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Novel 2′-hydroxylfurylchalcones: synthesis and biological activity

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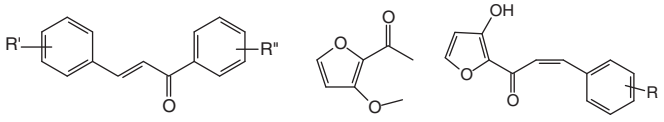
ABSTRACT

Twelve novel 2′-hydroxylfurylchalcones have been synthesized by Claisen–Schmidt condensation with galactosylisomaltol, a reagent prepared from lactose. The procedures are environmentally benign and economical. All the compounds are identified by IR, ^{1}H NMR and ^{13}C NMR spectroscopy and by mass spectrometry. Preliminary bioassays indicate that all the title compounds show moderately high herbicidal activities against the height and/or the fresh weight of the seedlings of cucumber, rape, amaranth, wheat, sorghum and Chinese sprangletop at 7.5 g of active ingredient per hm^2. However, the compounds exhibit weak fungicidal activities against cucumber powdery mildew, and no activities against rice blast, cucumber grey mould and cucumber downy mildew. The structure–activity relationships are discussed. The present work demonstrates that 2′-hydroxylfurylchalcones could be used as potential lead compounds for further study of novel herbicides.

1. Introduction

Chalcones, the precursors of flavonoids, are widely distributed in edible plants such as vegetables, fruits, spices, tea and soy-based foodstuffs.[1] Hydroxylated chalcones mostly exhibit free-radical quenching properties, and therefore display many biological activities, for example, anti-inflammatory, antimicrobial, antifungal, antioxidant, cytotoxic, antitumour and anticancer activities.[2] The development of chalcone-based drugs has been given considerable attention recently.[3] Chemically they consist of open-chain flavonoids in which the two aromatic rings are joined by a three-carbon α,β-unsaturated carbonyl system (structure **A**). The structural modifications on the two aromatic rings provide some structural bases for different activities.[4]

2-Acetyl-3-methoxyfuran (structure **B**), a secondary metabolite that was purified from the broth of Actinomycete SPRI-10304, showed considerable control efficiency against cucumber powdery mildew (*Erysiphe cichoracearum*). Its bioisosteric structure was presumed to be very similar to that of methoxyacrylic acid, a well-known strobilurins fungicide.[5] It is of interest to carry out further structural modifications to generate potential intermediates for improving pesticide activity. Galactosylisomaltol, a water-soluble, nonvolatile, nonenzymic browning product that is formed by the action of free amino acids during the bread-baking process, is chemically prepared by the condensation of lactose and maltose with secondary amino acids. Since the active methyl groups on galactosylisomaltol can then be condensed with aldehydes to generate chalcone-like compounds,[6] we designed the general structure **C** that was spliced by active groups of 2-acetyl-3-methoxyfuran and chalcone for the purpose of obtaining an optimized compound with improved biological activity. Twelve new 2′-hydroxylfurylchalcones were then synthesized (Scheme 1). Interestingly, some compounds did not show antifungal activity, but revealed good herbicidal activities. This research to some degree extends the knowledge of the physicochemical and biological properties of novel chalcones as potential herbicides. Herein, the synthesis of these 2′-hydroxylfurylchalcones is reported as shown in Scheme 1. Antifungal activity in vivo and whole plant herbicidal activity are determined, and the primary structure–activity relationships among those novel compounds are also discussed.



A B C

2. Results and discussion

Many biologically active agents are usually discovered by either of two methods: (i) mass screening or (ii) chemical modification of diverse natural products. Those with antifungal activity, such as nereistoxins and strobilurins, have been exploited as excellent pesticides to protect crops from the damages caused by field pests.[7] Indeed, (*E*)-1-(3′-*O*-β-D-galactopyranosyloxy-2′-furanyl)-3-(3″-hydroxy-4″-methoxyphenyl)-2-propen-1-one was previously

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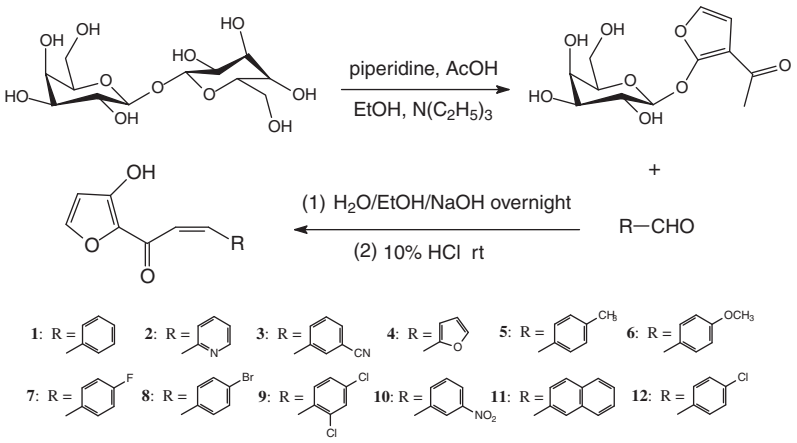

Scheme 1. General synthetic route for the title compounds (**1**–**12**).

synthesized by the aldol condensation of galactosylisomaltol with isovanillin and acid hydrolysis in a yield of 53.9%.[6] We improved the efficiency of the reaction by direct Claisen–Schmidt condensation and the hydrolysis of the galactosyl moiety in one step under alkaline conditions and obtained 2′-hydroxylfurylchalcones in yields of 63–84% within 24 h at room temperature. There was no need to protect the hydroxyl groups, and ethanol and water were used as solvents. All title compounds were characterized by IR, NMR (^{1}H, ^{13}C and COSY) spectroscopy and by mass spectrometry. The purity was established by TLC and microanalysis. The stereochemistry around the olefinic carbon–carbon bond was established using the corresponding ^{1}H NMR coupling constant.[6]

Antifungal and antibacterial activities of chalcones have been well documented. Licochalcone A shows antibacterial activity against spore-forming bacteria.[8] 5-Methylfuryl chalcones and 5-nitrofuryl chalcones that were modified from the structure of daphneolone show significant in vitro anti-plant pathogenic fungi activities.[9] Bioassays showed that the 2′-hydroxylfurylchalcones (**1**–**12**) possessed less than 10% control efficiency on cucumber powdery mildew and no activities on rice blast, cucumber grey mould and cucumber downy mildew (data not shown). However, most of them showed broad-spectrum and high herbicidal activities in postemergence treatments against three monocotyledonous and three dicotyledonous plants. Data are shown in Tables 1 and 2. Although the 2′-hydroxylfurylchalcones did not block seed germination, the growth of all seedlings was inhibited, their stems were slender and thin, and their fresh weight was decreased significantly. Compound **7** exhibited the highest inhibitory rate with about 56.8% against the seedling height of *Cucumis sativus*, and **11** showed the strongest activity against the fresh weight gain of *Amaranthus mangostanus* seedlings at a rate of 90.6%. In case of *Leptochloa chinensis* seedlings, the 2′-hydroxylfurylchalcones did not affect their height significantly, but **8** showed an inhibitory rate of 66.7% on its fresh weight gain. Obviously, the 2′-hydroxylfurylchalcones possessed higher activity against dicotyledons and less activity against monocotyledons than that of a commercial herbicide, haloxyfop-*p*-methyl, (methyl (*R*)-2-{4-[3-chloro-5-(trifluoromethyl)-2-pyridyloxy]phenoxy}propionate).

As substituent R is the only variable in the structure of the 2′-hydroxylfurylchalcones, its steric and electrostatic properties are naturally the most significant factors in determining the herbicidal activity. Activities of the compounds differ so much among individual plants that practically no definite conclusion regarding the relationship between structure and biological activity can be made at the present time. Nonetheless, in dicotyledonous plants the highest potencies were exhibited with compounds **4** and **8**–**12**. The high activity of naphthalene-2-yl derivative (**11**) could be the result of its high lipophilicity. Good activities of compounds **8**–**10** and **12** are in agreement with other reports that confirm the positive influence of electron-withdrawing groups (EWG) on the biological activities of chalcones.[10] In derivative **4**, the oxygen atom in the furan ring probably behaves as an EWG. Compound **3**, which has an electron-withdrawing cyano group in the *meta*-position, was not a very strong inhibitor. This could be explained by the

Table 1
Average inhibitory rates (% control) of 12 title compounds against three dicotyledons *C. sativus*, *B. campestris* and *A. mangostanus* at 15 days post-treatment

	Chemicals	Concentrations (g a.i./hm^2)[a]	*C. sativus*		*B. campestris*		*A. mangostanus*	
	Substituted moieties		Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
1	C_6H_5	7.5	33.7	1.3	38.1	60.3	18.8	32.6
2	2-C_5H_4N	7.5	31.0	33.1	52.4	31.8	18.8	23.9
3	3-CNC_6H_4	7.5	33.3	13.7	14.3	−5.9	37.5	31.7
4	2-C_4H_3O	7.5	36.1	49.7	38.1	82.1	12.5	69.6
5	4-$CH_3C_6H_4$	7.5	32.7	39.3	33.3	45.9	12.5	72.2
6	4-$OCH_3C_6H_4$	7.5	33.3	35.3	38.1	72.3	37.5	54.8
7	4-FC_6H_4	7.5	56.8	17.5	19.0	15.1	6.3	24.3
8	4-BrC_6H_4	7.5	40.5	34.5	52.4	66.7	37.5	71.7
9	2,4-$Cl_2C_6H_3$	7.5	35.1	37.3	42.9	87.2	18.8	69.6
10	3-$NO_2C_6H_4$	7.5	46.8	40.6	52.4	85.9	25.0	74.8
11	2-$C_{10}H_7$	7.5	41.3	44.0	52.4	72.9	37.5	90.6
12	4-ClC_6H_4	7.5	36.5	68.2	52.4	83.5	37.5	81.2
Haloxyfop-*p*-methyl		7.5	42.1	31.5	44.4	17.2	2.1	21.6

[a] a.i.: Active ingredient.

Table 2
Average inhibitory rates (% control) of 12 title compounds against three monocotyledons *T. aestivum*, *S. vulgare* and *L. chinensis* at 15 days post-treatment [a]

	Chemicals	Concentrations (g a.i./hm^2)[b]	*T. aestivum*		*S. vulgare*		*L. chinensis*	
	Substituted moieties		Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
1	C_6H_5	7.5	37.2	46.2	55.3	36.0	−4.4	31.3
2	2-C_5H_4N	7.5	37.0	40.9	13.6	11.3	6.7	37.4
3	3-CNC_6H_4	7.5	30.5	36.1	34.0	24.0	−12.3	12.4
4	2-C_4H_3O	7.5	24.4	49.6	4.0	12.4	−3.2	56.1
5	4-$CH_3C_6H_4$	7.5	28.1	53.0	−3.8	32.3	−10.1	47.8
6	4-$OCH_3C_6H_4$	7.5	35.4	53.3	ND	ND	2.1	60.4
7	4-FC_6H_4	7.5	37.0	40.6	ND	ND	3.5	19.0
8	4-BrC_6H_4	7.5	42.5	64.2	ND	ND	4.2	66.7
9	2,4-$Cl_2C_6H_3$	7.5	39.5	63.4	ND	ND	−0.7	57.1
10	3-$NO_2C_6H_4$	7.5	33.9	52.5	ND	ND	1.4	63.1
11	2-$C_{10}H_7$	7.5	27.1	45.4	ND	ND	−7.4	55.9
12	4-ClC_6H_4	7.5	41.8	64.6	ND	ND	−3.9	52.6
Haloxyfop-*p*-methyl		7.5	100.0	100.0	100.0	100.0	100.0	100.0

[a] ND: Not determined.
[b] a.i.: Active ingredient.

polar character of the CN group. In monocotyledonous plants, the results are less consistent, but relationships similar to those for dicotyledonous plants can be observed as well.

In summary, the convenience of the synthetic method and the herbicidal activity of the title compounds, novel synthetic 2′-hydroxylfurylchalcones, suggest that they could be used as possible lead compounds for further developing new herbicides for use in agriculture.

3. Experimental

3.1. Instruments and reagents

Melting points were obtained via a Büchi Melting Point B-540 apparatus (Büchi Labortechnik AG, Switzerland) and are uncorrected. ^{1}H and ^{13}C NMR spectra were performed on a Bruker AM-400 (400 MHz) spectrometer in $CDCl_3$, DMSO or acetone with tetramethylsilane as the internal standard. The chemical shifts are reported in parts per million (ppm). EI high-resolution mass spectra (HREIMS) were carried out with a MicroMass GCT CA055 spectrometer. The reagents and solvents were commercially available and were purified by conventional methods. Only those compounds with purity around 95% were tested for biological activity.

3.2. General procedure for the syntheses of title compounds

Galactosylisomaltol (3-*O*-β-D-galactopyranosyloxy-2-furanyl methyl ketone) was prepared by the method of Hodge et al.[6] A Claisen–Schmidt condensation with NaOH was used to synthesize the title compounds (Scheme 1) by reacting the galactosylisomaltol with appropriate aryl aldehydes.[11] None of the compounds have been reported before.

To a mixture of galactosylisomaltol (0.58 g, 2.0 mmol) and aryl aldehydes (2.0 mmol) in EtOH (15 mL) was added dropwise a solution of NaOH (4.8 g, 12.0 mmol) in water (10 mL) with stirring. The reaction mixture was stirred at room temperature for 12 h. When the reaction was complete, most of the EtOH was removed by vacuum distillation, and ice-cold water (15 mL) was added. The mixture was neutralized by HCl (2.0 mol L^{-1}) with continuous stirring. The precipitated product was dried by vacuum filtration to give a yellow solid. Recrystallization from EtOH or *N,N*-dimethylformamide (DMF) gave the desired compounds.

3.2.1. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-phenylprop-2-en-1-one (1)

Yield: 71%. Yellow crystalline solid, mp 108–109 °C; IR (KBr) ν_{max}: 3028, 2634, 1640, 1538, 1468, 1091 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ 7.81 (d, *J* 2.0 Hz, 1H), 7.70 (d, *J* 1.6 Hz, 1H), 7.68 (d, *J* 1.6 Hz, 1H), 7.65 (d, *J* 6.0 Hz, 2H), 7.43–7.48 (m, 3H), 6.42 (d, *J* 2.0 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 175.2, 154.6, 148.6, 141.0, 137.3, 135.2, 130.6, 129.5, 106.7; HREIMS: calcd for $C_{13}H_{10}O_3$ (M^+), 214.0630; found: 214.0629.

3.2.2. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-(pyridin-2-yl)prop-2-en-1-one (2)

Yield: 68%. Yellow solid, mp 189–191 °C; IR(KBr) ν_{max}: 3011, 2528, 1648, 1583, 1454, 1004, 782 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.66 (d, *J* 4.0 Hz, 1H), 8.07 (d, *J* 15.6 Hz, 1H), 7.81–7.87 (m, 2H), 7.68 (d, *J* 5.6 Hz, 1H), 7.63 (s, 1H), 7.40 (t, *J* 6.4 Hz, 1H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 171.5, 155.2 (d, *J* 22.8 Hz), 153.2, 150.4, 149.2 (d, *J* 24.0 Hz), 140.1, 137.7, 137.4, 126.9, 125.6, 124.9, 106.7; HREIMS: calcd for $C_{12}H_9NO_3$ (M^+), 215.0582; found: 215.0585.

3.2.3. 3-[(1*E*)-3-(3-Hydroxyfuran-2-yl)-3-oxoprop-1-en-1-yl]benzonitrile (3)

Yield: 63%. Pale-yellow solid, mp 162–163 °C; IR(KBr) ν_{max}: 2612, 2224, 1642, 1476, 1080, 878 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.16 (s, 1H), 8.02 (d, *J* 7.6 Hz, 1H), 7.86 (d, *J* 7.6 Hz, 1H), 7.82 (s, 1H), 7.62–7.72 (m, 3H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 174.8, 155.1, 148.9, 138.7, 137.3, 136.6, 133.6, 132.6, 132.3, 130.6, 125.8, 118.8, 112.6, 106.8; HREIMS: calcd for $C_{14}H_9NO_3$ (M^+), 239.0582; found: 239.0579.

3.2.4. (2*E*)-3-(Furan-2-yl)-1-(3-hydroxyfuran-2-yl)prop-2-en-1-one (4)

Yield: 79%. Yellow crystals, mp 164–166 °C; IR (KBr) ν_{max}: 3018, 2644, 1710, 1518, 1390, 1091 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ 7.84 (s, 1H), 7.78 (s, 1H), 7.39–7.49 (m, 2H), 6.93 (d, *J* 2.8 Hz, 1H), 6.63 (s, 1H), 6.39 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 174.8, 154.4, 151.6, 148.5, 146.0, 137.3, 127.7, 120.7, 116.5, 113.3, 106.7; HREIMS: Calcd for $C_{11}H_8O_4$ (M^+), 204.0423; found: 204.0422.

3.2.5. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-(4-methylphenyl)prop-2-en-1-one (5)

Yield: 65%. Yellow needles, mp 126–127 °C; IR (KBr) ν_{max}: 2966, 2629, 1642, 1538, 1460, 1246, 1091, 810 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ 7.78 (s, 1H), 7.55–7.66 (m, 4H), 7.25 (d, *J* 7.6 Hz, 2H), 6.41 (s, 1H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 174.8, 155.1, 148.9, 138.7, 137.3, 136.6, 133.6, 132.6, 132.3, 130.6, 125.8, 118.8, 112.6, 106.8; HREIMS: calcd for $C_{14}H_{12}O_3$ (M^+), 228.0786; found: 228.0789.

3.2.6. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-(4-methoxyphenyl)prop-2-en-1-one (6)

Yield: 71%. Yellow crystalline solid, mp 108–109 °C; IR (KBr) ν_{max}: 3062, 2579, 1721, 1577, 1750, 1321, 1151, 802 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ 7.77 (s, 1H), 7.63 (t, *J* 8.0 Hz, 3H), 7.48 (d, *J* 16.0 Hz, 1H), 7.01 (d, *J* 8.8 Hz, 2H), 6.40 (s, 1H), 3.80 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 175.6, 161.4, 154.3, 148.2, 141.1, 137.3, 130.4, 127.8, 121.1, 115.0, 106.7, 55.8; HREIMS: calcd for $C_{14}H_{12}O_4$ (M^+), 244.0736; found: 244.0737.

3.2.7. (2*E*)-3-(4-Fluorophenyl)-1-(3-hydroxyfuran-2-yl)prop-2-en-1-one (7)

Yield: 84%. Yellow crystalline solid, mp 143–144 °C; IR (KBr) ν_{max}: 3129, 2640, 1642, 1603, 1479, 1243, 818 cm^{-1}; ^1H NMR (400 MHz, acetone-d_6): δ 7.73–7.79 (m, 3H), 7.66 (d, *J* 15.6 Hz, 1H), 7.56 (d, *J* 16.0 Hz, 1H), 7.25–7.29 (m, 2H), 6.51 (s, 1H); ^{13}C NMR (100 MHz, acetone-d_6): δ 175.2, 164.7, 154.7, 148.5, 139.8, 137.3, 131.9, 130.8, 130.7, 123.4, 116.5, 116.3, 106.7; HREIMS: calcd for $C_{13}H_9FO_3$ (M^+), 232.0536; found: 232.0539.

3.2.8. (2*E*)-3-(4-Bromophenyl)-1-(3-hydroxyfuran-2-yl)prop-2-en-1-one (8)

Yield: 72%. Yellow crystalline solid, mp 199–201 °C; IR (KBr) ν_{max}: 3123, 2685, 1634, 1485, 875, 810 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ 7.83–7.89 (m, 4H), 7.73 (s, 1H), 7.65 (d, *J* 16.0 Hz, 1H), 7.51 (d, *J* 8.4 Hz, 1H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 174.4, 155.3, 149.2, 137.3, 135.5, 135.1, 134.7, 132.1, 130.0, 129.6, 128.6, 127.0, 106.7; HREIMS: calcd for $C_{13}H_9BrO_3$ (M^+), 293.9730; found: 293.9731.

3.2.9. (2*E*)-3-(2,4-Dichlorophenyl)-1-(3-hydroxyfuran-2-yl)prop-2-en-1-one (9)

Yield: 70%. Yellow crystalline solid, mp 177–179 °C; IR (KBr) ν_{max}: 2990, 2542, 1592, 1701, 1499, 1313, 856, 722 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.20 (d, *J* 16.0 Hz, 1H), 7.69 (d, *J* 8.8 Hz, 1H), 7.47–7.57 (m, 2H), 7.39 (s, 1H), 7.23–7.31 (m, 1H), 6.36 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.0, 147.0, 138.0, 136.8, 136.6, 136.2, 132.2, 130.1, 129.8, 128.4, 127.5, 123.2, 105.2; HREIMS: calcd for $C_{13}H_8O_3{}^{35}Cl_2$ (M^+), 281.9850; found: 281.9851; calcd for $C_{13}H_8O_3{}^{37}Cl_2$ (M^+), 285.9791; found: 285.9816.

3.2.10. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-(3-nitrophenyl)prop-2-en-1-one (10)

Yield: 73%. Pale yellow solid, mp 186–188 °C; IR (KBr) ν_{max}: 2816, 2021, 1849, 1552, 1376, 1187, 768 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.48 (s, 1H), 8.23 (d, *J* 8.0 Hz, 1H), 8.13 (d, *J* 7.6 Hz, 1H), 7.71–7.82 (m, 4H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 174.6, 155.1, 149.0, 148.8, 138.6, 137.3, 137.1, 134.5, 131.0, 126.2, 124.7, 122.8, 106.8; HREIMS: calcd for $C_{13}H_9NO_5$ (M^+), 259.0481; found: 259.0482.

3.2.11. (2*E*)-1-(3-Hydroxyfuran-2-yl)-3-(naphthalen-2-yl)prop-2-en-1-one (11)

Yield: 80%. Yellow crystals, mp 168–170 °C; IR (KBr) ν_{max}: 3124, 2528, 1677, 1618, 1453, 1067 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ 8.16 (s, 1H), 8.03 (d, *J* 7.6 Hz, 2H), 7.87 (d, *J* 7.6 Hz, 2H), 7.82 (s, 1H), 7.69 (m, 3H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 175.3, 154.7, 148.6, 141.1, 134.2, 134.1, 133.4, 132.8, 130.3, 129.1, 128.9, 128.1, 127.7, 127.2, 124.1, 123.9, 106.7; HREIMS: calcd for $C_{17}H_{12}O_3$ (M^+), 264.0786; found: 264.0783.

3.2.12. (2*E*)-3-(4-Chlorophenyl)-1-(3-hydroxyfuran-2-yl)prop-2-en-1-one (12)

Yield: 67%. Yellow crystalline solid, mp 165–167 °C; IR (KBr) ν_{max}: 3023, 2733, 1715, 1678, 1575, 1321, 778 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ 7.83–7.89 (m, 4H), 7.73 (s, 1H), 7.66 (d, *J* 5.2 Hz, 1H), 7.50 (d, *J* 8.0 Hz, 1H), 6.41 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 177.2, 166.7, 154.7, 151.5, 139.5, 134.3, 131.5, 130.7, 130.6, 123.4, 116.5, 116.3, 107.0. HREIMS: calcd for $C_{13}H_9{}^{35}ClO_3$ (M^+), 248.0216; found: 248.0217; calcd for $C_{13}H_9{}^{37}ClO_3$ (M^+), 250.0246; found: 250.0297.

3.3. Biological activity assays

3.3.1. In vivo assays for fungicidal activity

In vivo assays were investigated on four plant diseases such as rice blast (*Magnaporthe grisea*), cucumber grey mould (*Botrytis cinerea*), cucumber downy mildew (*Pseudoperonospora cubensis*) and cucumber powdery mildew (*E. cichoracearum*). The detailed procedures were according to those in the previous reports.[12] The compounds were dissolved in DMF and emulsified by water containing Triton X-100 (0.2 mL L^{-1}) at a range of concentrations, and then the solutions were sprayed onto plants. Fungal spores were inoculated on the plant leaf at 1 day after treating with the compounds. The same treatments that were sprayed and inoculated with the appropriate solvents, only, were utilized as controls.

3.3.2. Whole plant assays on herbicidal activity

A seedling assay on 2% agar medium was made for rapidly evaluating the activities of these compounds as herbicides according to the method of Burke et al. with minor modification.[13] The stock solution of the compounds dissolved with DMF was added to the melting medium by making the final doses at 7.5 g a.i./hm^2. The seeds of *C. sativus*, *Brassica campestris*, *A. mangostanus*, *Triticum aestivum*, *Sorghum vulgare* and *L. chinensis* were inoculated on the medium for 15 days under sunlight, and then the seedling height and the seedling fresh weight were measured. Each treatment was replicated three times. The same treatment without test compounds was used as a control. Inhibitory rates were calculated by referring to the control as in the following formula:

$$\text{Inhibitory rate } (\%) = \frac{\text{control} - \text{treated}}{\text{control}} \times 100\%$$

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Supplementary data

Supplementary data (^1H NMR spectra for compounds **1–12**) associated with this article can be found, in the online version, at doi:10.1016/j.carres.2010.05.017.

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