Design, Synthesis, Characterization, and Insecticidal Bioefficacy Screening of Some New Pyridine Derivatives

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ABSTRACT: A lot of insecticides are found nowadays, but neonicotinoids are considered the most famous. So, a series of pyridine derivatives neonicotinoids analogues, namely, 3-cyano-4,6-dimethylpyridine-2(1H)-one (1), 2-chloro-3-cyano-4,6-dimethylpyridine (2), 3-cyano-4,6-dimethylpyridine-2(1H)-thione (3), 3-cyano-4,6-distyrylpyridine-2(1H)-thione (4), 2-((3-cyano-4,6-distyrylpyridin-2-yl)thio)-N-phenylacetamide (5), 3-amino-N-phenyl-4,6-distyrylthiophen[2,3-b]pyridine-2-carboxamide (6), 2-((3-cyano-4,6-distyrylpyridin-2-yl)thio)-N-(p-tolyl)acetamide (7), 3-amino-4,6-distyrly-N-(p-tolyl)thieno[2,3-b]pyridine-2-carboxamide (8), 2-((3-cyano-4,6-distyrylpyridin-2-yl)thio)-N-(4-methoxyphenyl)acetamide (9), and 3-amino-N-(4-methoxyphenyl)-4,6-distyrylthieno[2,3-b]pyridine-2-carboxamide (10), have been designed and synthesized in pure state, and their agricultural bioefficacy as insecticides against cowpea aphid *Aphis craccivora* Koch was screened. The structures of the synthesized compounds were verified by means of spectroscopic and elemental analyses. Insecticidal bioefficacy data illustrated that some compounds are excellent against cowpea aphid, and the bioefficacy of the rest of the tested compounds ranged from good to moderate against the same insects.

INTRODUCTION

Pyridine derivatives exist widely in the nature and have different biological activities such as antimicrobial, anticancer, antioxidant, insecticidal, etc.1−3 As a result, these compounds have become an attractive target for chemists around the world. Pyridine moiety constitutes a part of the neonicotinoids structure, and nowadays, neonicotinoid insecticides are most commonly used in the world for insect control because of their advantages in protecting a great variety of crops, as well as high efficacy without cross-resistance to other insecticides, low mammalian toxicity, a novel mode of action specific for nAChRs, and broad insecticidal spectra.4−7

In contrast, there is a clear evidence for the need of synthesis of some new organic compounds neonicotinoids analogues although the advantages of neonicotinoids. This evidence shows that some recent studies monitoring the human and animal exposure to imidacloprid as neonicotinoid insecticide found that DNA damage, oxidative stress, genotoxic effect, and clastogenic effect can be produced after long-term exposure of rabbits to that insecticide.8−11

Pyridine derivatives that contain styryl group attached to the pyridine moiety were synthesized, and some of them with a significant biological activity.12−15 The data in our previous work encouraged us to continue the search for new heterocycles containing pyridine moiety with agricultural bioactivity.16−18 In view of these findings, we reported herein the synthesis of some new heterocyclic pyridine derivatives and studied their insecticidal bioefficacy against cowpea Aphid, *Aphis craccivora* Koch.

RESULTS AND DISCUSSION

The synthesis of the target compounds started from malononitrile, which on reaction with acetylacetone afforded compound 1 that undergoes chlorination with POCI₃ to give compound 2. Compound 3 was obtained by reaction of chloro compound 2 with thiourea. Condensation of compound 3 with benzaldehyde in the presence of few drops of piperidine resulted in the formation of distyryl derivative 4 (Scheme 1). All characterization data of compounds 1−4 were in agreement with those reported before.23−25

Compound 4 was reacted with α-halogenated carbonyl compounds (chloroacetonilide, p-methylchloroacetanilide, and p-methoxochloroacetanilide) to afford 3-cyano-4,6-distyryl-2-substituted mercaptopyridines 5, 7, and 9. The chemical structures of compounds 5, 7, and 9 were confirmed by spectral and elemental analyses. Compounds 5, 7, and 9 were active against cowpea aphid, with good to moderate insecticidal bioefficacy.26−35

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underwent the Thorpe—Ziegler cyclization upon heating in ethanolic sodium ethoxide solution affording the corresponding thieno[2,3-b]pyridines 6, 8, and 10. The mechanism of the Thorpe—Ziegler cyclization can be represented by Scheme 2. Spectroscopic data and elemental analyses of compounds 6, 8, and 10 are in agreement with their proposed structures.

IR spectrum of compound 5 showed absorption bands at 3290, 2209, and 1663 cm\(^{-1}\) characteristics for (NH), (C≡N), and (C=O) groups, respectively. The absorption band of (C≡N) of compound 5 disappeared when cyclized to give thienopyridine 6 and was replaced by bands at 3413 and 3303 cm\(^{-1}\) for NH\(_2\). \(^1\)H NMR spectrum (DMSO-\(d_6\), 400 MHz) of compound 5 illustrated singlet signals at 10.38 and 4.28 for (NH) and (CH\(_2\)) groups, respectively. The signal of the (CH\(_2\)) group of compound 5 disappeared when cyclized to give compound 6. DEPT 135 (DMSO-\(d_6\), 100 MHz) spectrum of compound 5 showed a characteristic signal at 35.68 for the (CH\(_2\)) group, which disappeared when cyclized to give compound 6.

IR spectrum of compound 7 showed absorption bands at 3279, 2207, and 1664 cm\(^{-1}\) characteristics for (NH), (C≡N), and (C=O) groups, respectively. The absorption band of
(C=N) of compound 7 disappeared when cyclized to give the thienopyridine compound 8 and was replaced by 3416 and 3301 cm⁻¹ for NH₂. 1H NMR spectrum (DMSO-d₆, 400 MHz) of compound 7 illustrated singlet signals at 10.32, 4.25, and 2.24 for (NH), (CH₂), and (CH₃) groups, respectively. The signal of the (CH₂) group of compound 7 disappeared when cyclized to give compound 8. DEPT 135 (DMSO-d₆, 100 MHz) spectrum of compound 7 showed characteristic signal at 35.64 for the (CH₃) group, which disappeared when cyclized to give compound 8.

IR spectrum of compound 9 showed absorption bands at 3281, 2215, and 1658 cm⁻¹ characteristics for (NH), (C≡N), and (C=O) groups, respectively. The absorption band of (C≡N) of compound 9 disappeared when cyclized to give thienopyridine 10 and was replaced by 3480 and 3299 cm⁻¹ for NH₂. 1H NMR spectrum (DMSO-d₆, 400 MHz) of compound 9 showed singlet signals at 10.12, 4.24, and 3.73 for (NH), (CH₂), and (CH₃ anilide) groups, respectively. The signal of (CH₂) group of compound 9 disappeared when cyclized to give compound 10. DEPT 135 (DMSO-d₆, 100 MHz) spectrum of compound 9 showed a characteristic signal at 35.37 for the (CH₃) group, which disappeared when cyclized to give compound 10.

## CONCLUSIONS

A new series of pyridine derivatives neonicotinoid analogues have been synthesized in our lab, and their structures were proved by elemental and spectroscopic analyses. The bioefficacy of all compounds as potential insecticides against cowpea Aphid, A. craccivora Koch, was evaluated. The presence of different functional groups in the structure of the compounds gave a variety of insecticidal activities as potential insecticides. This study illustrated that the synthesized pyridine derivatives have valuable agricultural bioactivities.

## EXPERIMENTAL SECTION

A Fisher-Johns apparatus was used to record the melting points of all synthesized compounds. Infrared spectra and elemental analyses (C, H, N, and S) were accomplished via a Pye-Unicam SP3-100 spectrophotometer using the KBr disk technique and a Varian EL C, H, N, S analyzer, respectively. A Bruker 400 MHz spectrometer was used to measure DEPT 135 spectra and the 1H and 13C NMR spectra in the presence of tetramethylsilane as an internal standard. Chemical shifts were measured in ppm. Reaction progress and purity of the synthesized compounds were monitored by thin-layer chromatography.

Compounds 1–4 were prepared according to the reported methods.23–25 The reference insecticide, acetamiprid neonicotinoid insecticide, was obtained from Sigma-Aldrich (France). Cowpea aphid batches were compiled from faba bean, Vicia faba L, fields of the experimental farm of Assiut University. The insecticidal activity of the reference neonicotinoid insecticide (acetamiprid) plus the synthesized compounds was checked against adults and nymphs of the gathered aphids.

**Synthetic Procedure for 3-Cyano-4,6-dimethylpyridine-2(1H)-thione (3).** In addition to the procedure found in ref 25, compound 3 was synthesized here by reaction of compound 2 with thiourea: a mixture of chloropyridine derivative 2 (7 g, 0.04 mol) and thiourea (9 g, 0.12 mol) in ethanol was refluxed for 4 h. The solid precipitate that formed on hot was filtered off and recrystallized from dioxane to give pale green crystals of 3. Yield: 92%; melting point (mp): 277–279 °C. IR (ν) (KBr cm⁻¹): 3180 (NH), 2931, 2880 (C–H aliphatic), 2218 (C≡N); 1H NMR (DMSO-d₆, 400 MHz): δ 3.35 (s, 3H, CH₃), 2.84 (s, 3H, CH₂), 1.60 (s, 3H, CH₃), 0.75 (s, 1H, Ar–H), 13.8 (br. s, 1H, NH). Elemental analysis calculated for C₈H₇N₂S (%): C, 58.51; H, 4.91; N, 17.06; S, 19.52. Found (%): C, 58.45; H, 4.8; N, 17.00; S, 19.45.

**Synthetic Procedure for 3-Cyano-4,6-distyrylpyridine-2(1H)-thione (4).** Fusion of the dimethyl mercaptopyridine compound 3 (1 g, 0.006 mol) with benzaldehyde (2 mL, 0.019 mol) for 5 min in the presence of few drops of piperidine, then adding ethanol (25 mL) followed by reflux for 2 h gave a solid precipitate. The precipitate was filtered off and recrystallized from ethanol–dioxane mixture (1:2) as pale red crystals of compound 4. Yield: 90%; melting point (mp): 178–180 °C. IR (ν) (KBr cm⁻¹): 3166 (NH), 2972, 2921, 2854 (C–H aliphatic), 2217 (C≡N), 1611 (C=O). 1H NMR (DMSO-d₆, 100 MHz): δ 1.78. 152.62, 151.39, 141.19, 135.57, 130.77, 130.54, 129.65, 128.30, 128.03, 122.25, 116.49, 111.52, 105.73. DEPT 135 (DMSO-d₆, 100 MHz): δ 135.57 (CH), 130.77 (CH), 130.54 (CH), 129.65 (CH), 128.30 (CH), 128.03 (CH), 122.25 (CH), 111.52 (CH). Elemental analysis calculated for C₈H₇N₂S (%): C, 77.62; H, 4.74; N, 8.23; S, 9.42. Found (%): C, 77.64; H, 4.77; N, 8.25; S, 9.40.

**Synthetic Procedure for 3-Cyano-4,6-distyryl-2-substituted Mercaptopyridines (5, 7, and 9)** via Reaction of 4 with N-Substituted Chloroacetamides. **General Procedure.** A mixture of distyryl compound 4 (2 g, 0.006 mol), the respective halocompound (chloroacetanilide, p-methylchloroacetanilide, p-methoxychloroacetanilide) (0.006 mol), and fused sodium acetate (0.6 g, 0.007 mol) in ethanol (25 mL) was heated under reflux for 30 min. The formed precipitate was collected and recrystallized from ethanol–dioxane mixture (1:2) to afford compounds 5, 7, and 9.

2-(3-Cyano-4,6-distyrylpyridin-2-ylthio)-N-phenylacetamide (5). Pale orange crystals in 86% yield, mp 222–224 °C. IR (ν) (KBr cm⁻¹): 3290 (NH), 3058 (C–H aromatic), 2920, 2851 (C–H aliphatic), 2209 (C≡N), 1663 (C=O), 1633 (C=N). 1H NMR (DMSO-d₆, 400 MHz): δ 10.38 (s, 1H, NH), 7.03–7.88 (m, 20H, 2eryl=CH and Ar–H), 4.28 (s, 2H, CH₂). 13C NMR (DMSO-d₆, 100 MHz): δ 136.53 (CH), 136.45 (CH), 130.28 (CH), 128.90 (CH), 128.52 (CH), 122.25 (CH), 111.69 (CH), 111.745 (CH), 35.68 (CH₂). Elemental analysis calculated for C₈H₇N₂O (%): C, 76.08; H, 4.9; N, 8.87; S, 6.77. Found (%): C, 76.11; H, 4.93; N, 8.84; S, 6.81.

2-(3-Cyano-4,6-distyrylpyridin-2-ylthio)-N-(p-tolyl)acetamide (7). Pale yellow crystals in 86% yield, mp 207–208 °C. IR (ν) (KBr cm⁻¹): 3279 (NH), 3035 (C–H aromatic), 2971 (C–H aliphatic), 2207 (C≡N), 1664 (C=O), 1633 (C≡N). 1H NMR (DMSO-d₆, 400 MHz): δ 10.32 (s, 1H, NH), 7.08–7.87 (m, 19H, 2eryl=CH and Ar–H), 4.25 (s, 2H, CH₂), 2.24 (s, 3H, CH₃). 13C NMR (DMSO-d₆, 100 MHz): δ 166.09, 162.35, 157.36, 149.57, 138.66, 137.11, 136.85, 136.15, 135.70, 132.77, 130.33, 129.60, 129.21, 128.10,
Table 1. Insecticidal Bioefficacy of Acetamiprid and Compounds 1–10 against the Nymphs of Cowpea Aphid, A. craccivora, after 24 and 48 h of Treatment

<table>
<thead>
<tr>
<th>compd</th>
<th>slope ± SE</th>
<th>LC_{50} (ppm)</th>
<th>toxic ratio</th>
<th>slope ± SE</th>
<th>LC_{50} (ppm)</th>
<th>toxicity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetamiprid</td>
<td>0.34 ± 0.02</td>
<td>0.045</td>
<td>1</td>
<td>0.42 ± 0.03</td>
<td>0.006</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.39 ± 0.03</td>
<td>2.341</td>
<td>0.019</td>
<td>0.37 ± 0.03</td>
<td>0.151</td>
<td>0.040</td>
</tr>
<tr>
<td>2</td>
<td>0.44 ± 0.02</td>
<td>0.175</td>
<td>0.257</td>
<td>0.46 ± 0.03</td>
<td>0.017</td>
<td>0.353</td>
</tr>
<tr>
<td>3</td>
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<td>1.382</td>
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<td>0.38 ± 0.03</td>
<td>0.101</td>
<td>0.060</td>
</tr>
<tr>
<td>4</td>
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<td>0.787</td>
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<td>0.30 ± 0.02</td>
<td>0.091</td>
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<tr>
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<td>0.079</td>
<td>0.40 ± 0.03</td>
<td>0.054</td>
<td>0.111</td>
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<tr>
<td>6</td>
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<td>0.040</td>
<td>0.35 ± 0.03</td>
<td>0.068</td>
<td>0.088</td>
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<tr>
<td>7</td>
<td>0.34 ± 0.02</td>
<td>0.421</td>
<td>0.107</td>
<td>0.40 ± 0.03</td>
<td>0.039</td>
<td>0.154</td>
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<tr>
<td>8</td>
<td>0.35 ± 0.02</td>
<td>0.551</td>
<td>0.082</td>
<td>0.40 ± 0.03</td>
<td>0.053</td>
<td>0.113</td>
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<tr>
<td>9</td>
<td>0.34 ± 0.02</td>
<td>0.284</td>
<td>0.158</td>
<td>0.31 ± 0.03</td>
<td>0.021</td>
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<tr>
<td>10</td>
<td>0.39 ± 0.03</td>
<td>0.334</td>
<td>0.135</td>
<td>0.47 ± 0.03</td>
<td>0.031</td>
<td>0.194</td>
</tr>
</tbody>
</table>

*Toxic ratio is defined as the ratio of the LC_{50} values of acetamiprid for baseline toxicity and the compound.*

127.88, 126.91, 122.05, 119.57, 114.67, 101.82, 35.64, 20.85. DEPT 135 (DMSO-d_{6}, 100 MHz): δ 138.66 (CH), 136.85 (CH), 130.33 (CH), 129.61 (CH), 129.58 (CH), 129.21 (CH), 128.10 (CH), 127.88 (CH), 126.91 (CH), 122.05 (CH), 119.57 (CH), 114.67 (CH), 35.64 (CH), 20.85 (CH). Elemental analysis calculated for C_{31}H_{25}N_{3}OS (%): C, 76.36; H, 5.17; N, 8.62; S, 6.57. Found (%): C, 76.39; H, 5.15; S, 6.57.

2-(3-Cyano-4,6-distyrpyridin-2-yliothio)-N-(4-methoxyphenyl)acetamide (9). Yellowish crystals in 87% yield, mp 191–193 °C. IR (ν (KBr) cm⁻¹): 3281 (NH), 2922, 2851 (C–H aliphatic), 2215 (C=N), 1658 (C=O), 1612 (C=C). 1H NMR (DMSO-d_{6}, 400 MHz): δ 10.12 (s, 1H, NH), 8.88–7.79 (m, 19H, 2CH=CH and Ar–H), 4.24 (s, 2H, CH₂), 3.73 (s, 3H, OCH₃). 13C NMR (DMSO-d_{6}, 100 MHz): δ 165.89, 161.84, 157.35, 155.84, 149.57, 136.16, 135.70, 132.79, 130.77, 129.54, 129.24, 128.04, 127.89, 126.92, 122.20, 115.44, 114.65, 114.41, 101.82, 55.66, 35.37. DEPT 135 (DMSO-d_{6}, 100 MHz): δ 135.70 (CH), 132.79 (CH), 129.54 (CH), 129.24 (CH), 128.04 (CH), 127.88 (CH), 126.91 (CH), 122.20 (CH), 114.65 (CH), 114.40 (CH), 55.66 (OCH₃), 35.37 (CH). Elemental analysis calculated for C_{31}H_{25}N_{3}OS (%): C, 73.93; H, 5.00; N, 8.34; S, 6.37. Found (%): C, 73.97; H, 5.05; N, 8.32; S, 6.40.

**Synthetic Procedure for 3-Amino-4,6-distyrpyridin-2-ylthio-N-(4-methoxyphenyl)acetamide (6).** Yellow crystals in 83% yield, mp 263–264 °C. IR (ν (KBr) cm⁻¹): 3413, 3303 (NH, NH₂), 3023 (C–H aromatic), 2891 (C–H aliphatic), 1647 (C=C), 1633 (C=C=N). 1H NMR (DMSO-d_{6}, 400 MHz): δ 9.53 (s, 1H, NH), 6.95–8.06 (m, 22H, 2CH=CH, NH and Ar–H). 13C NMR (DMSO-d_{6}, 100 MHz): δ 164.51, 160.65, 155.96, 149.18, 144.38, 139.21, 136.75, 136.48, 134.42, 129.37, 129.26, 128.89, 128.12, 127.75, 124.17, 123.74, 123.31, 122.00, 117.64, 116.71, 100.17. DEPT 135 (DMSO-d_{6}, 100 MHz): δ 136.75 (CH), 134.42 (CH), 129.37 (CH), 129.26 (CH), 128.89 (CH), 128.12 (CH), 127.75 (CH), 124.17 (CH), 123.73 (CH), 122.31 (CH), 117.64 (CH), 116.69 (CH). Elemental analysis calculated for C_{30}H_{23}N_{3}OS (%): C, 76.08; H, 4.90; N, 8.87; S, 6.77. Found (%): C, 76.13; H, 4.92; N, 8.82; S, 6.79.

**Laboratory Bioassay.** The insecticidal bioefficacy of all synthesized pyridine derivatives was evaluated via the leaf dip bioassay method. Laboratory screening results are reported here for the title compounds to find out the concentrations that are required to kill 50% (LC_{50}) of the gathered insects. In this work, six concentrations of each synthesized pyridine derivative plus 0.1% Triton X-100 (surfactant) were used. A total of 20 adults and 20 nymphs of cowpea aphids, almost of the same size, were dipped three times in every concentration for 10 s. Tested cowpea aphids were dried at room temperature for 0.5 h. Cowpea aphids control batches were also used. Batches of aphids after drying were transported for

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Petri dishes (9 cm diameter) and grapsed for 24 and 48 h at a
photoperiod of 12:12 light/dark cycle, 22 ± 2 °C, and 60 ± 5% relative humidity. Mortality of the aphids was counted after 24 and 48 h of test by means of a binocular microscope. The aphids that are not capable of coordinating forward movement were considered dead. Bioefficacy check of the synthesized compounds was iterated twice, and the results of this check were corrected using Abbott's formula.28 Slope values and median lethal concentrations (LC50) of the title compounds were calculated through a computerized Probit regression analysis program and recorded in (ppm).29

■ INSECTICIDAL BIOEFFICACY SCREENING

The synthesized compounds have been screened for their insecticidal bioefficacy, as described below:

Insecticidal Bioefficacy Test for the Nymphs of Cowpea Aphid. Compounds 1–10 were tested against the nymphs of the collected aphids for their insecticidal bioefficacy, and the results are presented in Table 1. After 24 h of treatment, bioefficacy results indicated that all of these compounds exhibit high to low insecticidal activity against the cowpea aphid nymphs and the LC50 values ranged from 0.175 to 2.341 ppm, whereas the LC50 value of acetamiprid was 0.045 ppm. After 48 h of treatment, it is found that the insecticidal bioefficacy of all compounds against cowpea aphid nymphs varied from strong to weak with LC50 values assorted from 0.017 to 0.151 ppm, while the LC50 value of acetamiprid was 0.023 ppm. Compounds 1 and 3 showed a reasonable insecticidal bioefficacy with LC50 values of 1.172 and 0.472 ppm, respectively.

Insecticidal Bioefficacy Test for the Adults of Cowpea Aphid. Compounds 1–10 were tested also against the adults of the collected aphids for their insecticidal bioefficacy, and the results are presented in Table 2. The results indicated that after 24 h of insecticidal bioefficacy test, the compounds own strong to weak bioefficacy and LC50 values assorted from 0.887 to 9.431 ppm, while 0.225 ppm was the LC50 value of acetamiprid. Compounds 2, 4, 5, 6, 7, 8, 9, and 10 possess a high insecticidal bioefficacy, and their LC50 values are 1.660, 0.887, 2.612, 1.482, 1.265, 2.262, 2.623, and 2.101 ppm, respectively. The insecticidal activities of the tested compounds strongly increased against cowpea aphid adults after 48 h of bioefficacy test, and the values of LC50 assorted from 0.103 to 1.172 ppm. Thus, compound 2 showed a high insecticidal bioefficacy close to that of acetamiprid because the value of LC50 of compound 2 is 0.103 ppm, while the LC50 value of acetamiprid is 0.023 ppm. Compounds 1 and 3 showed a reasonable insecticidal bioefficacy with LC50 values of 1.172 and 0.472 ppm, respectively.

■ STRUCTURE–ACTION RELATIONSHIP

It appears from the general framework structure of the synthesized pyridine moiety-containing compounds that the compounds 2-chloro-3-cyano-4,6-dimethylpyridine 2 and 2-((3-cyano-4,6-distyrylpyridin-2-yl)thio)-N-(4-methoxyphenyl)acetamide 9 are more active against cowpea aphid than the rest of tested compounds. It also appears that compounds that contain a distyrylpyridine part in the structure own a high insecticidal bioefficacy than compounds 1 and 3 that contain a dimethylpyridine part in the structure. So, compounds 4, 5, 6, 7, 8, 9, and 10 have insecticidal activity more than that of compounds 1 and 3. Compounds 5, 7, and 9 are more active than compounds 6, 8, and 10, which may be due to the presence of cyanophenyl group in the former and its absence in the latter. Compound 9 has more activity than compounds 5 and 7, which may be due to the presence of 4-methoxyphenyl moiety in its structure and the absence of this moiety in compounds 5 and 7. Also, compound 10 is more active against cowpea aphid than compounds 6 and 8, which may be due to the presence of 4-methoxyphenyl moiety in its structure. Although compounds 1 and 3 that contain a dimethylpyridine part have a reasonable insecticidal bioefficacy, compound 2 which contain this part in its structure is considered more active than all synthesized compounds, which may be due to the presence of chlorine atom attached to the pyridine ring. Finally, the insecticidal bioefficacy of compound 3-cyano-4,6-dimethylpyridine-2(1H)-thione 3 is more than that of compound 3-cyano-4,6-dimethylpyridine-2(1H)-one 1, which may be due to the presence of thiol group in its structure.

Table 2. Insecticidal Bioefficacy of Acetamiprid and Compounds 1–10 against the Adults of Cowpea Aphid, A. craccivora, after 24 and 48 h of Treatmenta

<table>
<thead>
<tr>
<th>compd</th>
<th>slope ± SE</th>
<th>LC50 (ppm)</th>
<th>toxic ratio</th>
<th>slope ± SE</th>
<th>LC50 (ppm)</th>
<th>toxicity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetamiprid</td>
<td>0.24 ± 0.02</td>
<td>0.225</td>
<td>1</td>
<td>0.32 ± 0.03</td>
<td>0.023</td>
<td>1</td>
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<tr>
<td>1</td>
<td>0.42 ± 0.03</td>
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<td>1.172</td>
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<td>0.37 ± 0.02</td>
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<td>0.103</td>
<td>0.223</td>
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<td>7</td>
<td>0.42 ± 0.03</td>
<td>1.265</td>
<td>0.178</td>
<td>0.38 ± 0.03</td>
<td>0.137</td>
<td>0.168</td>
</tr>
<tr>
<td>8</td>
<td>0.36 ± 0.02</td>
<td>2.262</td>
<td>0.099</td>
<td>0.38 ± 0.02</td>
<td>0.151</td>
<td>0.152</td>
</tr>
<tr>
<td>9</td>
<td>0.37 ± 0.03</td>
<td>2.623</td>
<td>0.086</td>
<td>0.35 ± 0.03</td>
<td>0.213</td>
<td>0.108</td>
</tr>
<tr>
<td>10</td>
<td>0.36 ± 0.02</td>
<td>2.101</td>
<td>0.107</td>
<td>0.40 ± 0.03</td>
<td>0.151</td>
<td>0.152</td>
</tr>
</tbody>
</table>

*aToxic ratio is defined as the ratio of the LC50 values of acetamiprid for baseline toxicity and the compound.
Annu. Rev. Entomol. attributed to specificity of insect and mammalian nicotinic receptors.

REFERENCES

Corresponding Author

AUTHOR INFORMATION

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