100 mmol), Et_3N (100 mmol), Et_2O (200 mL), rt, 5 h; (d) mixture of compounds from (c) without separation, DMF (20 mL), MW (800 W), 15–20 min.

triethylamine as a base. When we carried out dehydrohalogenation of **2a**–**c** under conditions[20,23,24] (inorganic bases or steam distillation) side reactions and substitution of halogen atoms took place.

Reactions of *N*,*N*-dimethylhydrazine, alkyl- or benzylhydrazines with 1,1-dichlorovinylketones **3a**,**b** proceeded at room temperature and resulted in 3-(1-haloalkyl)-5-chloropyrazoles **4a**–**d** (see Scheme 1). Triethylamine (1 equiv) as an additional base was found to increase the yield of pyrazoles **4a**–**d**.

The formation of **4a**–**d** was shown to proceed chemospecifically, so, neither the isomeric 3-chloro-5-(haloalkyl)pyrazoles nor products of nucleophilic substitution of halogen atoms in haloketones **3a**,**b** with hydrazine were identified. Apparently, the process went through heterocyclization of intermediate hydrazones, as in the case of earlier studied[22] reactions of hydrazines with 1,1-dichloroalk-1-en-3-ones.

To find optimal conditions for 3-alkenylpyrazoles **5** formation we studied dehydrochlorination of pyrazole **4c** as an example (Table 1).

Table 1
Optimization of the reaction conditions for the dehydrochlorination process of 3-haloalkylpyrazole **4** by the example of **4c** (R^1=H, R^2=Bn)

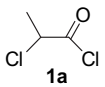
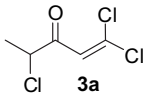
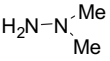
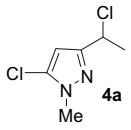
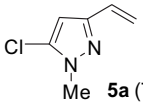
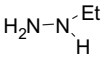
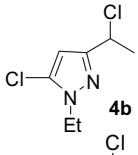
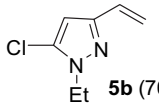
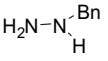
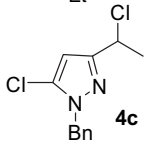
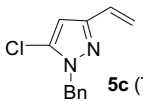
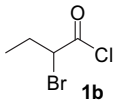
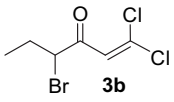
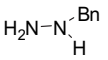
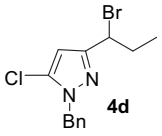
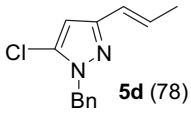
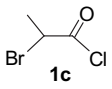
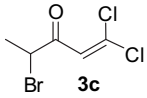
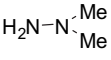
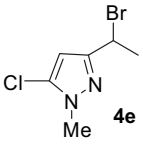
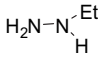
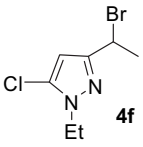
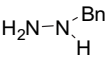
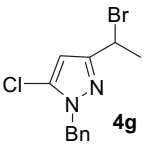
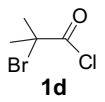
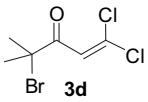
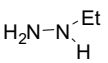
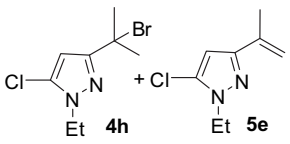
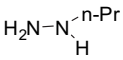
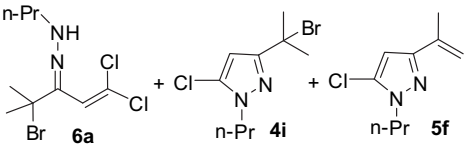
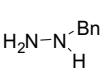
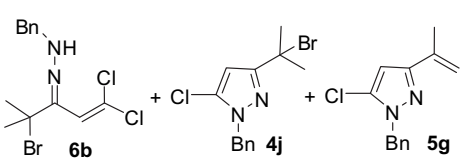
Entry	Conditions[a]	Time	Conversion of **4c**, %	Yield of **5c**, %
1	Et_3N (1 equiv), Et_2O, 35 °C	50 h	0	0
2	NaOH (1 equiv), DMSO, 80–90 °C	30 h	50	3
3	DMF, 120–130 °C	20 h	50	25
4	No solvent, 150–200 °C	1 h	100	10[b]
5	DMSO, MW[c]	10 min	100	12[b]
6	HMPA, MW[c]	10 min	100	18[b]
7	DMF, MW[c]	10 min	100	72

[a] 3-Haloalkylpyrazole **4c** (50 mmol), 20 mL of solvent.
[b] Intensive resinification took place.
[c] Microwave activation, maximum power level 800 W.

Thermolysis or base treatment (KOH, NaOH, triethylamine) of **4c** resulted in mixture containing starting pyrazole **4c**, target 3-alkenylpyrazole **5c**, and products of resinification. When aqueous alkalines were used, hydrolytic processes were observed. Chloroalkylpyrazole **4c** was established to be dehydrohalogenated under microwave irradiation in DMF as a solvent. In the same manner the corresponding 3-alkenylpyrazoles **5a**–**d** were obtained in 70–78% yield (Table 2).

There were no great distinctions in reactivity between chloro- and bromoalkylpyrazoles **4a**–**j**. Though, dehydrobromination took less time than dehydrochlorination.

Table 2
Reagents, intermediate products **3**, **4**, **6** and target 3-alkenylpyrazoles **5**

Entry	Starting haloacyl chlorides **1**	Intermediate ketones **3**	Hydrazines	Products of the reaction of **3** with hydrazines	Resulting alkenylpyrazoles **5** (yield, %)
1	 **1a**	 **3a**		 **4a**	 **5a** (72)
2	**1a**	**3a**		 **4b**	 **5b** (70)
3	**1a**	**3a**		 **4c**	 **5c** (72)
4	 **1b**	 **3b**		 **4d**	 **5d** (78)
5	 **1c**	**3a** +  **3c**		**4a** +  **4e**	**5a** (75)
6	**1c**	**3a**+**3c**		**4b** +  **4f**	**5b** (73)
7	**1c**	**3a**+**3c**		**4c** +  **4g**	**5c** (78)
8	 **1d**	 **3d**		 **4h** **5e**	**5e** (68)
9	**1d**	**3d**		 **6a** **4i** **5f**	**5f** (65)
10	**1d**	**3d**		 **6b** **4j** **5g**	**5g** (92)

The reaction of 2-bromopropanoyl chloride **1c** with vinylidene chloride in the presence of $AlCl_3$ was accompanied by bromine substitution with a chlorine atom and resulted in a mixture of chloroethyl and bromoethyl 2,2-dichlorovinylketones **2a** and **2c** (Scheme 2). A similar substitution in chloroalkanes under the action of $AlBr_3$ is known.[22g,25]

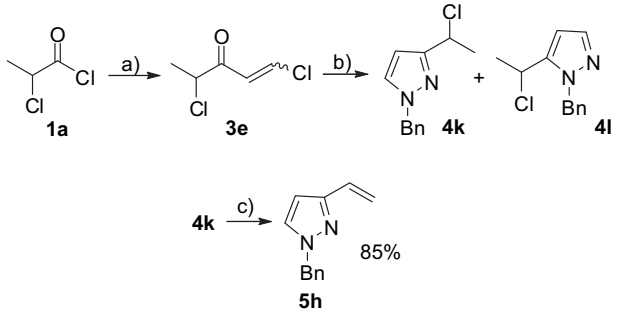
There was no necessity to separate **2a** and **2c** from the mixture obtained. The further reaction with hydrazines resulted in mixtures of 3-(1-chloroethyl)pyrazoles **4a**–**c** and 3-(1-bromoethyl)pyrazoles **4e**–**g**, which gave the same corresponding 3-vinylpirazoles **5a**–**c** after dehydrohalogenation.

4-Bromo-1,1-dichloro-4-methylpent-1-en-3-one **3d** obtained from 2-bromo-2-methylpropanoyl chloride **1d** was shown to form mixtures of products irrespective of the structure of the hydrazine (Scheme 3). Heterocyclization with ethylhydrazine resulted in 3-(1-bromo-1-methylethyl)-5-chloro-1-ethylpyrazole **4h** and target 5-chloro-1-ethyl-3-(1-methylethenyl)pyrazole **5e** as a mixture.

Propyl- or benzylhydrazine under the same conditions reacted with ketone **3d** to give mixtures of 3-(1-bromo-1-methylethyl)-5-chloropyrazoles **4i**,**j** target alkenylpyrazoles **5f**,**g** and corresponding intermediate hydrazones **6a**,**b**, which confirmed the pathway of pyrazole ring formation.

Further conversion of the mixtures obtained into the target 3-alkenylpyrazoles **5e**–**g** was achieved under microwave irradiation during 15–30 min. Intermediate 3-(1-bromoalkyl)pyrazoles **4h**–**j** and hydrazones **6a**,**b** without isolation were fully transformed into corresponding 3-(*iso*-propenyl)pyrazoles **5e**–**g** in 65–92% yield (See Table 2).

1,4-Dichloropent-1-en-3-on **3e** was synthesized by the reaction of 2-chloropropionyl chloride **1a** with acetylene.[25] Heterocyclization of **3e** with benzylhydrazine led to a mixture of 1-benzyl-3-(1-chloroethyl)- and 1-benzyl-5-(1-chloroethyl)pyrazoles **4k**,**l** in the ratio ≈7:1 (Scheme 4). Only 3-chloroethylpyrazole **4k** was isolated in pure form by column chromatography. Dehydrochloration of **4k** was carried out under microwave activation during 20 min to give 3-vinylpyrazole **5h** in 85% yield.

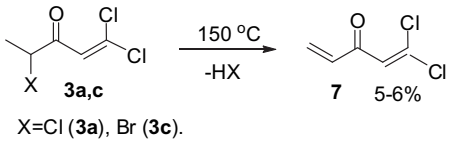


Scheme 4. Reaction of 1,4-dichloro-1-penten-3-one with benzylhydrazine; (a) **1a** (50 mmol), C_2H_2 (200 mmol), $AlCl_3$ (50 mmol), CH_2Cl_2 (200 mL), from 0 °C to rt for 10 h; (b) **3e** (50 mmol), H_2N–NHBn (50 mmol), Et_3N (50 mmol), Et_2O (100 mL), −60 °C 1 h, rt, 4 h; (c) pyrazole **4k** (50 mmol), DMF (20 mL), MW (800 W), 30 min.

Ketones **2**, **3** synthesized are lachrymatory liquids, very soluble in organic solvents and stable only in the cold (−10 to 0 °C). In the IR spectra of **3**, there are intensive absorption bands of C=C and =C–H bonds, and C=O groups. In ^{1}H NMR spectra of **3**, there are singlets of dichlorovinyl fragments in 6.82–7.24 ppm, similar to the chemical shift for alkyl- or aryl-2,2-dichlorovinylketones.[22j] The ^{13}C NMR spectra confirms the structures proposed.

We observed the formation of 1,1-dichloro-1,4-pentadien-3-one **7** in 5–6% yield during the distillation of **3a**,**c** even at reduced pressure (Scheme 5).

Ketone **7** also was produced as a side product when intermediate trichloroethylketones **2a**,**c** underwent dehydrochloration by other method.[26]



Scheme 5. The formation of 1,1-dichloro-1,4-pentadien-3-one **7**.

Unfortunately, we failed to synthesize haloenones by reactions of 3-halopropionyl chlorides with acetylene or 1,1- and 1,2-dichloroethenes when the known procedures[21,22f,24,26] were employed. When we used the conditions[27,28] the starting 3-halopropionyl chlorides underwent dehydrohalogenation to give acryloyl chloride followed by its oligomerization. We failed also to isolate pyrazoles after reaction of divinylketone **7** with alkyl- or dialkylhydrazines. NMR and MS data pointed to the formation of complicated mixtures. And research on synthesis of pyrazole derivatives from ketone **7** is to be continued.

Pyrazoles **4**, **5** obtained are liquids or colourless crystals with a moldy smell, they are stable in the cold (−10 to 0 °C). During a months storage at room temperature, 3-vinylpyrazoles **5** are spontaneously transformed into transparent polymers.

The structures of alkenylpyrazoles **5** were proved by MS, IR and NMR methods and elemental analysis.

Absorption bands of alkenyl groups and characteristic narrow bands of C^4H pyrazole bonds in 3120–3130 cm^{-1} were observed in IR spectra of 5-chloroalkenylpyrazoles **5**.

^{1}H and ^{13}C NMR spectra agreed with the structures proposed. The mixture of pyrazoles **4k**,**l** was presented by two groups of signals corresponding to different moieties in the position 5 or 3 and by pyrazole ring proton signals.

3. Conclusions

We have developed a convenient method for synthesis of earlier unknown and hard-to-reach 3-alkenyl-5-chloropyrazoles from available reagents. The method consists of dehydrohalogenation of 3-(1-chloroalkyl)- or 3-(1-bromoalkyl)-5-chloropyrazoles obtained by reaction of polyhaloenones with alkyl-, benzyl- or *N*,*N*-dialkylhydrazines.

Further investigations on the chemistry of 3-alkenylpyrazoles are of theoretical and practical importance for these substances are evident precursors of functionally-substituted pyrazole derivatives—promising biologically active substances, technically valued products, special-purpose polymers, etc.

4. Experimental section

4.1. General remarks

^{1}H and ^{13}C NMR spectra were recorded on a Bruker DPX-400 spectrometer (400.13 and 100.61 MHz, respectively) for solutions in $CDCl_3$. Chemical shifts (δ) in parts per million are reported with use of the residual chloroform (7.25 for ^{1}H and 77.2 for ^{13}C) as internal standard. IR spectra were recorded on a Bruker IFS spectrophotometer. MS analyses were recorded on a Shimadzu GC–MS-QP5050A instrument (ionization potential 70 eV). MW activation was carried out with a CEM Discover *S*-class oven at the wattage indicated.

4.2. Reactions of haloacyl chlorides 1a–d with vinylidene chloride. General procedure for the synthesis of 1,1-dichloro-4-haloalken-3-ones (3a–d)

A solution of a haloacylchloride (100 mmol) in CH_2Cl_2 (200 mL) and $AlCl_3$ (100 mmol, 13.33 g) was shaken for 15–20 min at −5 °C.

Then vinylidene chloride (120 mmol, 11.63 g) was added dropwise over a period of 20 min to avoid the temperature exceeding of 0 °C. After that, the reaction mass was stirred for 5 h at 0 °C and 4 h at rt, poured upon ice. An organic layer was separated and a water layer was extracted with CH_2Cl_2 (3×100 mL). The organic layer combined with the extract was dried over $CaCl_2$ and evaporated under reduced pressure. The residual mass was dissolved in diethyl ether (200 mL), treated with triethylamine (100 mmol, 10.10 g) at −5 °C for 10 min and kept at rt for 20 min, filtered, washed with water (100 mL), dried over $CaCl_2$ and evaporated. The crude product was distilled in vacuum.

*4.2.1. 1,1,4-Trichloropent-1-en-3-one (**3a**).* Colourless liquid, bp 102–104 °C (15 mm Hg), 12.02 g, 64% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.01 (s, 1H, =CH), 4.38 (q, $^3J_{H,H}$=6.8 Hz, 1H, CHCl), 1.62 (d, $^3J_{H,H}$=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=189.3 (C=O), 139.2 (CCl_2), 122.3 (=CH), 58.7 (CHCl), 19.8 (Me); IR (film): 3057, 2986, 2935, 2869, 1739, 1710, 1574 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 186 (M^+, 3), 155 (5), 151 (8), 127 (12), 125 (70), 123 (100), 95 (16), 63 (28), 60 (31); calcd $C_5H_5Cl_3O$ (187.452): C 32.04, H 2.69, Cl 56.74. Found C 32.02, H 2.68, Cl 56.78.

*4.2.2. 4-Bromo-1,1-dichlorohex-1-en-3-one (**3b**).* Light yellow liquid, bp 120–144 °C (15 mm Hg), 15.24 g, 62% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.92 (s, 1H, =CH), 4.21 (m, $^3J_{(H,H)}$=6.4 Hz, 1H, CH), 2.01 (m, $^3J_{(H,H)}$=6.4, 7.3 Hz, 2H, CH_2), 1.03 (t, $^3J_{(H,H)}$=7.3 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=188.4 (C=O), 138.8 (CCl_2), 123.1 (=CH), 56.0 (CHBr), 26.8 (CH_2), 12.1 (Me); IR (film): 3054, 2973, 2937, 2882, 2848, 1709, 1697, 1572 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 245 (M^+, <1), 211 (32), 209 (28), 127 (59), 125 (87), 123 (100), 95 (49), 55 (60), 41 (68). Elemental analysis calcd for $C_6H_7BrCl_2O$: C, 29.30; H, 2.87; Br, 32.49; Cl, 28.83. Found: C, 29.27; H, 2.86; Br, 32.53; Cl, 28.79.

*4.2.3. 4-Bromo-1,1-dichloropent-1-en-3-one (**3c**).* The compound **3c** was obtained as a mixture of **3a** (72% **3c** and 28% **3a**). The mixture was used for further synthesis without separation. Light yellow liquid, bp of the mixture 98–106 °C (12 mm Hg); yield of **3c** 46% (on NMR data); **3c** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.88 (s, 1H, =CH), 4.37 (q, $^3J_{(H,H)}$=6.8 Hz, 1H, CHBr), 1.77 (d, $^3J_{(H,H)}$=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)= 188.4 (C=O), 138.8 (CCl_2), 123.1 (=CH), 48.1 (CHBr), 19.7 (Me); MS (EI, 70 eV), *m*/z (%): 231 (M^+, <1), 196 (20), 195 (18), 127 (46), 125 (88), 123 (100), 95 (30), 60(68), 55 (25).

*4.2.4. 4-Bromo-1,1-dichloro-4-methylpent-1-en-3-one (**3d**).* Light yellow liquid, bp 104–106 °C (15 mm Hg), 16.73 g, 68% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.24 (s, 1H, =CH), 1.85 (s, 6H, 2Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=190.3 (C=O), 138.7 (CCl_2), 121.8 (=CH), 63.3 (CBr), 29.4 (Me); IR (film): 3063, 2994, 2979, 2930, 2896, 2864, 1701, 1571 cm^{-1}. Elemental analysis calcd for $C_6H_7BrCl_2O$: C, 29.30; H, 2.87; Br, 32.49; Cl, 28.83. Found: C, 29.31; H, 2.88; Br, 32.41; Cl, 28.80.

*4.2.5. 1,4-Dichloropent-1-en-3-one (**3e**).* A solution of 2-chloropropionyl chloride **1a** (50 mmol, 6.34 g) in CH_2Cl_2 (200 mL) was saturated with acetylene (200 mmol) for an hour and $AlCl_3$ (50 mmol, 13.33 g) was added such that the temperature remained below 0 °C. Acetylene was allowed to bubble through the mixture again and the reaction mass was stirred for 8 h at rt. Then the mixture was poured onto ice. An organic layer was separated and a water layer was extracted with CH_2Cl_2 (3×100 mL) dried over $CaCl_2$ and evaporated. The crude product was distilled in vacuum. Colourless liquid, 4.09 g, 54% yield (Yield 55%[26a]). The *E*/*Z* isomer ratio ≈1:1. *E* isomer: ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.45 (d, $^3J_{(H,H)}$=13.3 Hz, 1H, =CHCl), 6.89 (d, $^3J_{(H,H)}$=13.3 Hz, 1H, =CH), 4.43 (q, $^3J_{(H,H)}$=6.8 Hz, 1H, CHCl), 1.63 (d, $^3J_{(H,H)}$=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz,) δ (ppm)=191.1 (C=O), 139.2 (=CHCl), 127.9 (=CH), 58.6 (CHCl), 19.8 (Me); *Z* isomer: ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.78 (s, 2H, =CH, =CHCl), 4.48 (q, $^3J_{(H,H)}$=6.8 Hz, 1H, CHCl), 1.61 (d, $^3J_{(H,H)}$=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=191.6 (C=O), 133.1 (=CHCl), 124.1 (=CH), 57.5 (CHCl), 19.7 (Me); IR (film): 3077, 2986, 2935, 1704, 1587 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 152 (M^+, 6), 115 (40), 99 (63), 79 (100), 77 (53), 63 (11), 51 (9). Elemental analysis calcd for $C_5H_6Cl_2O$: C, 39.25; H, 3.95; Cl, 46.34. Found C, 39.21; H, 3.97; Cl, 46.30.

4.3. Reactions of 1,1-dichloro-4-haloalken-3-ones 3a–d with hydrazines

A hydrazine (50 mmol) and triethylamine (50 mmol, 5.05 g) were added dropwise to a solution of dichlorovinylketones **3a**–**d** (50 mmol) or to the mixture of **3a** and **3c** in diethyl ether (150 mL) for 20 min. In the synthesis of *N*-methylpyrazoles **4a**,**e** 2 equiv of dimethylhydrazine was used instead of triethylamine. On completion of the exotherm, the reaction mixture was stirred for 5 h and poured into water (150 mL). The organic layer was separated and the water layer was extracted with diethyl ether (3×50 mL). The organic layer combined with the extract was dried over $CaCl_2$, filtered off. After evaporating of diethyl ether individual pyrazoles **4a**–**d** or mixtures of **4**, **5**, **6** usable for further purposes without additional purification were obtained.

*4.3.1. 5-Chloro-3-(1-chloroethyl)-1-methylpyrazole (**4a**).* Colourless liquid, bp 100–102 °C (15 mm Hg), 7.15 g, 80% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.19 (s, 1H, H-4), 4.94 (q, *J*=6.9 Hz, 1H, CHCl), 3.75 (s, 3H, NMe), 1.77 (d, *J*=6.9 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=153.3 (C-3), 127.9 (C-5), 102.5 (C-4), 51.9 (CHCl), 36.2 (NMe), 24.7 (Me); IR (film): 3135, 2980, 2920, 2873, 1640, 1510 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 178 (M^+, 22), 163 (12), 145 (53), 143 (100), 128 (4), 117 (4), 107 (16), 81 (19), 66 (18), 54 (27), 42 (29). Elemental analysis calcd for $C_6H_8Cl_2N_2$: C, 40.25; H, 4.50; Cl, 39.60; N, 15.65. Found: C, 40.21; H, 4.51; Cl, 39.82; N, 15.61.

*4.3.2. 5-Chloro-3-(1-chloroethyl)-1-ethylpyrazole (**4b**).* Colourless liquid, bp 110–112 °C (15 mm Hg), 7.53 g, 78% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.21 (s, 1H, H-4), 5.04 (q, *J*=6.9 Hz, 1H, CHCl), 4.09 (q, *J*=7.3 Hz, 2H, NCH_2), 1.78 (d, *J*=6.9 Hz, 3H, Me), 1.35 (t, *J*=7.3 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)= 153.4 (C-3), 127.0 (C-5), 102.5 (C-4), 52.1 (CHCl), 41.7 (NCH_2), 24.9 (Me), 15.0 (Me); IR (film): 3135, 2982, 2925, 2873, 1638, 1511 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 192 (M^+, 39), 158 (68), 157 (100), 130 (59), 129 (88), 93 (25), 73 (19), 67 (44), 52 (30). Elemental analysis calcd for $C_7H_{10}Cl_2N_2$: C, 43.55; H, 5.22; Cl, 36.72; N, 14.51. Found: C, 43.60; H, 5.20; Cl, 36.75; N, 14.50.

*4.3.3. 1-Benzyl-5-chloro-3-(1-chloroethyl)-pyrazole (**4c**).* Colourless liquid, bp 130–132 °C (15 mm Hg), 10.99 g, 86% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.28–7.14 (m, 5H, C_6H_5), 6.27 (s, 1H, H-4), 5.23 (s, 2H, NCH_2), 5.06 (q, *J*=6.9 Hz, 1H, CHCl), 1.79 (d, *J*=6.9 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=153.9 (C-3), 135.8 (C′-1), 128.8 (C′-3,5), 128.0 (C′-4), 127.8 (C-5), 127.4 (C′-2,6), 103.0 (C-4), 52.9 (NCH_2), 52.0 (CHCl), 24.8 (Me); IR (film): 3141, 3089, 3064, 3032, 2981, 2931, 2875, 1694, 1514 cm^{-1}. Elemental analysis calcd for $C_{12}H_{12}Cl_2N_2$: C, 56.49; H, 4.74; Cl, 27.79; N, 10.98. Found: C, 56.44; H, 4.74; Cl, 27.75; N, 11.00.

*4.3.4. 1-Benzyl-3-(1-bromopropyl)-5-chloropyrazole (**4d**).* Light yellow liquid, bp 148–150 °C (3 mm Hg), 12.22 g, 78% yield; ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.30–7.14 (m, 5H, C_6H_5), 6.27 (s, 1H, H-4), 5.26 (s, 2H, NCH_2), 4.90 (t, *J*=7.2, 7.4 Hz, 1H, CHBr), 2.17 (m, *J*=7.2, 7.4 Hz, 2H, CH_2), 1.00 (t, *J*=7.2 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$,

100.61 MHz) δ (ppm)=153.6 (C-3), 135.9 (C′-1), 128.9 (C′-3,5), 128.1 (C′-4), 128.0 (C-5), 127.4 (C′-2,6), 103.7 (C-4), 53.0 (CHBr), 49.3 (NCH_2), 32.3 (CH_2), 12.8 (Me); IR (film): 3134, 3089, 3065, 3032, 2971, 2934, 2875, 1511, 1497 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 233 ([M−Br]$^+$, 10), 232 (25), 91 (100), 65 (33), 51 (13). Elemental analysis calcd for $C_{13}H_{14}BrClN_2$: C, 49.79; H, 4.50; Br, 25.48; Cl, 11.30; N, 8.93. Found: C, 49.71; H, 4.53; Br, 25.58; Cl, 11.22; N, 8.86.

*4.3.5. 3-(1-Bromoethyl)-5-chloro-1-methylpyrazole (**4e**).* The compound **4e** was obtained with admixture of **4a** (69% **4e** and 31% **4a**). The mixture was used for further synthesis without separation. Light yellow liquid, bp of the mixture 110–112 °C (15 mm Hg), yield of **4e** (57%) (based on NMR data); **4e** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.26 (s, 1H, H-4), 5.16 (q, *J*=6.9 Hz, 1H, CHBr), 3.78 (s, 3H, NMe), 1.99 (d, *J*=6.9 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=153.8 (C-3), 128.1 (C-5), 102.9 (C-4), 41.4 (CHBr), 36.3 (NMe), 25.5 (Me); IR (film): 3135, 2979, 2929, 2875, 1649, 1639, 1510 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 223 (M$^+$, 2), 141 (63), 143 (100), 128 (6), 107 (21), 81 (27), 67 (23), 54 (38), 42 (35).

*4.3.6. 3-(1-Bromoethyl)-5-chloro-1-ethylpyrazole (**4f**).* The compound **4f** was obtained with as a mixture of **4b** (70% **4f** and 30% **4b**). The mixture was used for further synthesis without separation. Light yellow liquid, bp of the mixture 121–123 °C (15 mm Hg), yield of **4f** 58% (based on NMR data); **4f** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.25 (s, 1H, H-4), 5.17 (q, *J*=6.9 Hz, 1H, CHBr), 4.13 (q, *J*=7.3 Hz, 2H, NCH_2), 2.00 (d, *J*=6.9 Hz, 3H, Me), 1.39 (t, *J*=7.3 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=153.8 (C-3), 127.0 (C-5), 102.8 (C-4), 44.4 (CHBr), 41.7 (NCH_2), 25.6 (Me), 15.0 (Me); IR (film): 3134, 2981, 2937, 2882, 1656, 1510 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 237 (M$^+$, <1), 158 (62), 157 (100), 130 (48), 129 (86), 93 (19), 73 (11), 67 (35), 54 (22).

*4.3.7. 1-Benzyl-3-(1-bromoethyl)-5-chloropyrazole (**4g**).* The compound **4g** was obtained as a mixture of **4c** (77% **4g** and 23% **4c**). The mixture was used for further synthesis without separation. Light yellow liquid, bp of the mixture 173–175 °C (20 mm Hg), yield of **4g** 65% (based on NMR data); **4g** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=7.24–7.13 (m, 5H, C_6H_5), 6.23 (s, 1H, H-4), 5.19 (s, 2H, NCH_2), 5.06 (q, *J*=6.9 Hz, 1H, CHBr), 1.97 (d, *J*=6.9 Hz, 3H, Me); ^{13}C NMR (CCl_4, HMDS, 100.61 MHz) δ (ppm)=154.4 (C-3), 136.2 (C′-1), 129.1 (C′-3,5), 128.7 (C′-4), 127.9 (C′-2,6), 127.5 (C-5), 104.0 (C-4), 53.3 (NCH_2), 41.2 (CHBr), 25.8 (Me); IR (film): 3135, 3089, 3065, 3032, 2979, 2928, 2868, 1511, 1496 cm^{-1}.

*4.3.8. 3-(2-Bromopropan-2-yl)-5-chloro-1-ethylpyrazole (**4h**).* The compound **4h** was obtained as a mixture of 5-chloro-1-ethyl-3-(prop-1-en-2-yl)-pyrazole **5e** (80% **4h** and 20% **5e**). The mixture was used for further synthesis without separation. Light yellow liquid, yield of **4h** 62% (based on NMR data); **4h** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.06 (s, 1H, H-4), 4.07 (q, *J*=7.2 Hz, 2H, NCH_2), 1.42 (s, 6H, 2Me), 1.37 (t, *J*=7.2 Hz, 3H, Me); **5e** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.21 (s, 1H, H-4), 5.30, 4.94 (s, 2H, =CH_2), 4.07 (q, *J*=7.2 Hz, 2H, NCH_2), 2.01 (s, 3H, Me), 1.37 (t, *J*=7.2 Hz, 3H, Me).

*4.3.9. 3-(2-Bromopropan-2-yl)-5-chloro-1-propylpyrazole (**4i**).* The compound **4i** was obtained in mixture with 5-chloro-3-(prop-1-en-2-yl)-1-propylpyrazole **5e** and 1-(4-bromo-1,1-dichloro-4-methylpent-1-en-3-ylidene)-2-propylhydrazine **6a** (40% **4i**, 40% **5f** and 20% **6a**). The mixture was used for further synthesis without separation. Yellow liquid, yield of **4i** 30% (based on NMR data); **4i** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.06 (s, 1H, H-4), 3.99 (m, *J*=7.0 Hz, 2H, NCH_2), 1.84 (m, *J*=7.0, 7.4 Hz, 2H, CH_2), 1.42 (s, 6H, 2Me), 0.92 (m, *J*=7.4 Hz, 3H, Me); **5f** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.21 (s, 1H, H-4), 5.30, 4.94 (s, s, 2H, =CH_2), 3.99 (m, *J*=7.0 Hz, 2H, NCH_2), 2.01 (s, 3H, Me), 1.84 (m, *J*=7.0, 7.4 Hz, 2H, CH_2), 0.92 (m, *J*=7.4 Hz, 3H, Me); **6a** ^{1}H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.23 (s, 1H, =CH), 3.99 (m, *J*=7.4 Hz, 2H, NCH_2), 1.86 (s, 6H, 2Me), 1.84 (m, *J*=7.4 Hz, 2H, CH_2), 0.92 (m, *J*=7.4 Hz, 3H, Me); IR (film): 3330, 3095, 2985, 2930, 2875, 1620 cm^{-1}.

*4.3.10. 1-Benzyl-3-(2-bromopropan-2-yl)-5-chloropyrazole (**4j**).* The compound **4j** was obtained in mixture with 1-benzyl-5-chloro-3-(prop-1-en-2-yl)-pyrazole **5g** and 1-benzyl-2-(4-bromo-1,1-dichloro-4-methylpent-1-en-3-ylidene)hydrazine **6b** (33% **4j**, 50% **5g** and 17% **6b**). The mixture was used for further synthesis without separation. Yellow liquid, yield of **4j** 27% (based on NMR data); **4j** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.28–7.18 (m, 5H, C_6H_5), 6.17 (s, 1H, H-4), 5.29 (s, 2H, NCH_2), 1.53 (s, 6H, 2Me); **5g** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.28–7.18 (m, 5H, C_6H_5), 6.33 (s, 1H, H-4), 5.46, 5.06 (s, s, 2H, =CH_2), 5.31 (s, 2H, NCH_2), 2.08 (s, 3H, Me); MS (EI, 70 eV), *m*/z (%): 232 (M$^+$, 18); **6b** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.28–7.18 (m, 5H, C_6H_5), 6.32 (s, 1H, =CH), 5.26 (s, 2H, NCH_2), 1.92 (s, 6H, 2 Me); IR (film): 3335, 3090, 2979, 2930, 2875, 1630 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 268 ([M−HBr]$^+$, 16).

*4.3.11. Mixture of 1-benzyl-3-(1-chloroethyl)-pyrazole (**4k**) and 1-benzyl-5-(1-chloroethyl)-pyrazole (**4l**).* Benzylhydrazine (50 mmol, 6.11 g) and triethylamine (50 mmol, 5.06 g) were added dropwise to a solution of **3e** (50 mmol, 7.65 g) in diethyl ether (100 mL) for 20 min at −60 °C. The mixture was stirred for 1 h at −60 °C and for 4 h at rt, poured into water (150 mL). The organic layer was separated and the water layer was extracted with diethyl ether (3×50 mL). The organic layer combined with the extract was dried over $CaCl_2$, filtered off. After evaporating diethyl ether the mixture of **4k** and **4l** was obtained (yield 6.72 g (61%), 88% **4k** and 12% **4l**). The compound **4k** was separated from 1.10 g of the mixture by column chromatography (silica gel 230–400 mesh, Et_2O/hexane in ratio 1: 2). Colourless liquid, 0.60 g, 54% yield; **4k** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.37–7.21 (m, 5H, C_6H_5), 7.29 (d, *J*=2.2 Hz, 1H, H-5), 6.36 (d, *J*=2.2 Hz, 1H, H-4), 5.26 (s, 2H, NCH_2), 5.24 (q, *J*=6.8 Hz, 1H, CHCl), 1.91 (d, *J*=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=153.9 (C-3), 136.2 (C′-1), 130.3 (C-5), 128.8 (C′-3,5), 128.0 (C′-4), 127.6 (C′-2,6), 103.7 (C-4), 55.9 (NCH_2), 52.2 (CHCl), 25.0 (Me); **4l** ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.30–7.17 (m, 6H, C_6H_5, H-3), 6.33 (d, *J*=1.8 Hz, 1H, H-4), 5.25 (s, 2H, NCH_2), 4.93 (q, *J*=6.8 Hz, 1H, CHCl), 1.80 (d, *J*=6.8 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=143.1 (C-5), 138.6 (C-3), 136.8 (C′-1), 128.9 (C′-3,5), 127.9 (C′-4), 127.0 (C′-2,6), 104.8 (C-4), 53.5 (NCH_2), 47.5 (CHCl), 25.1 (Me).

4.4. General procedure for the synthesis of 3-alkenyl-5-chloropyrazoles (5a–h)

A solution of 3-haloalkylpyrazole **4a–d**, **4k** (50 mmol) or the mixtures of compounds **4a** and **4e**; **4b** and **4f**; **4c** and **4g** (obtained from 100 mmol of 2-bromopropanoyl chloride **1c**, Scheme 2) or the mixture of compounds **4h** and **5e**; **4i**, **5f** and **6a**; **4j**, **5g** and **6b** (obtained from 50 mmol of **3d**, Scheme 3) in DMF (20 mL) was exposed under MW irradiation (800 W) for 10–30 min. Then the reaction mixture was diluted with water (200 mL) and extracted with diethyl ether (3×50 mL). The extract was dried over $MgSO_4$ and filtered off. Diethyl ether was evaporated and a target 3-alkenylpyrazole was distilled in vacuum or recrystallized.

*4.4.1. 5-Chloro-1-methyl-3-vinylpyrazole (**5a**).* Colourless liquid, bp 79–82 °C (15 mm Hg), 5.16 g, 72% yield from **4a** (MW exposure for 30 min), 5.33 g, 75% yield from the mixture of **4a** and **4e** (MW exposure for 10 min); ^{1}H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.57 (dd, *J*=11.2, 17.7 Hz, 1H, CH=), 6.28 (s, 1H, H-4), 5.66 (dd, *J*=1.2, 17.7 Hz, 1H, =CH_2), 5.27 (dd, *J*=1.2, 11.2 Hz, 1H, =CH_2), 3.78 (s, 3H, Me); ^{13}C

NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=150.4 (C-3), 128.9 (=CH), 128.1 (C-5), 115.7 (=CH_2), 101.4 (C-4), 36.2 (Me); IR (film): 3132, 3091, 3018, 2944, 2852, 1638, 1505 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 142 (M^+, 100), 127 (5), 116 (6), 107 (38), 81 (58), 66 (23), 54 (26), 42 (12). Elemental analysis calcd for $C_6H_7ClN_2$: C, 50.54; H, 4.95; Cl, 24.86; N, 19.65. Found: C, 50.49; H, 4.93; Cl, 24.89; N, 19.61.

*4.4.2. 5-Chloro-1-ethyl-3-vinylpyrazole (**5b**).* Colourless liquid, bp 108–112 °C (15 mm Hg), 5.51 g, 70% yield from **4b** (MW exposure for 30 min), 5.72 g, 73% yield from the mixture of **4b** and **4f** (MW exposure for 10 min); ^1H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=6.55 (dd, *J*=10.9, 17.8 Hz, 1H, CH=), 6.24 (s, 1H, H-4), 5.61 (dd, *J*=1.0, 17.8 Hz, 1H, =CH_2), 5.23 (dd, *J*=1.0, 10.9 Hz, 1H, =CH_2), 4.09 (q, *J*=7.2 Hz, 2H, CH_2), 1.35 (t, *J*=7.2 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=150.4 (C-3), 129.0 (=CH), 127.0 (C-5), 115.5 (=CH_2), 101.3 (C-4), 44.2 (NCH_2), 15.0 (Me); IR (film): 3132, 3091, 2982, 2938, 2875, 1638, 1503 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 156 (M^+, 55), 141 (42), 128 (100), 114 (12), 105 (8), 93 (15), 67 (38), 52 (22). Elemental analysis calcd for $C_7H_9ClN_2$: C, 53.68; H, 5.79; Cl, 22.64; N, 17.89. Found: C, 53.62; H, 5.78; Cl, 22.66; N, 17.85.

*4.4.3. 1-Benzyl-5-chloro-3-vinylpyrazole (**5c**).* Colourless liquid, bp 140–145 °C (15 mm Hg), 7.87 g, 72% yield from **4c** (MW exposure for 30 min), 8.55 g, 78% yield from the mixture of **4c** and **4g** (MW exposure for 10 min); ^1H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)= 7.31–7.17 (m, 5H, C_6H_5), 6.61 (dd, *J*=11.0, 17.7 Hz, 1H, =CH), 6.33 (s, 1H, H-4), 5.67 (dd, *J*=1.0, 17.7 Hz, 1H, =CH_2), 5.29 (dd, *J*=1.0, 11.0 Hz, 1H, =CH_2), 5.27 (s, 2H, NCH_2); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=150.9 (C-3), 136.1 (C′-1), 129.1 (=CH, C-5), 128.9 (C′-3,5), 128.1 (C′-4), 127.5 (C′-2,6), 116.0 (=CH_2), 101.9 (C-4), 52.9 (NCH_2); IR (film): 3133, 3109, 3087, 3063, 3031, 3006, 2927, 2853, 1504 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 218 (M^+, 57), 183 (51), 91 (100), 77 (15), 65 (75), 51 (35). Elemental analysis calcd for $C_{12}H_{11}ClN_2$: C, 65.91; H, 5.07; Cl, 16.21; N, 12.81. Found: C, 65.90; H, 5.07; Cl, 16.25; N, 12.77.

*4.4.4. 1-Benzyl-5-chloro-3-(prop-1-enyl)-pyrazole (**5d**) (mixture of E and Z-isomers).* The ratio *E*/*Z* isomer ≈1:1. Colourless liquid, bp 187–190 °C (15 mm Hg), 9.06 g, 78% yield (MW exposure for 10 min); ^1H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.27–7.15 (m, 5H, C_6H_5), 6.31 (dd, 9.2, 15.7 Hz, 1H, CH=), 6.23–6.11 (m, *J*=6.3, 7.2, 9.2, 15.7 Hz, 1H, =CH), 6.23 (s, 1H, H-4), 5.24 (s, 2H, NCH_2), 1.93, 1.82 (d, d, *J*=6.3, 7.2 Hz, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)= 151.0 (C-3), 136.3 (C′-1), 128.8 (C′-3,5), 128.4 (=CH), 127.9 (C′-4), 127.5 (C-5), 127.4 (C′-2,6), 123.1 (=CH), 101.6 (C-4), 52.8 (NCH_2), 18.4 (Me); IR (film): 3134, 3111, 3088, 3065, 3032, 3008, 2962, 2935, 2913, 2878, 2851, 1511 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 232 (M^+, 58), 141 (21), 141 (22), 106 (8), 91 (100), 77 (12), 65 (68), 51 (32). Elemental analysis calcd for $C_{13}H_{13}ClN_2$: C, 67.10; H, 5.63; Cl, 15.23; N, 12.04. Found: C, 67.13; H, 5.62; Cl, 15.28; N, 12.04.

*4.4.5. 5-Chloro-1-ethyl-3-(prop-1-en-2-yl)-pyrazole (**5e**) (mixture of S-trans, S-cis conformers).* Colourless liquid, bp 124–128 °C (15 mm Hg), 5.82 g, 68% yield from the mixture **4h** and **5e** (MW exposure for 15 min); ^1H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)= 6.20, 6.17 (s, s, 2H, 2H-4), 5.29, 4.93 (s, s, 2H, =CH_2), 5.27, 4.92 (d, d, *J*=1.2 Hz, 2H, =CH_2), 4.08 (q, *J*=7.2 Hz, 4H, 2NCH_2), 2.02, 2.00 (s, s, 6H, 2Me), 1.38 (t, *J*=7.2 Hz, 3H, Me); ^{13}C NMR (CCl_4, HMDS, 100.61 MHz) δ (ppm)=152.2 (C-3), 137.3 (=C), 126.8 (C-5), 112.1 (=CH_2), 101.4 (C-4), 50.7 (NCH_2), 23.7, 20.1 (Me), 11.6 (Me); IR (film): 3131, 3081, 2981, 2946, 2885, 1635, 1506 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 170 (M^+, 100), 155 (24), 142 (48), 115 (21), 106 (12), 77 (10), 67 (14), 51 (11). Elemental analysis calcd for $C_8H_{11}ClN_2$: C, 56.31; H, 6.50; Cl, 20.78; N, 16.42. Found: C, 56.37; H, 6.51; Cl, 20.74; N, 16.40.

*4.4.6. 5-Chloro-3-(prop-1-en-2-yl)-1-propylpyrazole (**5f**).* Colourless liquid, bp 130–133 °C (15 mm Hg), 6.04 g, 65% yield from the mixture of **4i**, **5f** and **6a** (MW exposure for 15 min); ^1H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.20 (s, 1H, H-4), 5.31, 4.95 (s, s, 2H, =CH_2), 3.99 (t, *J*=7.0 Hz, 2H, NCH_2), 2.03 (s, 3H, Me), 1.84 (m, *J*=7.0, 7.4 Hz, 2H, CH_2), 0.91 (t, *J*=7.4 Hz, 3H, Me); ^{13}C NMR (CCl_4, HMDS, 100.61 MHz) δ (ppm)=152.3 (C-3), 137.2 (=C), 126.3 (C-5), 112.1 (=CH_2), 101.6 (C-4), 44.3 (NCH_2), 31.1 (CH_2), 20.2 (Me), 15.5 (Me); IR (film): 3132, 3088, 2969, 2878, 1635, 1506 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 184 (M^+, 4), 170 (100), 155 (19), 142 (34), 115 (16), 77 (9), 67 (14), 51 (11). Elemental analysis calcd for $C_9H_{13}ClN_2$: C, 58.67; H, 7.12; Cl, 19.00; N, 15.21. Found: C, 58.64; H, 7.10; Cl, 19.06; N, 15.19.

*4.4.7. 1-Benzyl-5-chloro-3-(prop-1-en-2-yl)-pyrazole (**5g**).* Light yellow solid, mp 44–46 °C (hexane), 10.73 g, 92% yield from the mixture of **4j**, **5g** and **6b** (MW exposure for 20 min); ^1H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.31–7.17 (m, 5H, C_6H_5), 6.33 (s, 1H, H-4), 5.43, 5.05 (s, s, 2H, =CH_2), 5.30 (s, 2H, NCH_2), 2.08 (s, 3H, Me); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=136.8 (=C), 136.4 (C′-1), 128.8 (C′-3,5), 127.9 (C′-4), 127.7 (C-5), 127.4 (C′-2,6), 112.6 (=CH_2), 102.2 (C-4), 53.0 (NCH_2), 19.9 (CH_3); IR (KBr): 3127, 3086, 3061, 3025, 2981, 2953, 2922, 1634, 1496 cm^{-1}; MS (EI, 70 eV), *m*/z (%): 232 (M^+, 65), 217 (19), 197 (31), 91 (100), 77 (9), 65 (68), 51 (19). Elemental analysis calcd for $C_{13}H_{13}ClN_2$: C, 67.10; H, 5.63; Cl, 15.23; N, 12.24. Found: C, 67.15; H, 5.66; Cl, 15.19; N, 12.25.

*4.4.8. 1-Benzyl-3-vinylpyrazole (**5h**).* White solid, mp 35–37 °C (hexane), 7.80 g, 85% yield (MW exposure for 30 min); ^1H NMR ($CDCl_3$, 400.13 MHz) δ (ppm)=7.26–7.11 (m, 5H, C_6H_5), 7.19 (d, *J*=2.0 Hz, 1H, H-5), 6.75 (dd, *J*=10.9, 17.9 Hz, 1H, =CH), 6.33 (d, *J*=2.0 Hz, 1H, H-4), 5.68 (dd, *J*=<1.0, 17.9 Hz, 1H, =CH_2), 5.22 (dd, *J*=<1.0, 10.9 Hz, 1H, =CH_2), 5.17 (s, 2H, NCH_2); ^{13}C NMR ($CDCl_3$, 100.61 MHz) δ (ppm)=151.0 (C-3), 136.5 (C′-1), 130.2 (C′-5), 129.3 (=CH), 128.7 (C′-3,5), 127.9 (C′-4), 127.5 (C′-2,4), 114.7 (=CH_2), 102.8 (C-4), 55.8 (NCH_2). Elemental analysis calcd for $C_{12}H_{12}N_2$: C, 78.22; H, 6.57; N, 15.21. Found: C, 78.27; H, 6.59; N, 15.20.

*4.4.9. 1,1-Dichloropenta-1,4-dien-3-one (**7**).* Compound **7** was isolated under distillation (>150 °C) of **3a** or mixture of **3a** and **3c**, bp 70–72 °C (25 mm Hg), 5–6% yield; ^1H NMR (CCl_4, HMDS, 400.13 MHz) δ (ppm)=6.82 (s, 1H, CH=CCl_2), 6.48, 6.43 (d, d, *J*=10.5, 17.4 Hz, 1H, =CH), 6.28 (d, *J*=17.4 Hz, *Z* isomer, 1H, =CH), 5.90 (d, *J*=10.5 Hz, 1H, *E* isomer, =CH); ^{13}C NMR (CCl_4, HMDS, 100.61 MHz) δ (ppm)=236.0 (C=O), 126.6, 124.2, 122.0 (=CH), 107.1 (=CCl_2); IR (film): 3077, 1704, 1587 cm^{-1}. Elemental analysis calcd for $C_5H_4Cl_2O$: C, 46.96; H, 2.67; Cl, 46.96. Found: C, 47.00; H, 2.65; Cl, 46.94.

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Supplementary data

Supplementary data includes NMR spectra of the products obtained. Supplementary data associated with this article can be found in online version at doi:10.1016/j.tet.2011.01.028. These data include MOL files and InChiKeys of the most important compounds described in this article.

References and notes

1. Elguero, J.; Goya, P.; Jagerovic, N.; Silva, A. M. S. In *Targets in Heterocyclic Systems. Chemistry and Properties*; Attanasi, O. A., Spinelli, D., Eds.; Italian Soc. Chem.; 2002; Vol. 6, pp 53–99.
2. Grapov, A. F. *Russ. Chem. Rev.* **1999**, *68*, 697–707.

3. Cristodoulou, S. A.; Kasiotis, K. M.; Fokialakis, N.; Tillitu, I.; Haroutounian, M. S. *Tetrahedron Lett.* **2008**, *49*, 7100–7102.
4. Martins, M. A. P.; Frizzo, C. P.; Moreira, D. N.; Buriol, L.; Machado, P. *Chem. Rev.* **2009**, *109*, 4140–4182 and references therein.
5. Jones, N.O. British Patent 887,365, 1962; *Chem. Abstr.* **1962**, *57*, 1077.
6. (a) Shagun, V. A.; Tarasova, O. A.; Trofimov, B. A. *Russ. J. Org. Chem. Engl. Transl.* **2006**, *42*, 1039–1044; (b) Trofimov, B. A.; Tarasova, O. A.; Shemetova, M. A.; Afonin, A. V.; Klyba, L. V.; Baikalova, L. V.; Mikhaleva, A. I. *Russ. J. Org. Chem. Engl. Transl.* **2003**, *39*, 408–414.
7. Tsuchimoto, T.; Aoki, K.; Wagatsuma, T.; Suzuki, Y. *Eur. J. Org. Chem.* **2008**, *23*, 4035–4040.
8. (a) Trofimenko, S. *J. Am. Chem. Soc.* **1970**, *92*, 5118–5126; (b) Trofimenko, S. *J. Org. Chem.* **1970**, *35*, 3459–3462.
9. (a) Attaryan, O. S.; Matsoyan, S. G.; Martirosyan, S. S. *Chem. Heterocycl. Compd.* **2005**, *41*, 452–455; (b) Iddon, B.; Tonder, J.; Hosseini, M.; Begtrup, M. *Tetrahedron* **2007**, *63*, 56–61; (c) Bogdal, D.; Jaskot, K. *Synth. Commun.* **2000**, *30*, 3341–3352.
10. (a) Finar, I. L.; Lord, J. H. *J. Org. Chem.* **1957**, *22*, 3314–3315; (b) Jones, R. A.; Gonzalez, B. A.; Argues, J. S.; Pardo, J. Q.; King, T. J. *J. Chem. Soc., Perkin Trans. 1* **1984**, 1423–1425; (c) Finar, I. L.; Saunders, K. J. *J. Chem. Soc., Perkin Trans. 1* **1963**, 3967–3970; (d) Bratenko, M. K.; Chornous, V. A.; Vovk, M. V. *Russ. J. Org. Chem. Engl. Transl.* **2002**, *38*, 411–414; (e) Bratenko, M. K.; Kadel'nik, J. V.; Chornous, V. A.; Vovk, M. V. *Russ. J. Org. Chem. Engl. Transl.* **2008**, *44*, 247–250.
11. (a) Tanitame, A.; Oyamada, Y.; Ofuji, K.; Suzuki, K.; Ito, H.; Kawasaki, M.; Wachi, M.; Yamagishi, J. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 2863–2866; (b) Dariusz, B.; Krzysztof, J. *Synth. Commun.* **2000**, *30*, 3341–3352.
12. (a) Wang, X.; Tan, J.; Grozinger, K. *Tetrahedron Lett.* **2000**, *41*, 4713–4717; (b) Collot, V.; Varlet, D.; Rault, S. *Tetrahedron Lett.* **2000**, *41*, 4363–4366.
13. Medio, S. M.; Alvarez, L. M. J.; Sepulveda, J. A. *J. Chem. Soc., Perkin Trans. 1* **1990**, 2749–2750.
14. Carrillo, J. R.; Diaz-Ortiz, A.; de la Hoz, A.; Gomez-Escaljnilla, M. J.; Moreno, A.; Pieto, P. *Tetrahedron* **1999**, *55*, 9623–9630.
15. Haneda, A.; Imagawa, T.; Kawanici, M. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 748–749.
16. Tomilov, Y. V.; Shulishov, E. V.; Kostitsyn, A. B.; Nefedov, O. M. *Russ. Chem. Bull.* **1994**, *43*, 612–618.
17. (a) Manecke, G.; Schenck, H. *Tetrahedron Lett.* **1969**, *10*, 617–619; (b) Han, L. M.; Timmons, R. B. *Chem. Mater.* **1998**, *10*, 1422–1429.
18. (a) Diaz-Requejo, M. M.; Belderrain, T. R.; Perez, P. J. *Chem. Commun.* **2000**, 1653–1656; (b) Gai, X.; Grigg, R.; Sridharan, R.; Collard, S.; Muir, J. E. *Chem. Commun.* **2000**, 2053–2054; (c) Skvortsova, G. G.; Eskova, L. A.; Domnina, E. S.; Voronov, V. K.; Olivson, A. I.; Chipanina, N. N.; Shulunova, A. M.; Mabarakshina, N. S. *Russ. J. Coord. Chem.* **1982**, *8*, 1629–1632.
19. (a) Diaz-Ortiz, A.; Carrillo, J. R.; Diez-Barra, E.; de la Hoz, A.; Gomez-Escalonilla, M.; Moreno, A.; Langa, F. *Tetrahedron* **1996**, *52*, 9237–9248; (b) Diaz-Ortiz, A.; de la Hoz, A.; Langa, F. *Green Chem.* **2000**, *2*, 165–172; (c) Simon, M. M.; Sepulveda, J. *Tetrahedron* **1986**, *42*, 6683–6686.
20. (a) Pohland, A. E.; Benson, W. R. *Chem. Rev.* **1966**, *66*, 161–197; (b) Levkovskaya, G. G.; Bozhenkov, G. V.; Mirskova, A. N. In *Selected Methods for Synthesis and Modification of Heterocycles*; Kartsev, V. G., Ed.; IBS: Moscow, 2003; Vol. 2, pp 207–227; (c) Moiseev, I. K.; Makarov, N. V.; Zemzova, M. N. *Izv. Vysshykh Uchebnykh Zavedeniy. Khimia i Khimicheskay Tekhnologia* **2007**, *59*, 3–17.
21. (a) Savosik, V. A.; Rudyakova, E. V.; Albanov, A. I.; Bozhenkov, G. V.; Levkovskaya, G. G. *Russ. J. Org. Chem. Engl. Transl.* **2009**, *45*, 617–618; (b) Bozhenkov, G. V.; Savosik, V. A.; Rudyakova, E. V.; Ha, K. Q.; Albanov, A. I.; Klyba, L. V.; Mirskova, A. N.; Levkovskaya, G. G. *Russ. J. Org. Chem. Engl. Transl.* **2008**, *44*, 1745–1751.
22. (a) Bozhenkov, G. V.; Savosik, V. A.; Mirskova, A. N.; Levkovskaya, G. G. *Russ. J. Org. Chem. Engl. Transl.* **2008**, *44*, 184–188; (b) Bozhenkov, G. V.; Savosik, V. A.; Larina, L. I.; Klyba, L. V.; Zhanchipova, E. R.; Mirskova, A. N.; Levkovskaya, G. G. *Russ. J. Org. Chem. Engl. Transl.* **2008**, *44*, 1014–1023; (c) Bozhenkov, G. V.; Savosik, V. A.; Larina, L. I.; Klyba, L. V.; Zhanchipova, E. R.; Mirskova, A. N.; Levkovskaya, G. G. *Russ. J. Org. Chem. Engl. Transl.* **2008**, *44*, 1195–1199; (d) Bozhenkov, G. V.; Levkovskaya, G. G.; Mirskova, A. N.; Larina, L. I. *Chem. Heterocycl. Compd.* **2005**, *7*, 1012–1019; (e) Bozhenkov, G. V.; Levkovskaya, G. G.; Larina, L. I.; Ushakov, P. E.; Dolgushin, G. V.; Mirskova, A. N. *Russ. J. Org. Chem. Engl. Transl.* **2004**, *40*, 1583–1592; (f) Bozhenkov, G. V.; Levkovskaya, G. G.; Mirskova, A. N.; Dolgushin, G. V.; Larina, L. I.; Ushakov, P. E. *Russ. J. Org. Chem. Engl. Transl.* **2003**, *39*, 1069–1075; (g) Bozhenkov, G. V.; Frolov, Y. L.; Toryashinova, D. S. D.; Levkovskaya, G. G.; Mirskova, A. N. *Russ. J. Org. Chem. Engl. Transl.* **2003**, *39*, 807–813; (h) Bozhenkov, G. V.; Levkovskaya, G. G.; Mirskova, A. N. *Russ. J. Org. Chem. Engl. Transl.* **2002**, *38*, 134–135; (i) Levkovskaya, G. G.; Bozhenkov, G. V.; Larina, L. I.; Mirskova, A. N. *Russ. J. Org. Chem. Engl. Transl.* **2002**, *38*, 1501–1506; (j) Levkovskaya, G. G.; Bozhenkov, G. V.; Larina, L. I.; Evstaf'eva, I. T.; Mirskova, A. N. *Russ. J. Org. Chem. Engl. Transl.* **2001**, *37*, 644–648.
23. (a) Ioffe, B. V.; Zelenina, N. L. *Chem. Heterocycl. Compd.* **1973**, *6*, 1321–1325; (b) Nesmeyanov, A. N.; Kochetkov, N. K.; Rybinskaya, M. I. *Izv. Acad. Nauk SSSR. Otdel. Khim. Nayk* **1950**, 350–356; *Chem. Abstr.* **1951**, *45*, 1585; (c) Grandberg, I. I. *Chem. Heterocycl. Compd.* **1965**, *1*, 184–187; (d) Julia, M. *Ann. Chem.* **1950**, *5*, 595–641; *Chem. Abstr.* **1952**, 7035d; (e) Roedig, A.; Becker, H.-J. *Liebigs Ann. Chem.* **1955**, *597*, 214–227; (f) Prins, H. J.; Haring, H. G. *Rec. Trav. Chim.* **1954**, *73*, 479–495; Chem. Abstr. **1955**, 12265; (g) Ichikava, J.; Kobayashi, M.; Noda, Y.; Yokota, N.; Amano, K.; Minami, T. *J. Org. Chem. Engl. Transl.* **1996**, *61*, 2763–2769; (h) Beltrán-Rodil, S.; Edwards, M. G.; Pugh, D. S.; Reid, M.; Taylor, R. J. K. *Synlett* **2010**, *4*, 602–606.
24. Atavin, A. A.; Levkovskaya, G. G.; Mirskova, A. N. *Zh. Org. Khim.* **1973**, *9*, 318–321; *Chem. Abstr.* **1973**, *78*, 159137.
25. (a) Vesper, H. G.; Rollefson, G. K. *J. Am. Chem. Soc.* **1934**, *56*, 1455–1461; (b) Calingaert, G.; Soroos, H.; Hnizda, V.; Shapiro, H. *J. Am. Chem. Soc.* **1940**, *62*, 1545–1547; (c) Soroos, H.; Hinkamp, J. B. *J. Am. Chem. Soc.* **1945**, *67*, 1642–1643; (d) McKinley, J. W.; Pincock, R. E.; Scott, W. B. *J. Am. Chem. Soc.* **1973**, *6*, 2030–2032.
26. (a) Kochetkov, N. K.; Khorlin, A. A. *Zh. Obshch. Khim.* **1958**, *28*, 1937–1940; *Chem. Abstr.* **1959**, *53*, 1308; (b) Kochetkov, N. K.; Khorlin, A. A.; Gottikh, B. P.; Nesmeyanov, A. N. *Izv. Acad. Nauk SSSR. Otdel. Khim. Nauk.* **1956**, 1053–1058; *Chem. Abstr.* **1957**, *51*, 5065.
27. Nelles, J.; Bayer, O. German patent 642,147, 1937; *Chem. Abstr.* **1937**, *31*, 1301.
28. Yakubovich, A.; Merkulova, E. *Zh. Obshch. Khim.* **1946**, *16*, 55–60; *Chem. Abstr.* **1947**, *41*, 91.