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TMSCl as Greener and Effective Solvent for the Synthesis of Carbaryl Derivatives

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Abstract

This work introduces a method that is both effective and ecologically sustainable for the production of carbaryl derivatives. Through the utilization of sodium cyanate, phenol/alcohol, and TMSCl (Me_3SiCl), a notable level of purity and yield of the synthesized derivatives was attained significantly, this method showcased the efficacy of TMSCl as a gentle, convenient, and effective solvent in supporting this transformation.

Keywords: Carbaryl derivatives; Insecticides; Fungicides; Herbicides.

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1. Introduction

The utilization of multi-component reactions (MCRs) has become increasingly prevalent in the exploration of physiologically active molecules with unique properties. The main contributing factors to their widespread use are their experimental simplicity, great atom economy, and capacity to efficiently combine three or more reactants in a single reaction vessel, leading to the formation of larger molecular weight compounds with significant product yields [1,2]. Heterocyclic compounds have attracted considerable attention in the field of organic chemistry due to their abundance in natural products and diverse array of biological properties [3-8]. The necessity to develop innovative environmentally conscious and sustainable methodologies and strategies for the chemical idea referred to as "benign by design" has triggered a shift in perspective among researchers in academic and industry

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environments [9-13]. This involves the utilization of safer reagents or solvents, the reduction of both hazardous and non-hazardous waste output, and the minimization of solvent usage [14]. Mechanochemistry is an emerging field of scientific inquiry that is dedicated to the execution of chemical processes in the absence of solvents [15-23].

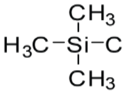
Insecticides commonly utilize carbaryl compounds, specifically naphthalen-1-yl N-methylcarbamates. Carbaryl derivatives have widespread application in various domains, including the field of pest control (particularly against insects), as well as in the manufacturing processes of paints and polyurethanes. Furthermore, they are utilised as safeguarding agents for amines in the context of chemical synthesis. There has been a notable surge of interest in the application of carbaryl compounds within the realm of medication design and discovery. Numerous authorized medicines and prodrugs have a notable structural characteristic referred to as the carbaryl group. There is a growing trend in the field of medicinal chemistry towards the application of carbaryls, namely in the synthesis of carbaryl derivatives that enhance drug-target interactions. Carbaryl, a chemical substance, is frequently utilized in the form of baits or sprays for the aim of insect extermination. The mechanism by which it operates entails the interference with the nervous systems and cerebral functions of specifically targeted insects. To efficiently oversee a diverse array of insect species, surpassing a total of 100, within various agricultural and horticultural settings encompassing citrus, fruit, cotton, forests, lawns, nuts, ornamentals, shade trees, and other crops, as well as in conjunction with poultry, livestock, and pets, these techniques are utilized in both agricultural and domestic domains. Acaricide and molluscicide are other applications for the chemical discussed before. The appropriate utilization of carbaryl pesticides produces positive societal outcomes through the preservation and improvement of agricultural productivity, as well as the preserving of human and animal health against diseases transmitted by insects. The utilization of carbaryl compounds has generated increasing attention owing to their multifaceted applications across several industries. These compounds are employed in the agrochemical industry for their pesticidal, fungicidal, and herbicidal properties. Moreover, carbaryls fulfil the function of pharmaceutical intermediates within the pharmaceutical industry and assume a pivotal part in the synthesis of polyurethane and peptides within the polymer sector. The carbonylation method, frequently utilized in the production of compounds from amines and alcohols, involves the application of phosgene in volatile organic solvents that exhibit dangerous characteristics [24–27]. Notwithstanding the utilization of corrosive and exceedingly hazardous chemicals, these approaches present notable operational and environmental complexities. Continual efforts have been undertaken to substitute phosgene with carbon dioxide and organic carbonates [28]. Nevertheless, the synthesis of N-unsubstituted (primary) carbaryls utilizing the aforementioned techniques is not viable. Various one-pot reaction techniques have been utilized in the synthesis of N-unsubstituted carbaryls from alcohols. Various methods have been employed to achieve these objectives, including the utilization of trichloroacetyl isocyanate [29,30], chloroformates (which necessitate the handling of hazardous phosgene) [31], chlorosulfonyl isocyanate [23], and cyanogen chloride [32-34]. Various initiatives have been implemented to ascertain substitute solvents, with the aim of mitigating the harmful effects and environmental unfriendliness connected with specific solvents, as examined from the perspective of green chemistry. This work presents a succinct process for the synthesis of carbaryls, emphasizing a significant level of yield and purity. The process entails the employment of sodium cyanate, a combination of phenol and alcohol, and trimethyl silyl chloride (TMSCl). Currently, there exists a dearth of documented data pertaining to the application of TMSCl in the production of carbaryl compounds.

2. Materials and Methods

The melting points were determined via a Buchi B2540 microscopic melting apparatus, USA. The acquisition of the infrared (IR) spectra was performed via a Bruker-Equinox 55 spectrophotometer, USA employing KBr pellets. The acquisition of the ^{1}H-NMR spectra was performed utilizing a Bruker 400 NMR spectrometer, USA. The solvent used for the spectra was $CDCl_3$, while TMS was employed as the internal standard. The chemical alterations (δ) were documented and quantified in parts per million (ppm) units. The acquisition of mass spectra was performed utilizing an SCIEX API 2000 spectrometer, USA. All compounds were obtained directly from commercial sources without requiring any further purification. All the chemicals utilized in this work are of Analytical-grade and utilized directly without any additional purification. 1-naphtol, methylcarbamoyl chloride and TMSCl of 99 % purity were acquired from Merck, India and throughout the experiment doubly distilled water was utilized whenever required. All the reactions were conducted in an ambient condition at room temperature.

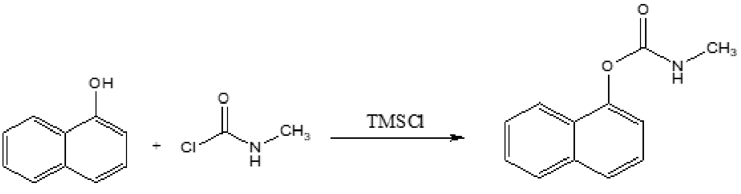
2.1. *TMSCl (Me_3SiCl)*

Trimethylsilyl chloride, sometimes known as chlorotrimethylsilane, is an organosilicon chemical. The chemical formula of the compound is $(CH_3)_3SiCl$. The substance in question is a liquid that is both transparent and odorless. It possesses the property of volatility and remains stable in the absence of water, as depicted in Fig. 1.



$$H_3C-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{Si}}-Cl$$

Fig. 1. Structure of TMSCl.

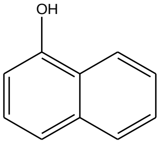
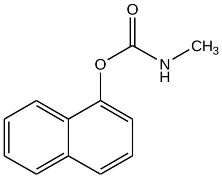
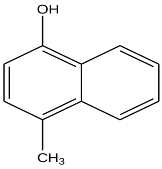
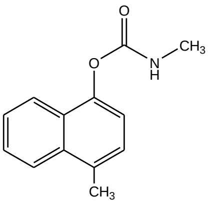
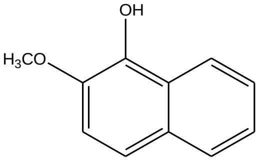
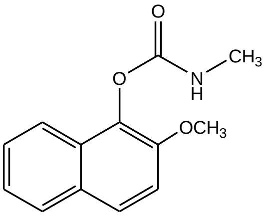
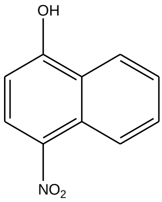
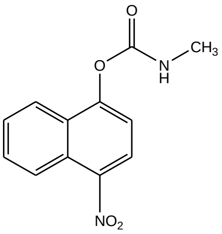


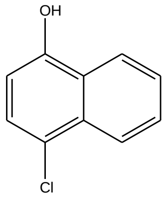
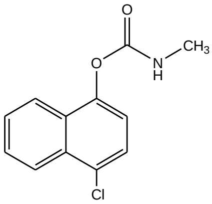
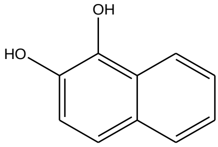
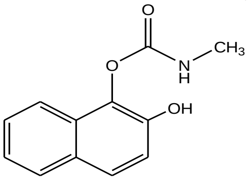
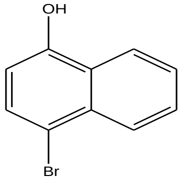
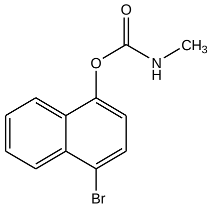
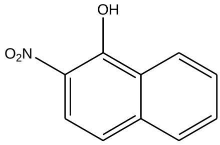
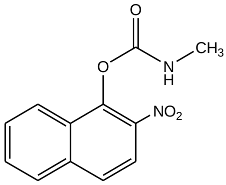
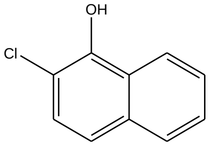
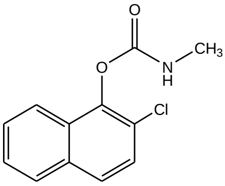
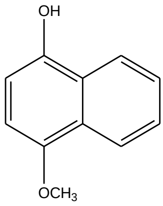
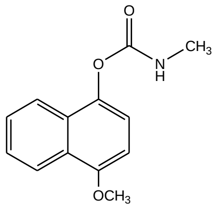
Scheme 1. Synthesis of carbaryl derivatives.

2.2. *General procedure for the synthesis of carbaryl derivatives*

A mixture of a 1-naphtol (10 mmol)1, and methylcarbamoyl chloride (10 mmol) 2 in the presence of TMSCl was refluxed at 55 °C for 40 min and the reaction was monitored by thin-layer chromatography (n-hexane: ethyl acetate 3:1). After completion of the reaction, the reaction mixture was filtered and the product was re-crystallized using ethanol to give the corresponding pure product (3a-j), as illustrated in Table 1 and Scheme 1. The pure products were characterized by FTIR, 1H-NMR and MASS spectra.

Table 1. Synthesis of carbaryl derivatives.

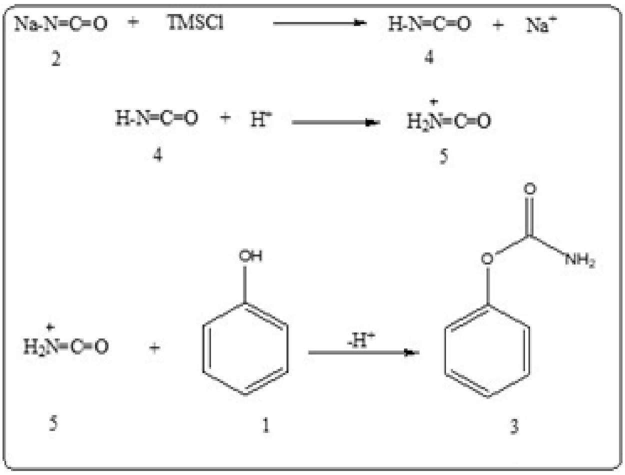
SL. No.	Napthol	Carbaryl derivative	Time (min)	Yield (%)
1	 1(a)	 3(a)	40	95
2	 1(b)	 3(b)	45	95
3	 1(c)	 3(c)	45	93
4	 1(d)	 3(d)	40	95

5	 1(e)	 3(e).	40	96
6	 1(f)	 3(f)	45	93
7	 1(g)	 3(g)	45	95
8	 1(h)	 3(h)	45	94
9	 1(i)	 3(i)	45	95
10	 1(j)	 3(j)	45	93

3. Results and Discussion

3.1. *Plausible mechanism for the formation of carbaryl derivatives*

As illustrated in Scheme 2. An early stage that may be considered is the reaction between sodium cyanate 2 and TMSCl, leading to the production of isocyanic acid 4. The proton from TMSCl is subsequently added to isocyanic acid 4, leading to the production of intermediate 5. During this procedure, the proton is transferred to the nitrogen atom instead of the oxygen atom. In the context of Scheme 2, it has been discovered that the carbon atom of the intermediate 5 is prone to nucleophilic attack by either an alcohol or phenol molecule 1. The likelihood of carbaryls 3 being formed is high due to the occurrence of this reaction [23,30].



Scheme 2. Plausible mechanism for the formation of Carbaryl derivatives.

3.2. *Spectral data for the synthesized carbaryl derivatives*

Naphthalen-1-yl methylcarbamate 3(a)
White solid, M.P. = 164 °C; IR(KBr) cm^{-1}: 2133.97 (N-H str), 1605 (C=O Str), 1521 (Ar, C=C Str), ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.93 (m, 2H), 7.25-7.18 (m, 3 H), 6.17-5.70 (m, 2 H). ESI-MS m/z(%): 201 $[M+H]^+$ (100).

1-methylnaphthalen-4-yl methylcarbamate 3(b)
White solid, M.P. = 171 °C; IR(KBr) cm^{-1}: 2211.13 (N-H str), 1652 (C=O Str), 1454 (Ar , C=C Str), ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.94 (m, 2H), 7.21-7.15 (m, 2 H), 6.12-5.61(m, 2 H), 2.27 (s, 3 H) . ESI-MS m/z(%): 215 $[M+H]^+$ (100).

2-methoxynaphthalen-1-yl methylcarbamate 3(c)
White solid, M.P. = 196 °C; IR(KBr) cm^{-1}: 2125.12(N-H str), 1622 (C=O Str), 1556 (Ar , C=C Str), ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.64-8.20 (m, 2H), 7.45-7.21 (m, 2 H), 6.27-5.71 (m, 2 H), 3.84 (s, 3 H). ESI-MS m/z(%): 231 $[M+H]^+$ (100).

1-nitronaphthalen-4-yl methylcarbamate 3(d)
White solid, M.P. = 194-195 °C; IR(KBr) cm^{-1}: 2133.84 (N-H str), 1634(C=O Str),1494 (Ar, C=C Str), ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.14-7.85 (m, 2H), 7.27-7.14 (m, 2 H), 5.91-5.74 (m, 2 H). ESI-MS m/z(%): 246 $[M+H]^+$ (100).

1-chloronaphthalen-4-yl methylcarbamate 3(e)
White solid, M.P. = 175-176 °C; IR(KBr) cm^{-1}: 2114.47(N-H str), 1622 (C=O Str), 1567 (Ar , C=C Str), ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.23-7.96 (m, 2H), 7.12-7.06 (m, 2 H), 6.14-5.83 (m, 2 H). ESI-MS m/z(%): 235 $[M+H]^+$ (100).

3.3. *Effect of temperature on synthesis of carbaryl derivatives*

Based on the data presented in Table 2, the reaction temperature employed in the synthesis of carbaryls is documented as 55 °C. It has been observed that the product yield is substantially poor and the reaction duration is comparably long when the temperature is maintained below 55 °C. The best temperature for this specific procedure has been established to be 55 °C.

Table 2. Effect of temperature on the formation of carbaryl derivatives.

S. No.	Catalyst	Temperature (°C)	Time (min)	Yield (%)
1	TMSCl	R. T.	3hr	60
2	TMSCl	35	2hr	75
3	TMSCl	40	50	80
4	TMSCl	55	30	96

4. Conclusion

In brief, this methodological approach facilitates the synthesis of a wide range of carbaryl derivatives at standard environmental conditions. The process demonstrates efficient reaction kinetics, desirable product yields and purity, economically viable starting materials, and the absence of undesirable secondary products. Furthermore, it has been determined that TMSCl has exceptional efficacy as a reagent in the production of carbaryl derivatives. Based on our present knowledge, there exists a dearth of recorded empirical data about the application of TMSCl in the synthesis of carbaryl derivatives.

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