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·研究论文·

2-苄硫基烟酰胺类衍生物的合成及生物活性

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摘 要:以 2-苄硫基烟酸为原料,设计并合成了 26个 2-苄硫基烟酰胺类化合物,其化学结构经核磁共振氢谱和元素分析确证。初步的生物活性测定结果表明,该类化合物具有一定的杀虫及除草活性。其中 **C-9、C-10、C-11**在 50 mg/L 时对淡色库蚊 *Culex pipiens pallens*的致死率达到 100%; **C-3、C-6、C-15**在 100 mg/L 对稗草 *Echinochloa crusgalli* Link、马唐 *Digitaria sanguinalis*、苋菜 *Ambrosia tricolor* Linn的白化度大于 80%。

关键词:烟酰胺;衍生物;合成;生物活性
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Synthesis and Bioactivity of 2-Benzylsulfanyl Nicotinamide Derivatives

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Abstract: In search for novel pesticides with high effects, high selectivity and low toxicity, 26 compounds belong to 2-benzylsulfanyl nicotinamide derivatives were designed and synthesized starting from 2-benzylsulfanyl nicotinic acid. Their chemical structures were confirmed by ^{1}H NMR and elemental analysis. Preliminary bioassays showed that some compounds exhibited certain insecticidal and herbicidal activities. The mortality of *Culex pipiens pallens* from **C-9, C-10** and **C-11** at the concentration of 50 mg/L reached 100%. The albino rate of **C-3, C-6, C-15** to *Echinochloa crusgalli*, *Digitaria sanguinalis*, *Ambrosia tricolor* and *Brassica alboglabra* at the concentration of 100 mg/L was above 80%.

Key words: nicotinamide; derivative; synthesis; bioactivity

在近几年开发的新农药中,有一半以上为杂环化合物,特别是含氮的杂环化合物更引人注目[1]。烟酰胺系维生素 B族类物质,主要存在于动物体内 ,是辅酶 I和辅酶 II的组成部分,对其衍生物的合成是建立在药理性质研究基础上的,对这一类衍生物的研究亦成为当今新农药开发的热点[2]。如由 May & Baker Ltd.开发的烟酰胺类除草剂吡氟草胺 (diflufenican)以及由德国巴斯夫公司开发的新型烟酰胺类杀菌剂啶酰菌胺 (boscalid)等[3,4]。

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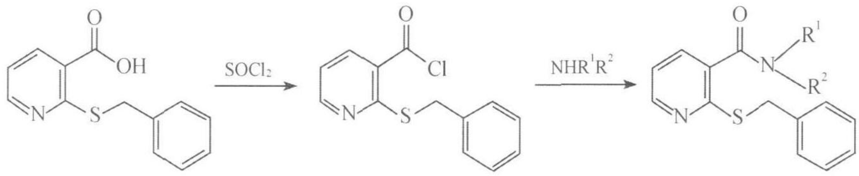
为了进一步开发高效、高选择性、低毒且结构简单的活性化合物,笔者以 2-苄硫基烟酸为起始原料,设计合成了 26个未见文献报道的 2-苄硫基烟酰胺类化合物,所有目标化合物结构经过核磁共振氢谱和元素分析确证。初步生物活性测试表明部分化合物具有不同程度的杀虫、抑菌及除草活性。目标化合物合成路线如下:



A B C

1 合成实验

1.1 仪器与试剂

Bruker AC300型核磁共振仪 (以 $CDCl_3$ 为溶剂, TMS为内标); WRS-1A 型数字熔点仪 (温度未校正)。所用试剂均为化学纯或分析纯。

1.2 中间体 B的制备[5]

于 250 mL 的反应瓶中加入 2-苄硫基烟酸 (**A**) 2.45 g (0.01 mol)、二氯亚砜 30 mL 和 0.1 g DMF,搅拌回流反应 8 h。将反应液冷却至室温减压蒸去过剩的二氯亚砜,得到 2-苄硫基烟酰氯 (**B**)。

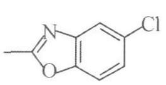
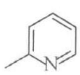
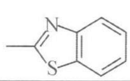
1.3 目标化合物 C的合成[6]

以化合物 2-苄硫基-N-苯基烟酰胺 (**C-4**)的合成为例。置苯胺 0.93 g (0.010 mol)、三乙胺 1.52 g (0.015 mol)及二氯甲烷 30 mL 于 100 mL 反应瓶中,冷却至 0℃,滴加 2.64 g (0.01 mol)化合物 **B**溶于 15 mL 二氯甲烷的溶液,室温反应 3 h。加入 50 mL 水,分出有机相,并经水洗、无水硫酸镁干燥,减压脱溶得到深黄色粘稠液。经柱层析 [石油醚-乙酸乙酯 (3∶1,体积比)]分离提纯,得到白色固体 2.35 g。收率 70.5%,熔点: 167.1～168.4℃。

同法合成其他目标化合物,其理化数据及元素分析数据见表 1,^{1}H NMR数据见表 2。

表 1 化合物 C 的理化及元素分析数据

Table 1 Physical and elemental analytical data of compounds C

化合物 Compd.	R^1	R^2	熔点 m.p./℃	收率 Yield(%)	元素分析(计算值,%) Elemental analysis(Calcd.,%)		
					C	H	N
C-1	H	2-$CH_3C_6H_4$	165.4～166.8	79.3	71.90 (71.83)	5.43 (5.42)	8.35(8.38)
C-2	H	*n*-$C_4H_9O(CH_2)_3$	70.4～71.3	81.9	67.09 (67.01)	7.16(7.31)	7.78 (7.81)
C-3	H	*n*-C_3H_7	123.2～123.7	90.4	67.10 (67.10)	6.28 (6.34)	9.81 (9.78)
C-4	H	C_6H_5	167.1～168.4	80.5	71.07 (71.22)	5.26 (5.03)	8.70 (8.74)
C-5	H	4-$CF_3OC_6H_4$	147.1～147.2	70.3	59.14 (59.40)	4.08 (3.74)	7.15 (6.93)
C-6	H	*i*-C_3H_7	125.4～125.8	91.3	67.12(67.10)	6.30(6.34)	9.68(9.78)
C-7	H	4-ClC_6H_4	146.6～148.9	74.6	64.29 (64.31)	4.25 (4.26)	7.76 (7.89)
C-8	H		159.5～160.1	69.6	60.71(60.68)	3.80(3.56)	10.56(10.61)
C-9	H		134.6～134.8	74.1	67.32 (67.27)	4.75(4.70)	13.10(13.07)
C-10	H	*cyclo*-C_6H_{11}	156.4～157.0	88.5	69.88 (69.90)	6.65 (6.79)	8.62(8.58)
C-11	C_2H_5	C_2H_5	117.3～117.6	50.4	67.91 (67.97)	6.65 (6.71)	9.30(9.32)
C-12	H		165.5～167.1	65.4	63.65(63.64)	3.97(4.01)	11.15(11.13)

续表 Continued

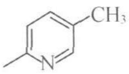
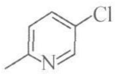
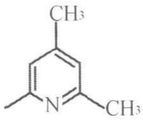
化合物 Compd.	R^1	R^2	熔点 m. p. /℃	收率 Yield(%)	元素分析(计算值,%) Elemental analysis(Calcd.,%)		
					C	H	N
C-13	H		118.1~119.7	67.9	68.06(68.04)	5.09(5.11)	12.53(12.53)
C-14	H		106.7~108.7	64.9	60.67(60.76)	3.95(3.97)	11.92(11.81)
C-15	H	*n*-C_4H_9	99.4~99.8	92.1	68.03(67.97)	6.68(6.71)	9.31(9.32)
C-16	H	*i*-C_4H_9	107.2~107.4	91.7	67.78(67.97)	6.90(6.71)	9.44(9.32)
C-17	H	*sec*-C_4H_9	106.2~106.4	92.0	68.10(67.97)	6.63(6.71)	9.38(9.32)
C-18	H	$(CH_3)_3CCH_2$	110.5~111.2	89.1	68.78(68.75)	7.10(7.05)	8.81(8.91)
C-19	H	*cyclo*-$C_6H_{11}(CH_3)CH$	155.3~156.9	77.8	71.42 (71.32)	7.16(7.01)	7.97(7.88)
C-20	H	4-$CH_3C_6H_4$	154.5~155.3	76.9	71.89 (71.83)	5.69(5.42)	8.29(8.38)
C-21	H		128.3~129.1	54.7	68.63(68.74)	5.68(5.48)	12.37(12.02)
C-22	H	2,4,6-$(CH_3)_3C_6H_2$	151.3~152.5	72.3	72.93(72.91)	6.08(6.12)	7.71(7.73)
C-23	H	2-$CH_3OC_6H_5$	153.5~154.3	76.1	68.51 (68.55)	5.11(5.18)	7.96(7.99)
C-24	H	2-Cl,6-$CH_3C_6H_3$	128.7~130.4	61.2	65.14(65.12)	4.60(4.65)	7.58(7.69)
C-25	H	3-Cl,2-$CH_3C_6H_3$	176.6~176.8	70.2	65.51 (65.12)	4.31(4.65)	7.86(7.69)
C-26	*n*-C_4H_9	*n*-C_4H_9	69.9~71.3	51.1	70.79(70.75)	7.87(7.92)	7.83(7.86)

表 2　化合物 C的核磁共振氢谱数据

Table 2　^1H NMR data of compounds **C**

化合物 Compd.	^1H NMR ($CDCl_3$/TMS), δ
C-1	2.32 (s, 3H, CH_3), 4.55 (s, 2H, SCH_2), 6.93~7.46 (m, 10H, ArH, Ar′H, PyH-5), 7.95 (s, 1H, NH), 8.01 (d, 1H, J = 5.70 Hz, PyH-4), 8.60 (d, 1H, J = 4.80 Hz, PyH-6)
C-2	0.88 (t, 3H, J = 7.35 Hz, CH_3), 1.25~1.35 (m, 2H, CH_2), 1.45~1.54 (m, 2H, CH_2), 1.83~1.91 (m, 2H, CH_2), 3.40 (t, 2H, J = 6.46 Hz, NCH_2), 3.53~3.59 (m, 4H, 2OCH_2), 4.47 (s, 2H, SCH_2), 6.90 (s, 1H, NH), 7.04~7.08 (m, 1H, PyH-5), 7.23~7.32 (m, 3H, ArH-3, 4, 5), 7.42 (d, 2H, J = 8.10 Hz, ArH-2, 6), 7.76 (d, 1H, J = 7.65 Hz, PyH-4), 8.52 (d, 1H, J = 4.80 Hz, PyH-6)
C-3	0.98 (t, 3H, J = 7.50 Hz, CH_3), 1.57~1.71 (m, 2H, CH_2), 3.36~3.43 (m, 2H, NCH_2), 4.49 (s, 2H, SCH_2), 6.34 (s, 1H, NH), 7.05~7.07 (m, 1H, PyH-5), 7.09~7.42 (m, 5H, ArH), 7.82 (d, 1H, J = 7.20 Hz, PyH-4), 8.52 (d, 1H, J = 4.65 Hz, PyH-6)
C-4	4.54 (s, 2H, SCH_2), 7.12~7.61 (m, 11H, ArH, Ar′H, PyH-5), 7.95 (d, 1H, J = 7.80 Hz, PyH-4), 8.06 (s, 1H, NH), 8.59 (d, 1H, J = 5.10 Hz, PyH-6)
C-5	4.54 (s, 2H, SCH_2), 7.13~7.33 (m, 6H, ArH-3, 4, 5, ArH-3′, 5′, PyH-5), 7.41 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.63 (d, 2H, J = 8.40 Hz, ArH-2′, 6′), 7.95 (d, 1H, J = 6.90 Hz, PyH-4), 8.16 (s, 1H, NH), 8.60 (d, 1H, J = 3.90 Hz, PyH-6)
C-6	1.25 (d, 6H, J = 6.00 Hz, 2CH_3), 4.22~4.29 (m, 1H, CH), 4.48 (s, 2H, SCH_2), 6.13 (s, 1H, NH), 7.04~7.09 (m, 1H, PyH-5), 7.21~7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 8.10 Hz, ArH-2, 6), 7.80 (d, 1H, J = 7.50 Hz, PyH-4), 8.51 (d, 1H, J = 4.65 Hz, PyH-6)
C-7	4.12 (s, 2H, SCH_2), 7.04~7.11 (m, 1H, PyH-5), 7.22~7.32 (m, 5H, ArH-3, 4, 5, ArH-3′, 5′), 7.49 (d, 2H, J = 6.60 Hz, ArH-2, 6), 7.55 (d, 2H, J = 9.00 Hz, ArH-2′, 6′), 7.92 (d, 1H, J = 7.50 Hz, PyH-4), 8.22 (s, 1H, NH), 8.57 (d, 1H, J = 4.95 Hz, PyH-6)
C-8	4.43 (s, 2H, SCH_2), 6.88~6.92 (m, 1H, PyH-5), 7.07 (d, 1H, J = 8.42 Hz, ArH-6′), 7.17~7.31 (m, 5H, ArH-3, 4, 5, 4′, 7′), 7.51 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.87~7.90 (m, 2H, PyH-4, NH), 8.46 (d, 1H, J = 3.60 Hz, PyH-6)

续表 Continued

化合物 Compd.	^{1}H NMR (CDCl$_3$/TMS), δ
C-9	4.46 (s, 2H, SCH$_2$), 6.77～8.63 (m, 12H, ArH, PyH, PyH′), 11.25 (s, 1H, NH)
C-10	1.15～2.04 (m, 10H, 5cycloCH$_2$), 3.93～4.02 (m, 1H, CH), 4.49 (s, 2H, SCH$_2$), 6.19 (d, 1H, J = 6.60 Hz, NH), 7.05～7.10 (m, 1H, PyH-5), 7.21～7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 7.20 Hz, ArH-2, 6), 7.81 (d, 1H, J = 7.65 Hz, PyH-4), 8.51 (d, 1H, J = 4.50 Hz, PyH-6)
C-11	1.00 (t, 3H, J = 6.90 Hz, CH$_3$), 1.25 (t, 3H, J = 6.90 Hz, CH$_3$), 3.03～3.10 (m, 2H, NCH$_2$), 3.51～3.58 (m, 2H, NCH$_2$), 4.48 (s, 2H, SCH$_2$), 7.04～7.08 (m, 1H, PyH-5), 7.22～7.30 (m, 3H, ArH-3, 4, 5), 7.38～7.43 (m, 3H, ArH-2, 6, PyH-4), 8.51 (d, 1H, J = 4.80 Hz, PyH-6)
C-12	4.47 (s, 2H, SCH$_2$), 6.87～7.01 (m, 1H, PyH-5), 7.19～7.40 (m, 9H, ArH-2, 3, 4, 5, 6, 4′, 5′, 6′, 7′), 7.83 (d, 1H, J = 7.20 Hz, PyH-4), 7.93 (s, 1H, NH), 8.52 (d, 1H, J = 3.60 Hz, PyH-6)
C-13	2.26 (s, 3H, CH$_3$), 4.48 (s, 2H, SCH$_2$), 7.07～7.11 (m, 1H, ArH, PyH-5), 7.21～7.27 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.56 (d, 1H, J = 8.40 Hz, PyH-4′), 7.84～7.87 (m, 2H, PyH-4, 6′), 8.25 (d, 1H, J = 8.41 Hz, PyH-3′), 8.58 (d, 1H, J = 4.80 Hz, PyH-6), 9.03 (s, 1H, NH)
C-14	4.49 (s, 2H, SCH$_2$), 7.11～7.14 (m, 1H, PyH-5), 7.22～7.31 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.70 (d, 1H, J = 8.70 Hz, PyH-4′), 7.88 (d, 1H, J = 8.10 Hz, PyH-4), 8.10 (s, 1H, PyH-6′), 8.35 (d, 1H, J = 9.00 Hz, PyH-3′), 8.60 (d, 1H, J = 4.20 Hz, PyH-6), 8.97 (s, 1H, NH)
C-15	0.95 (t, 3H, J = 7.20 Hz, CH$_3$), 1.27～1.42 (m, 2H, CH$_2$), 1.54～1.64 (m, 2H, CH$_2$), 3.40～3.47 (m, 2H, NCH$_2$), 4.50 (s, 2H, SCH$_2$), 6.27 (s, 1H, NH), 7.07～7.11 (m, 1H, PyH-5), 7.22～7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 7.50 Hz, ArH-2, 6), 7.84 (d, 1H, J = 7.20 Hz, PyH-4), 8.53 (d, 1H, J = 4.20 Hz, PyH-6)
C-16	0.98 (d, 6H, J = 6.60 Hz, 2CH$_3$), 1.85～1.94 (m, 1H, CH), 3.28 (t, 2H, J = 6.30 Hz, NCH$_2$), 4.50 (s, 2H, SCH$_2$), 6.36 (s, 1H, NH), 7.08～7.12 (m, 1H, PyH-5), 7.24～7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.84 (d, 1H, J = 8.10 Hz, PyH-4), 8.53 (d, 1H, J = 4.50 Hz, PyH-6)
C-17	0.97 (t, 3H, J = 7.50 Hz, CH$_3$), 1.22 (d, 3H, J = 6.30 Hz, CH$_3$), 1.52～1.63 (m, 2H, CH$_2$), 4.09～4.14 (m, 1H, CH), 4.50 (s, 2H, SCH$_2$), 6.06 (d, 1H, J = 6.00 Hz, NH), 7.07～7.11 (m, 1H, PyH-5), 7.24～7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 6.60 Hz, ArH-2, 6), 7.82 (d, 1H, J = 7.50 Hz, PyH-4), 8.52 (d, 1H, J = 4.80 Hz, PyH-6)
C-18	0.99 (s, 9H, 3CH$_3$), 3.26 (d, 2H, J = 6.30 Hz, NCH$_2$), 4.52 (s, 2H, SCH$_2$), 6.40 (s, 1H, NH), 7.08～7.13 (m, 1H, PyH-5), 7.24～7.33 (m, 3H, ArH-3, 4, 5), 7.41 (d, 2H, J = 6.60 Hz, ArH-2, 6), 7.88 (d, 1H, J = 7.50 Hz, PyH-4), 8.54 (d, 1H, J = 4.80 Hz, PyH-6)
C-19	1.00～1.83 (m, 14H, 5cycloCH$_2$, CH, CH$_3$), 4.03～4.10 (m, 1H, CH), 4.50 (s, 2H, SCH$_2$), 6.18 (d, 1H, J = 8.10 Hz, NH), 7.06～7.32 (m, 5H, ArH), 7.41 (d, 1H, J = 6.60 Hz, PyH-5), 7.83 (d, 1H, J = 7.65 Hz, PyH-4), 8.52 (d, 1H, J = 4.50 Hz, PyH-6)
C-20	2.34 (s, 3H, CH$_3$), 4.54 (s, 2H, SCH$_2$), 7.13～7.49 (m, 10H, ArH, ArH′, PyH-5), 7.95 (d, 1H, J = 7.20 Hz, PyH-4), 8.00 (s, 1H, NH), 8.58 (d, 1H, J = 4.65 Hz, PyH-6)
C-21	2.35 (s, 3H, CH$_3$), 2.39 (s, 3H, CH$_3$), 4.50 (s, 2H, SCH$_2$), 6.77 (s, 1H, PyH-5′), 7.08～7.13 (m, 1H, PyH-5), 7.23～7.31 (m, 3H, ArH-3, 4, 5), 7.44 (d, 2H, J = 7.20 Hz, ArH-2, 6), 7.87 (d, 1H, J = 7.50 Hz, PyH-4), 8.01 (s, 1H, PyH-3′), 8.48 (d, 1H, NH), 8.57 (d, 1H, J = 4.80 Hz, PyH-6)
C-22	2.32 (s, 9H, 3CH$_3$), 4.46 (s, 2H, SCH$_2$), 6.93 (s, 2H, ArH-3′, 5′), 7.09～7.16 (m, 1H, PyH-5), 7.22～7.33 (m, 3H, ArH-3, 4, 5), 7.42 (d, 2H, J = 6.90 Hz, ArH-2, 6), 7.60 (s, 1H, NH), 8.02 (d, 1H, J = 7.80 Hz, PyH-4), 8.59 (d, 1H, J = 3.90 Hz, PyH-6)
C-23	3.85 (s, 3H, CH$_3$), 4.52 (s, 2H, SCH$_2$), 6.90 (s, 1H, NH), 6.99～7.43 (m, 7H, ArH-3, 4, 5, 4, 5, 6, PyH-5), 7.44 (d, 2H, J = 6.60 Hz, ArH-2, 6), 7.92 (d, 1H, J = 7.20 Hz, PyH-4), 8.51 (d, 1H, J = 7.50 Hz, ArH-3′), 8.58 (d, 1H, J = 5.10 Hz, PyH-6)
C-24	2.38 (s, 3H, CH$_3$), 4.55 (s, 2H, SCH$_2$), 7.14～7.33 (m, 7H, ArH-3, 4, 5, 3′, 4′, 5′, PyH-5), 7.44 (d, 2H, J = 7.50 Hz, ArH-2, 6), 7.79 (s, 1H, NH), 8.04 (d, 1H, J = 7.50 Hz, PyH-4), 8.61 (d, 1H, J = 4.80 Hz, PyH-6)
C-25	2.36 (s, 3H, CH$_3$), 4.56 (s, 2H, SCH$_2$), 7.14～7.34 (m, 7H, ArH-3, 4, 5, 3′, 4′, 5′, PyH-5), 7.42 (d, 2H, J = 7.50 Hz, ArH-2, 6), 7.79 (d, 1H, J = 8.40 Hz, PyH-4), 8.07 (s, 1H, NH), 8.61 (d, 1H, J = 4.65 Hz, PyH-6)
C-26	0.73 (t, 3H, J = 7.35 Hz, CH$_3$), 0.96 (t, 3H, J = 7.35 Hz, CH$_3$), 1.02～1.09 (m, 2H, CH$_2$), 1.33～1.45 (m, 4H, 2CH$_2$), 1.60～1.68 (m, 2H, CH$_2$), 2.96 (t, 2H, J = 7.65 Hz, NCH$_2$), 3.46 (t, 2H, J = 7.65 Hz, NCH$_2$), 4.48 (s, 2H, SCH$_2$), 7.03～7.07 (m, 1H, PyH-5), 7.21～7.30 (m, 3H, ArH-3, 4, 5), 7.38～7.42 (m, 3H, ArH-2, 6, PyH-4), 8.48 (d, 1H, J = 3.90 Hz, PyH-6)

2 生物活性

按《国家南方农药创制中心生测标准程序》,对所有化合物进行了杀虫、杀菌、除草的室内生物活性测试,由于所有化合物基本无杀菌活性,而在杀虫活性方面,仅对淡色库蚊表现出一定的活性。故本文仅介绍对淡色库蚊及除草活性的测试方法。称取一定量的药物,加入质量分数为 2%的 DMF使其溶解,用无菌水稀释成 1 000 mg/L 母液。然后再用无菌水分别稀释成 500、250、125、100 mg/L 系列浓度药液备用。

2.1 杀虫及除草活性测定

采用 SOP叶片浸渍法,测试化合物在 50 mg/L 浓度下对淡色库蚊 *Culex pipiens pallens*的杀虫活性。试验重复 3次,设空白对照。

采用平皿法,测定化合物在 100 mg/L 浓度下对稗草 *Echinochloa crusgalli* Link.、马唐 *Digitaria sanguinalis*、苋菜 *Ambrosia tricolor* Linn. 的除草活性。试验重复 3次,设空白对照。

2.2 结果与讨论

由测定结果 (表 3、表 4)可见,部分化合物具有明显的杀虫和除草 (白化)活性。

表 3　50 mg/L 浓度下部分化合物对淡色库蚊的致死率

Table 3　The motality to *Culex pipiens pallens* of some compounds at 50 mg/L

化合物 Compd.	死亡率 Mortality (%)
C-9	100
C-10	100
C-11	100
C-18	88
C-24	83

从杀虫活性测试结果可以看出,化合物 C-9、C-10、C-11、C-18、C-24、C-26 对淡色库蚊表现出良好的致死活性,其中 C-9、C-10、C-11 在浓度为 50 mg/L 时致死率皆为 100%,而这些化合物结构中的 R^1、R^2 基团为吡啶基及烷基,因此可进一步对 2-苄硫基 N-吡啶基、N-环烷基烟酰胺结构的新化合物进行研究。

表 4　100 mg/L 下部分化合物的除草活性

Table 4　Herbicidal activity of some compounds at 100 mg/L

化合物 Compd.	白化率 Albino rate (%)		
	苋菜 *A. tricolor*	稗草 *E. crusgalli*	马唐 *D. sanguinalis*
C-3	>80	>80	>80
C-6	>80	>80	>80
C-11	0	>80	0
C-15	>80	>80	>80
C-16	50	0	0
C-17	50	>80	>50

从除草活性测试结果可以看出, C-3、C-6、C-15对稗草的白化度均大于 80%; C-3、C-6、C-11、C-15、C-17 对马唐的白化度均大于 80%; C-3、C-6、C-15 对苋菜的白化度均大于 80%。大致可以看出, C-3、C-6、C-15 对杂草具有一定的白化活性,说明此类化合物对杂草的光合作用可能具有一定的影响。从结构上看,这些化合物中的 N取代基均为烷基,因此若以其为母体,进一步进行修饰和改造,极有可能开发出新型的除草剂。

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