Asian Journal of Chemistry Vol. 18, No. 4 (2006), 2831–2839

Fungicidal Properties of Some New Copolymer Resins Derived from 2,4-Dihydroxyphenylethyl Ketone and 2,4-Dihydroxyphenylbenzyl Ketone

CH. SANJEEVA REDDY* and P. JALAPATHI
Department of Chemistry, Kakatiya University, Warangal-506 009, India
E-mail: chsrkuc@yahoo.co.in

Fungicidal properties of some new copolymer resins, synthesized by condensing 2,4-dihydroxyphenyl ethyl ketone/2,4-dihydroxy phenyl benzyl ketone with substituted benzoic acids and formaldehyde or furfural in the presence of acid or base catalyst was assayed against *Dreschlera halodes* and *Fusarium oxysporum* causing post-harvest disease of tomatoes. The homo and copolymer resins have been characterized by spectral analysis, solubility characteristics and thermal analysis. All homo resins were devoid of antifungal activity, while some copolymer resins (obtained with comonomer) were toxic at one or the other concentration. Within the copolymer resins, furfural based resins were highly active against both the fungi and caused total germination inhibition at 640 μg/mL under investigation. Both the pathogens were equally sensitive to the copolymer resins.

Key Words: Fungicidal properties, Copolymer resins.

INTRODUCTION

Polymer coatings showing microbicidal properties are useful in many domains including marine applications. In fact, bactericidal and fungicidal properties are granted to a coating by incorporating a biocide that is slowly released. These are made in two ways: (1) a molecular biocide is simply added to a classical binder, which becomes active by migrating out of the polymer matrix, (2) a biocidal compound is grafted to a polymer by a bond sensitive to hydrolysis. For example, organotin polymers based on acrylic monomers are used in antifouling paints[1–3]. The anchored biocide is released by a chemical reaction (hydrolysis) with seawater. The rate of diffusion is slower than in the first case, protection is effective and longer. However, in both cases, the biocidal activity depends on the liberation of the biocide to the environment, with two consequences, *viz.*, a progressive loss of activity with time and a hazard to the environment. A different approach is to bind a biocidal group to a polymer through a covalent (unhydrolysable) bond that will not be cleaved in the presence of microorganisms. If the chemical groups present at the surface of the modified polymer are active by contact with the cell membrane of microorganisms and if they are not modified

during the process, a permanent activity may be expected without liberation of toxic products to the environment.

Polymers may display biological activity even if they do not contain biologically active moieties or repeating units. Normally, the monomers of such polymers of their dimer model do not show the same activity, which confirms that the biological activity is polymer-specific and owing to the repetitive structure. The polymer backbone influences some of the most important biological properties of polymers with bound moieties[4–6]. Hence, polymers with antimicrobial activity have received special attention. Copolymer resins are good candidates for this function, because they are known to be effective against a wide spectrum of microorganisms such as bacteria, algae, fungi.

In recent years, much attention has been focussed on synthetic resins derived from hydroxy aromatic compounds because of their use as ligating reagents, ion-exchangers, thermal stabilizers, antifungal and antibacterial reagents[7–16]. In view of the above findings, it was considered worth while to study the antifungal activity of some newly synthesized homo and copolymer resins, which was not reported so far. In the present investigation, a number of copolymer resins have been synthesized by reacting 2,4-dihydroxyphenylethyl ketone (2,4-DHPEK)/ 2,4-dihydroxyphenylbenzyl ketone (2,4-DHPBK)-substituted benzoic acid- formaldehyde/furfural using hydrochloric acid or sodium hydroxide solution as the catalyst to compare the thermal, fungicidal and bactericidal properties.

EXPERIMENTAL

Substituted benzoic acids were used as co-monomers after purification. Formaldehyde (BDH) and furfural (SD Fine Chemicals Ltd., Boisar, India) were used as such; 2,4-dihydroxyphenylethyl ketone (2,4-DHPEK) and 2,4-dihydroxyphenylbenzyl ketone (2,4-DHPBK) were prepared from resorcinol, $ZnCl_2$ and propionic acid/phenylacetic acid using standard procedures[17] and their purity was checked with mixed melting point, Co-TLC and spectral analysis. Solvents and other chemicals used were of AnalaR grade.

Resin synthesis: A mixture of monomer (0.01 mol, 2,4-DHPEK/2,4-DHPBK) condensing reagent (0.05 mol, formaldehyde or furfural) and co-monomer (0.01 mol, benzoic acid in case of copolymer resin) was taken in an R.B. flask. Catalyst (2 mL of 6 N HCl or 10 N aq. NaOH solution) was added slowly to the reaction mixture. The contents were refluxed to 100–120°C for 6–8 h with periodical shaking. After completion of the reaction, the mixture was poured in ice-cold water, filtered and washed with hot water to remove unreacted reactants. Finally, the resin was washed with alcohol, dried at vacuum and used for assaying fungicidal activity.

Antifungal assay: Monosporic cultures of *Drechlera halodes* and *Fusarium oxysporum* isolated from diseased fruits of tomato (*Lycopersicon esculentum*) and maintained on Asthana and Hawkers medium A mixture of glucose 5 g, potassium nitrate 3.5 g, potassium dihydrogen phosphate 1.7 g, magnesium sulphate 0.75 g, agar agar 15 g and distilled water 1 L was employed for these studies. The antifungal activity of the resins was assayed by glass slide humid chamber

technique as described by Horsfall[18]. Different concentrations of homo and copolymer resins (as listed in Table-3) were prepared by tube dilution technique. The spore suspension of different fungi was prepared in polymer (resin) solution of different concentrations so as to appear 30–40 spores in high power microscope field. A drop of such solution was placed on a sterilized glass slide and 100% relative humidity was maintained by placing moistened sterilized blotter at the bottom of a petri dish and incubated at 27 ± 2°C for 8 h. At the end of incubation period, spores germinated and non-germinated were scored in 10 randomly selected microscopic fields so as to cover 350–400 spores. The percentage of spore germination inhibition was calculated with the help of the formula

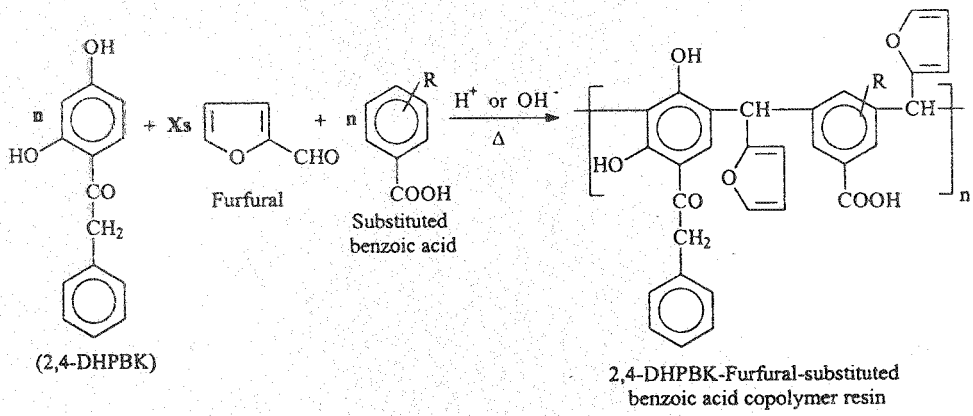
Percentage of spore germination inhibition

$$= 100 - \left(\frac{\text{Percentage of spore germination in treated}}{\text{Percentage of spore germination in control}} \times 100 \right)$$

Water in place of polymer (resin) solution served as control. The experiment was conducted three times, since the difference among replicates was insignificant; average of three replicates was recorded to calculate the percentage of the spore germination inhibition.

RESULTS AND DISCUSSION

The poly condensation reaction of 2,4-dihydroxyphenylbenzyl ketone(2,4-DHPBK) with furfural and substituted benzoic acid may be represented as in **Scheme-1.**



Scheme-1

A large number of homo and copolymer resins were prepared using different combinations of monomers (2,4-DHPEK/2,4-DHPBK), condensing agents (formaldehyde/furfural) and co-monomers (*ortho* and *para* substituted benzoic acids, in case of copolymer resins) in the presence of acid or base catalyst.

All these homo and copolymer resins have been characterized by spectral analyses (IR, ^{1}H NMR), solubility characteristics, molecular weight determination, viscosity measurements and thermal analysis. The spectral data and possible assignments for a few copolymer resins are given in Tables 1 and 2.

TABLE -1
INFRARED SPECTRAL ANALYSIS OF COPOLYMER RESINS

ν (cm^{-1})	Assignment of absorption bands
2,4-Dihydroxyphenylbenzylketone-furfural-ortho-hydroxybenzoic acid resin:	
3392	O—H stretching of hydroxy group of 2,4-DHPBK moiety
2970	C—H stretching of aromatic ring (benzene and furan)
1700	C=O stretching of carboxylic acid group of PCBA moiety
1624	C=O stretching of $COCH_2Ph$ group of 2,4-DHPBK moiety
1550	C=C stretching of aromatic ring
1430	—C—H bending vibration of methylene bridge
1370	In-plane O—H bending vibration of 2,4-DHPBK moiety
1235	C—O stretching vibration of 2,4-DHPBK moiety of the resin
970, 816	Vibrations of furanyl ring of furfural moiety of the resin
2,4-Dihydroxyphenylbenzylketone-furfural-para-aminobenzoic acid resin:	
3423 (broad)	O—H and N—H stretching of hydroxy group of 2,4-DHPBK moiety and amino group of PABA moiety
2950	C—H stretching of aromatic ring (benzene and furan)
1710	C=O stretching of carboxylic acid group of PABA moiety
1620	C=O stretching of $COCH_2Ph$ group of 2,4-DHPBK moiety
1608	C=C stretching of aromatic ring
1495	—CH— bending vibration of methyne bridge
1237	C—O stretching vibration of 2,4-DHPBK moiety of the resin
976, 915 and 860	Vibrations of furanyl ring of furfural moiety of the resin

X-ray diffraction studies showed that the resins were amorphous in nature as there was no sharp peak(s) in the intensity *vs.* scattering angle (2θ) curve. Formaldehyde based resins exhibited different colours (depending on the chemical nature of the co-monomer), while furfural based resins were dark brown-to-black. These resins show good adhesive property and are resistant to many chemicals including concentrated acids and alkaline solutions. In fact, it was observed that these resins are very good surface coatings with a good adhesion, and can be developed as heat and chemical resistant surface coatings which are durable with long life compared to the conventional acrylics, PVC and polyurethane coatings, hence concentrated on the biocidal properties.

Solubility behaviour of the resins was determined by using solvents of varying solubility parameters. All these resins were soluble in DMF, DMSO, THF and $CHCl_3$, sparingly soluble in acetone and insoluble in water, alcohol, ether, benzene and hexane. Number-average-molecular weight ($\overline{M}_n$) of the resins were determined by non-aqueous conductometric titrations[19, 20] and were found in the

range of 2500–3000. From DSC and TGA studies it was observed that the resins show high glass-transition-temperature (T_g), high decomposition temperature and 50% weight loss occurred above 500°C.

TABLE-2
^{1}H NMR SPECTRAL ANALYSIS OF COPOLYMER RESINS

δ (ppm)	Possible assignments
2,4-Dihydroxyphenylbenzylketone-furfural-ortho-hydroxybenzoic acid resin:	
4.2 (2H) s	—CH_2— group protons of 2,4-DHPBK moiety of the resin
6.3 (1H) s	*para*-OH group proton of 2,4-DHPBK moiety of the resin
7.3 (5H) s	Phenyl group protons of 2,4-DHPBK moiety of the resin
7.35 (1H) s	Orthohydrogen of 2,4-DHPBK moiety of the resin
7.4 (1H) s	Orthohydroxy of OHBA moiety of the resin
6.8–7.9 (3H)	Furanyl ring protons of furfural moiety of the resin
12.4 (1 H) s	*ortho*-OH group proton of 2,4-DHPBK moiety
12.6 (1H) s	—OH group proton of OHBA moiety of the resin
14.2 (1H) s	Carboxylic acid group proton of OHBA moiety of the resin
2,4-Dihydroxyphenylbenzylketone-furfural-para-aminobenzoic acid resin:	
3.3 (2H) s (broad)	—NH_2 group protons PABA moiety of the resin
4.2 (2H) s	—CH_2— group protons of 2,4-DHPBK moiety of the resin
6.3 (1H) s	*para*-OH group proton of 2,4-DHPBK moiety
6.32 (1H) s	Triaryl C—H group proton of the resin (overlapped)
7.3 (5H+H) s	Phenyl group protons and *ortho*-hydrogen of 2,4-DHPBK moiety of the resin
7.7 (2H) s	Orthohydrogens of PABA moiety of the resin
6.4-7.9 (3H)	Furanyl ring protons of furfural moiety of the resin
13.0 (1H) s	*ortho*-OH group (H-bonded) proton of 2,4-DHPBK moiety
14.2 (1H) s	Carboxylic acid group proton of PABA moiety of the resin

An observation of Table-3, which depicts the antifungal nature of the resins showed that the resins varied significantly in their antifungal activity. All homo resins namely, 2,4-DHPEK-FM, 2,4-DHPEK-FF, 2,4-DHPBK-FM and 2,4-DHPBK-FF and some copolymer resins such as 2,4-DHPEK-FM-OCBA, 2,4-DHPEK-FM-OHBA, 2,4-DHPE-FM-OABA and 2,4-DHPEK-FM-PABA failed to inhibit the spore germination of both the fungi under investigation. However, the other copolymer resins, obtained from substituted benzoic acids, were toxic and the degree of toxicity varied both with the chemical nature of the resin and the organism employed for testing.

TABLE-3
FUNGICIDAL (ANTIFUNGAL) ACTIVITY OF COPOLYMER RESINS

Copolymer resin	Concn, (μg/mL)	% of spore germination inhibition	
		D. halodes	*F. oxysporum*
2,4-DHPEK-FM-PCBA	160	43.0	62.1
	320	49.9	72.6
	480	67.3	81.4
	640	81.1	86.9
2,4-DHPEK-FF-OCBA	160	57.6	69.0
	320	71.2	78.2
	480	88.3	90.8
	640	98.7	99.6
2,4-DHPEK-FF-PCBA	160	56.2	69.8
	320	72.3	83.0
	480	89.8	89.7
	640	100.0	100.0
2,4-DHPEK-FF-OHBA	160	56.8	69.8
	320	72.7	83.0
	480	91.3	89.9
	640	96.7	98.9
2,4-DHPEK-FF-OABA	160	57.5	76.1
	320	67.1	82.7
	480	95.2	89.0
	640	97.7	98.8
2,4-DHPEK-FF-PABA	160	54.8	70.0
	320	69.8	81.2
	480	87.9	90.0
	640	100.0	100.0
2,4-DHPBK-FM-OCBA	160	52,3	70.8
	320	70.8	82.7
	480	74.6	86.6
	640	97.3	96.5
2,4-DHPBK-FM-PCBA	160	59.8	69.9
	320	70.0	83.4
	480	88.6	86.5
	640	99.0	98.3

Copolymer resin	Concn. (μg/mL)	% of spore germination inhibition	
		D. halodes	*F. oxysporum*
2,4-DHPBK-FM-OHBA	160	52.3	65.6
	320	63.3	69.5
	480	75.2	71.3
	640	87.8	72.3
2,4-DHPBK-FM-OABA	160	56.9	72.1
	320	67.5	83.9
	480	78.1	87.4
	640	93.2	94.6
2,4-DHPBK-FM-PABA	160	54.7	69.1
	320	69.1	75.3
	480	83.3	83.5
	640	98.0	100.0
2,4-DHPBK-FF-OCBA	160	58.8	69.6
	320	72.6	74.9
	480	91.4	93.3
	640	100.0	100.0
2,4-DHPBK-FF-PCBA	160	50.6	69.5
	320	73.7	78.6
	480	96.3	98.0
	640	100.0	100.0
2,4-DHPBK-FF-OHBA	160	54.9	70.6
	320	72.3	81.7
	480	98.8	99.4
	640	100.0	100.0
2,4-DHPBK-FF-OABA	160	57.3	69.8
	320	77.6	80.2
	480	100.0	100.0
	640	100.0	100.0
2,4-DHPBK-FF-PABA	160	56.1	67.7
	320	78.8	89.1
	480	100.0	100.0
	640	100.0	100.0

2,4-DHPEK = 2,4-dihydroxyphenyl ethyl ketone; FM = formaldehyde; 2,4-DHPBK = 2,4-dihydroxyphenyl benzyl ketone; FF = furfural; OHBA = orthohydroxybenzoic acid; OCBA = orthochlorobenzoic acid; PCBA = parachlorobenzoic acid; OABA orthoaminobenzoic acid; PABA = paraaminobenzoic acid.

2,4-DHPEK-FM-PCBA copolymer resin exhibited moderate antifungal activity, while 2,4-DHPBK-FM-OCBA, 2,4-DHPBK-FM-PCBA, 2,4-DHPBK-FM-OHBA, 2,4-DHPBK-FM-OABA, 2,4-DHPBK-FM-PABA, 2,4-DHPEK-FF-OCBA, 2,4-DHPEK-FF-PCBA, 2,4-DHPEK-FF-OHBA, 2,4-DHPBK-FM-PCBA copolymer resins were more active and exhibited good antifungal activity against both the plant pathogenic fungi.

The other copolymer resins namely 2,4-DHPBK-FF-OCBA, 2,4-DHPBK-FF-PCBA, 2,4-DHPBK-FF-OHBA, 2,4-DHPBK-FF-OABA and 2,4-DHPBK-FF-PABA were highly toxic as they caused total (100%) spore germination inhibition at 640 μg/mL concentration. In fact, these copolymer resins showed more than 50% inhibition of spore germination of both the fungi under investigation even at 160 μg/mL concentration.

F. oxysporum was relatively more sensitive than *D. halodes* as the percentage inhibition was more than 60 even at 160 μg/mL concentration. The co-monomer substituted benzoic acid in combination with other part of the resin was responsible for the antifungal activity, as homo resins failed to inhibit the spore germination. These resins whose antifungal potency was comparable with that of the standard (chlotrimazole) may be evaluated further to view them as the possible fungicidal, heat resistant, chemical resistant surface coatings mainly in marine applications. Interestingly these resins were also potent antibacterial agents[16], surpassing the standard, streptomycin sulphate and benzylpencillin.

In general, furfural based resins were more potent fungicidal agents when compared to formaldehyde based resins. Among the two monomers, 2,4-DHPBK was more potent than 2,4-DHPEK in combination with condensing agent (formaldehyde/furfural) and co-monomer. The order of fungitoxicity was amino > hydroxy > chloro substituted benzoic acids. It is pertinent to present here that the fungicidal activity of these copolymer resins is much more superior than the earlier reports made by using copolymer resins derived from hydroxy-acetophenone[8], resacetophenone and quinacetophenone[9] and picoline and lutidine[10].

Many parameters may influence the antifungal activity: modification of biocidal group during interaction with fungi, acidity or alkalinity of the medium, hardness of water, UV radiation, adsorption of organic products, etc. Antifungal activity of the resins under study could be referred to a number of causes like injurious effect on the cell wall or cell division, effect on permeability of cell membrane and cell enzyme system, chelation and precipitation of chemicals. Oxygen and nitrogen atoms present in the resin can act as hydrogen acceptors in metabolic systems and by doing so disturb the normal hydrogenation and dehydrogenation reactions in the cell. This might be the reason for high activity of furfural and *ortho-* or *para*-aminobenzoic acid based copolymer resins. The high activity of *para*-chlorobenzoic acid based copolymer resin against both pathogenic fungi may be due to the presence of chlorine atom at the *para* position, free from steric hindrance. In general, a synergistic structural effect may be playing its role in fungicidal activity.

The present observation may serve as a guide for designing new biocidal coatings that have the advantage of being non-polluting. Ideally, the activity may be permanent because the biocidal group (comonomer-substituted benzoic acid)

is not consumed during the course of interaction with microorganisms. In conclusion, 2,4-DHPBK-FF-substituted benzoic acid copolymer resins are excellent antifungal agents and may be exploited as surface coatings specially for marine applications.

REFERENCES

1. J. Hazziza-Laskar, N. Nurdin, G. Helary and G. Sauvet, *J. Appl. Polym. Sci.*, **50**, 801 (1993).
2. J. Hazziza-Laskar, G. Helary and G. Sauvet, *Makromol. Chem., Macromol. Symp.*, **47**, 383 (1991).
3. D. Battice and M. Hales, *J. Cell. Plastics*, **21**, 332 (1985).
4. D.H. Lewis (Ed.), Controlled Release of Bioactive Materials, Plenum Press, New York, p. 161 (1981).
5. M.V. Solovskii, E.V. Anufrieva, E.F. Panarim, V.D. Pantov and G.E. Afingenov, *Macromol. Chem.*, **183**, 1775 (1982).
6. E.P. Goldberg and A. Nakagima, Biomedical Polymers, Academic Press, New York, p. 401 (1980).
7. S. Mizobuchi and Y. Sato, *Agric. Biol. Chem.*, **49**, 1327 (1985).
8. A.P. Das, P.L. Nayak and S. Lenka, *J. Appl. Polym. Sci.*, **34**, 2139 (1987).
9. P.K. Nayak, S. Lenka and P.L. Nayak, *J. Appl. Polym. Sci.*, **41**, 1491 (1990).
10. P.K. Mohanty and S. Lenka, *J. Appl. Polym. Sci.*, **42**, 2261 (1991).
11. H.B. Pancholi and M.M. Patel, *J. Polym. Mater.*, **13**, 261 (1996).
12. P.K. Nayak, S. Lenka and P.L. Nayak, *J. Appl. Polym. Sci.*, **43**, 2329 (1991).
13. M. Senapati, S.P.N.S. Burma and P.L. Nayak, *J. Appl. Polym. Sci.*, **45**, 521 (1992).
14. S.P.N.S. Burma, S. Lenka and P.L. Nayak, *J. Appl. Polym. Sci.*, **44**, 1311 (1992).
15. Ch. Sanjeeva Reddy, B. Chandramouli, P. Jalapathi, S.M. Reddy and T. Rajakomuraiah, *J. Polym. Mater.*, **19**, 189 (2002).
16. Ch. Sanjeeva Reddy, P. Jalapathi, T. Rajakomuraiah and S.M. Reddy, *Proc. Nat. Acad. Sci. India*, **73B**, 205 (2003).
17. G.G. Bedlack, G.W.K. Caril, A. Robertson and B. Whallyeir, *J. Chem. Soc.*, 2961 (1950).
18. J.S. Horsfall, Principals of Fungicidial Action, Waltham MA, p. 176 (1956).
19. S.K. Chaterjee and N.D. Gupta, *J. Macromol. Sci. Chem.*, **2A**, 451 (1974).
20. R.N. Patel and S.R. Patel, *Angew. Makromol. Chem.*, **93**, 85 (1981).

(*Received*: 8 September 2005; *Accepted*: 5 May 2006) AJC-4807