JOURNAL OF PURE AND APPLIED MICROBIOLOGY, Sept. 2015. Vol. **9**(3), p. 1971-1977

TD-GC-MS Analysis on Antimicrobial Properties of *Vitex negundo* Wood/PF Bio Composites for Drug Store

Rui-lin He, Zi-xiang Chen, Ji-juan Zhang and Zhong-feng Zhang*

College of Furniture, Central South University of Forestry and Technology, Changsha 410004, China.

(Received: 25 April 2015; accepted: 04 July 2015)

The materials for drug store need be antimicrobial. However, Vitex negundo was easy to go mouldy. Therefore, Vitex negundo wood was pretreated by PF and made composite by hot pressing, the antimicrobial properties of wood/PF bio composites was analyzed by thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS). The results showed that *Vitex negundo* wood/PF bio composites contained much phenol and little formaldehyde, suggesting that wood/PF bio composites could inhibit mold growth. And the wood/PF bio composites could safely be used for drug store.

Key words: Drug store, *Vitex negundo*, Wood/PF bio composites, Antibacterial properties, TD-GC-MS.

Drugs were used to treat manage symptoms of infectious diseases, chronic diseases, and helped relieve suffering and pain. Drugs might be generally safe if they were correctly used and safely stored[1]. However, drugs have both benefits and risks, and there were all risks in taking any drug[2]. Especially, Patients couldn't be helped reduce the risk of harm if drugs were unintentionally polluted and took, resulting that more than 700,000 visits to hospital emergency departments only in the United States each year[3,4]. Though the guidance document had either a long-term or short-term drug need and put into place effective management systems to support them in the setting, drug poisoning continued to occur on a regular basis[5,6]. In remote rural areas and desolate mountains, drugs were polluted and took very much because storage apparatuses easy went moldy [7-16].

Vitex negundo, which was commonly known as the five-leaved chaste tree, was a large aromatic shrub with quadrangular, densely whitish, tomentose branchlets. It was widely used in folk medicine, particularly in South and Southeast Asia. *Vitex negundo* was used for treating stored garlic against pests and as a cough remedy in the Philippines. Roots and leaves used in eczema, ringworm and other skin diseases, liver disorders, rheumatic pain, spleen enlargement, gout, abscess, backache; seeds used as vermicide. It was also used to control population of mosquitoes. In the USA, hardiness zone 6–9, its purple flowers bloom most of the summer and it is a popular plant visited by bees and butterflies. However, Vitex negundo contained richly the extractives which had lots of constituents[10-32], and was easy to go mouldy. To be happy, phenol formaldehyde resin, which contained phenol and formaldehyde, had antibacterial effect. Therefore, Vitex negundo wood was pretreated by PF and made composite by hot pressing, the antimicrobial properties of wood/PF bio composites was analyzed by thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS).

MATERIALS AND METHODS

Vitex negundo, which was grown in Shaoyang Forest, was dried at 105°C for 10 h. Phenol formaldehyde resin had a relative molecular mass of 300 Da, a viscosity of 12–17 MPa·s at

* To whom all correspondence should be addressed.
E-mail: csfuzzf@163.com

25°C, a solid content of 40–42%, and a cure time of 80–100 s.

Sample preparation

Vitex negundo wood was soaked in phenol formaldehyde resin at room temperature for 30 h, and was air-seasoned for 2 days to about 5%. And the wood was soaked in phenol formaldehyde resin for 90 to 120 s, then dried for 2–3 days. The pieces were formed into wood/PF bio composites by hot pressing with the temperature of 160°C, pressure of 4 MPa, and time of 3 min. then wood/PF bio composites was crushed into 200mu powder[33].

TD-GC-MS analysis

Samples (5 g) were placed in the sample tubes of a Master TD thermal desorber (DANI Co., Ltd., Italy), and the sample tubes were purged with 120 °C He for 30 min. The trap adsorption temperature was set to 120 °C, trap resolution temperature to 130 °C, valve temperature to 130 °C, and transmission line temperature to 130 °C. The volatiles were desorped for 15 min and analyzed by an online linked gas chromatograph/mass spectrometer (GC/MS), an Agilent 6890N+5795C GCMSTM (Agilent Co., Ltd., USA), which was linked to a mass selective detector. An elastic quartz capillary column (DB-5MS; 30 m × 0.25 mm × 0.25 ìm) coated with a neutral phase (Hewlett-Packard-5 cross-linked 5% phenyl methyl silicone) was used. The carrier gas was helium and the injection port temperature was 280 °C. The GC temperature program began at 45 °C for 3 min, increased at 8 °C/min to 120 °C, then increased at 20°C /min to 300 °C, was held for 5 min, followed by a split injection at a ratio of 30:1. The MS program scanned over a range of 29–500 AMU (m/z), at an ionizing voltage of 70 eV. The flow velocity of the He carrier gas was 1.2 mL/min. Ion source temperature: 23 0 °C, quadropole temperature: 150 °C[34].

RESULTS AND DISCUSSION

The total ion chromatograms of *Vitex negundo* wood/PF bio composites as measured by TD-GC-MS are shown in Fig.1. The relative content of each component was counted by area normalization. The data was analyzed using the NIST standard MS map software[9-34]. Comparison with reported literature allowed individual components to be identified, and the results were listed in Table 1, Table 2 and Table 3.

According to GC/MS result, 20 components were identified from the 21 peaks of Y-1 samples which constituted 97.21% of the total peak area. The result showed that the components were acetic acid, phenol, phenol, benzaldehyde, 2-hydroxy-, nonanal, 2-furancarboxaldehyde, 5-(hydroxymethyl)-, salicyl alcohol, phenol, 2,6-dimethoxy-, 2,5-dihydroxypropiophenone, vanillin, phenol, 2-methoxy-4-(1-propenyl)-,(e)-, ethanone, 1-(4-hydroxy-3-methoxyphenyl)-, phenol, 2,4-bis(1,1-dimethylethyl), benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester, phenol, 2,6-dimethoxy-4-(2-propenyl)-, pentadecane, 2,6,10,14-tetramethyl, nonahexacontanoic acid, octacosyl heptafluorobutyrate, eicosane, 1,2-benzenedicarboxylic acid, bis 2-methylpropyl) ester, 1,4-dimethyl-8-isopropylidenetricyclo[5.3.0.0(4,10)]decane.

According to GC/MS result, 24 components were identified from the 24 peaks of J-1 samples. The result showed that the components were formaldehyde, hydrazine, 1,2-dimethyl-, acetic acid, 2-isopropoxyethylamine, formic acid, acetic acid, phenol, benzaldehyde, 2-hydroxy-, phenol, 4-methyl-, benzoic acid, 2-furancarboxaldehyde, 5-(hydroxymethyl)-, methenamine, salicyl alcohol, phenol, 2,6-dimethoxy-, benzaldehyde, 3-hydroxy-4-methoxy-, phenol, 2-methoxy-4-(1-propenyl)-(e)-, ethanone, 1-(4-hydroxy-3-methoxyphenyl)-, phenol, 2,4-bis(1,1-dimethylethyl), benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester, phenol, 2,6-dimethoxy-4-(2-propenyl)-, pentadecane, 2,6,10,14-tetramethyl, ethanol, 2-(dodecyloxy)-, phthalic acid, isobutyl nonyl ester, 1,4-dimethyl-8-isopropylidenetricyclo[5.3.0.0(4,10)]decane.

According to GC/MS result, 31 components were identified from the 32 peaks of S-1 samples. The result showed that the components were acetic acid, oxo-, acetic acid, dimethyl ether, acetic acid, phenol, 1h-pyrrole-2-carboxaldehyde, phenol, benzaldehyde, 2-hydroxy-, phenol, 4-methyl-, nonanal, benzoic acid, benzofuran, 2,3-dihydro-, 2-furancarboxaldehyde, 5-(hydroxymethyl)-, salicyl alcohol, 2-furancarboxylic acid, hydrazide, 2-methoxy-4-vinylphenol, phenol, 2,6-dimethoxy-, 2,5-dihydroxypropiophenone, vanillin, phenol, 2-methoxy-4-(1-propenyl)-,(e)-, ethanone, 1-[4-

(methylthio)phenyl], phenol, 2,4-bis(1,1-dimethylethyl), benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester, pentadecane, 3-methyl-, phenol, 2,6-dimethoxy-4-(2-propenyl)-, tridecane, 3-methyl-, n-tetracosanol-1, pentadecane, 2,6,10,14-tetramethyl, tetratriacontane, 17-hexadecyl-, 1,2-benzenedicarboxylic acid, bis(2-methylpropyl) ester, phenol, 1,4-dimethyl-8-isopropylidenetricyclo [5.3.0.0(4,10)]decane.

Comparative results of the GC/MS analysis are shown in Table 4. It can be seen from the data in the table that the volatiles of the dip-treated wood bunches are mainly phenols, alkanes, and aldehydes; the volatiles of the dip-treated board are mainly phenolic acids, and aldehydes; and the volatiles of the non-pretreated plain boards are mainly phenols, aldehydes, and acids. reconstructed timber, the antibacterial properties of the pretreated dipping wood bunches, the hot-pressed dipping sheet, and the non-pretreated plain boards were substantial. However, their antibacterial chemical compositions differed.

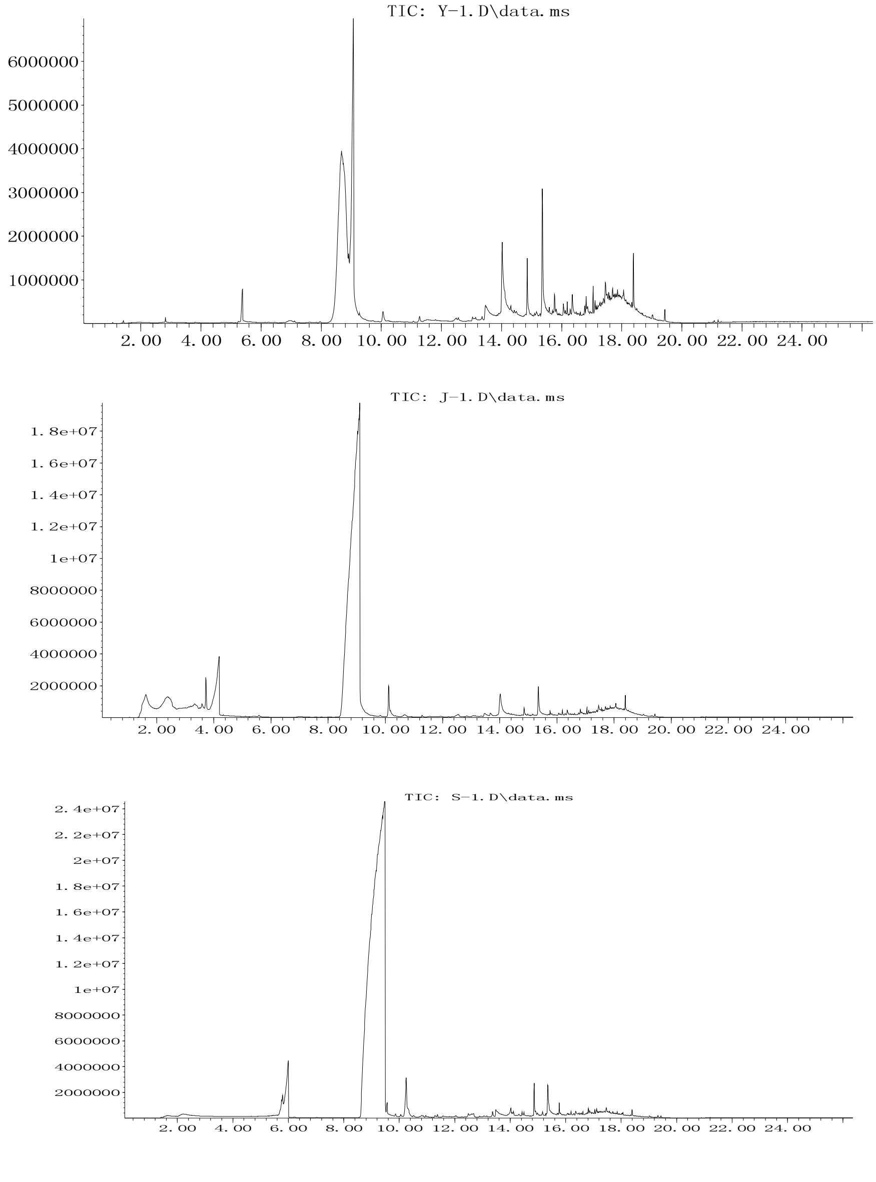

Fig. 1. Total ion of Wood/PF Bio Composites by DT-GC-MS

Table 1. Result of Y-1 samples by DT-GC-MS

No.	RT (min)	Peak area %	Chemical component
1	5.375	1.10	Acetic acid
2	8.690	36.24	Phenol
3	9.057	17.87	Phenol
4	10.064	0.57	Benzaldehyde, 2-hydroxy-
5	11.271	0.18	Nonanal
6	13.484	1.90	2-Furancarboxaldehyde, 5-(hydroxymethyl)-
7	14.030	7.78	Salicyl Alcohol
8	14.869	2.14	Phenol, 2,6-dimethoxy-
9	15.173	0.57	2,5-Dihydroxypropiophenone
10	15.362	5.35	Vanillin
11	15.771	1.65	Phenol, 2-methoxy-4-(1-propenyl)-,(E)-
12	16.065	0.77	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-
13	16.191	0.44	Phenol, 2,4-bis(1,1-dimethylethyl)
14	16.369	1.89	Benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester
15	16.831	1.83	Phenol, 2,6-dimethoxy-4-(2-propenyl)-
16	17.471	7.46	Pentadecane, 2,6,10,14-tetramethyl
17	17.702	2.25	Nonahexacontanoic acid
18	17.869	2.79	Octacosyl heptafluorobutyrate
19	18.058	4.02	Eicosane
20	18.394	3.10	1,2-Benzenedicarboxylic acid, bis 2-methylpropyl) ester
21	19.433	0.10	1,4-Dimethyl-8-isopropylidenetricyclo[5.3.0.0(4,10)]decane

Table 2. Result of J-1 samples by DT-GC-MS

No.	RT (min)	Peak area %	Chemical component
1	1.629	4.20	Formaldehyde
2	2.385	5.32	Hydrazine, 1,2-dimethyl-
3	3.339	4.06	Acetic acid
4	3.591	0.96	2-Isopropoxyethylamine
5	3.728	1.14	Formic acid
6	4.168	5.28	Acetic acid
7	9.078	63.83	Phenol
8	10.127	1.05	Benzaldehyde, 2-hydroxy-
9	10.683	0.15	Phenol, 4-methyl-
10	12.551	0.16	Benzoic acid
11	13.484	0.23	2-Furancarboxaldehyde, 5-(hydroxymethyl)-
12	13.684	0.18	Methenamine
13	14.019	2.16	Salicyl Alcohol
14	14.859	0.47	Phenol, 2,6-dimethoxy-
15	15.352	1.18	Benzaldehyde, 3-hydroxy-4-methoxy-
16	15.771	0.47	Phenol, 2-methoxy-4-(1-propenyl)-(E)-
17	16.065	0.20	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-
18	16.191	0.16	Phenol, 2,4-bis(1,1-dimethylethyl)
19	16.369	0.45	Benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester
20	16.831	0.89	Phenol, 2,6-dimethoxy-4-(2-propenyl)-
21	17.471	1.84	Pentadecane, 2,6,10,14-tetramethyl
22	18.058	3.52	Ethanol, 2-(dodecyloxy)-
23	18.394	1.99	Phthalic acid, isobutyl nonyl este
24	19.433	0.09	1,4-Dimethyl-8-isopropylidenetricyclo[5.3.0.0(4,10)]decane

Table 3. Result of S-1 samples by DT-GC-MS

No.	RT (min)	Peak area %	Chemical component
1	1.651	0.05	Acetic acid, oxo-
2	2.217	0.43	Acetic acid
3	5.795	1.47	Dimethyl ether
4	5.983	2.81	Acetic acid
5	9.45	84.52	Phenol
6	9.865	0.12	1H-Pyrrole-2-carboxaldehyde
7	10.064	0.09	Phenol
8	10.253	1.58	Benzaldehyde, 2-hydroxy-
9	10.820	0.08	Phenol, 4-methyl-
10	11.376	0.10	Nonanal
11	12.666	0.32	Benzoic acid
12	13.369	0.13	Benzofuran, 2,3-dihydro-
13	13.495	0.63	2-Furancarboxaldehyde, 5-(hydroxymethyl)-
14	14.020	0.64	Salicyl Alcohol
15	14.324	0.09	2-Furancarboxylic acid, hydrazide
16	14.502	0.31	2-Methoxy-4-vinylphenol
17	14.869	0.73	Phenol, 2,6-dimethoxy-
18	15.174	0.20	2,5-Dihydroxypropiophenone
19	15.362	1.25	Vanillin
20	15.772	0.55	Phenol, 2-methoxy-4-(1-propenyl)-,(E)-
21	16.076	0.17	Ethanone, 1-[4-(methylthio)phenyl]
22	16.191	0.13	Phenol, 2,4-bis(1,1-dimethylethyl)
23	16.370	0.38	Benzeneacetic acid, 4-hydroxy-3-methoxy-, methyl ester
24	16.621	0.22	Pentadecane, 3-methyl-
25	16.831	0.65	Phenol, 2,6-dimethoxy-4-(2-propenyl)-
26	17.114	0.42	Tridecane, 3-methyl-
27	17.240	0.34	n-Tetracosanol-1
28	17.461	1.08	Pentadecane, 2,6,10,14-tetramethyl
29	17.859	0.21	Tetratriacontane, 17-hexadecyl-
30	18.394	0.23	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester
31	19.328	0.04	Phenol
32	19.433	0.02	1,4-Dimethyl-8-isopropylidenetricyclo[5.3.0.0(4,10)]decane

Table 4. GC-MS analysis results and comparison

Kind	Treated wood	Wood/PF Bio composites	Untreated wood
Aldehyde	8.00	6.66	3.68
Phenol	60.17	65.97	84.69
Alcohol	7.78	5.68	0.98
Acid	5.24	10.64	3.61
Ester	3.10	2.44	0.61
Alkyl	11.58	1.84	1.95
Ketone	1.34	0.20	0.37
others	2.79	6.55	2.34

The main antibacterial, volatile components of dipping wood bunches included phenol, 2,4-bis(1,1-dimethylethyl), etc., representing 54.55% of the total volatiles. The main antibacterial, volatile components of the hot-pressed dipping sheet included phenol, formaldehyde, 2,4-bis(1,1-dimethylethyl), phenol, and 4-methyl-, accounting for 68.19% of the total volatiles, while the main antibacterial, volatile components of the non-pretreated plain boards included phenol, 2,4-bis(1,1-dimethylethyl), phenol, and 4-methyl-, accounting for 84.86% of the total volatiles.

CONCLUSIONS

A GC/MS analysis of dip-treated wood bunches, a hot-pressed dipping sheet, and non-pretreated prime boards showed that their antimicrobial properties are substantial. The main antibacterial volatile components of the dip-treated wood bunches accounted for 54.55% of the total volatile matter; the main antibacterial volatile components of the hot-pressed dipping sheet constituted 68.19% of the total volatile matter; and the main antibacterial volatile components of the non-pretreated plain boards accounted for 84.86% of the total volatile matter. The results indicate that a pretreatment consisting of hot dipping with a phenolic resin and using an adhesive phenolic resin can effectively improve the antibacterial properties of *V. negundo* reconstructed timber.

ACKNOWLEDGMENTS

This work was financially supported by the National Department Public Benefit Research Foundation, China (201404519), Forestry Science and Technology Spreading Program ([2014]54) and Program for New Century Excellent Talents in University (NCET-12-0725).

REFERENCES

1. Deborah A. Establishing causality in the assessment of safety of medicines for children. *Acta Paediatr.* 2008, **97**: 1611–1616.
2. Madlen G, Linda VG. Long-term Reduction in Adverse Drug Events: An Evidence-Based Improvement Model. *Pediatrics* 2012, **129**: e1334 -e1342.
3. Thomas J, Hwang AB, Florence T, Bourgeois MD, John D, Seeger Pharm D. Drug Safety in the Digital Age. *N. Engl. J. Med.* 2014, **370**: 2460-2462.
4. Gallagher WM, Tweats D, Koenig J. Omic profiling for drug safety assessment: current trends and public-private partnerships. *Drug Discov. Today* 2009, **14**: 337-342.
5. Ralph IE. Risk Management of Medicines and Compensation for Harm. *Drug Safety* 2009, **32**: 87-90.
6. Hans R, Timothy K, Kimberly B, Ricci MS, McGuinn WD, Verbois SL. Regulatory aspects of oncology drug safety evaluation: Past practice, current issues, and the challenge of new drugs. *Toxicol. Appl. Pharm.* 2010, **243**: 125-133.
7. Lucy G, Joanna M. The Psychoactive Effects of Antidepressants and their Association with Suicidality. *Curr. Drug Safety* 2011, **6**: 1-7.
8. Wilens TE, Biederman J, Kwon A, Chase R, Greenberg L, Mick E, Spencer TJ. A systematic chart review of the nature of psychiatric adverse events in children and adolescents treated with selective serotonin reuptake inhibitors. *J. Child Adolesc. Psychopharmacol.* 2003, **13**: 143-52.
9. Brian L, Strom MD. How the US Drug Safety System Should Be Changed. *Jama.* 2006, **295**: 2072-2075.
10. Lin Z, Ge SB, Li DL, Peng WX. Structure Characteristics of Acidic Pretreated Fiber and Self-bind Bio-boards for Public Health. *Journal of Pure and Applied Microbiology,* 2015, **9**(SI): 221-226
11. Peng WX, Lin Z, Chen H, Wu JG. Biochemical Group Characteristics of Self-Bonded Boards During Acidic Oxidation for Public Health. *Journal of Pure and Applied Microbiology*, 2015, **9**(SI): 307-311
12. Xue Q, Peng WX, Ohkoshi M. Molecular bonding characteristics of Self-plasticized bamboo composites. *Pak J Pharm Sci,* 2014, **27**: 975-982
13. Peng WX, Xue Q, Ohkoshi M. Immune Effects of Extractives on Bamboo Biomass Self-plasticization. *Pak J Pharma Sci,* 2014, **27**: 991-999
14. Sun YC, Lin Z, Peng WX, Yuan TQ, Xu F, Wu YQ, Yang J, Wang YS , Sun RC. Chemical Changes of Raw Materials and Manufactured Binderless Boards during Hot Pressing:*Lignin Isolation and Characterization. Bioresources,* 2014, **9**(1): 1055-1071
15. Cui L, Peng WX, Sun ZJ, Lu HF, Chen GN. Variability of macroscopic dimensions of Moso bamboo. *Pak J Pharm Sci*, 2015, **28**: 675-679
16. Cui L, Peng WX, Sun ZJ, Shang LL, Chen GN. Weibull Statistical Analysis of Tensile Strength of Vascular Bundle in Inner Layer of Moso Bambooculm in Molecular Parasitology and Vector Biology. *Pak J Pharma Sci,* 2014, **27**: 1083-1087
17. Peng WX, Wang LS, Zhang ML, Lin Z. Separation characteristics of lignin from Eucalyptus camaldulensis lignincelluloses for biomedical cellulose. *Pak J Pharm Sci,* 2014, **27**: 723-728
18. Li DL, Peng WX, Ge SB, Mo B, Zhang ZF, Qin DC. Analysis on active molecules in Populus nigra wood extractives by GC-MS. *Pak J*

Pharma Sci, 2014, **27**: 2061-2065

19. Peng WX, Ge SB, Li DL, Mo B, Daochun Q, Ohkoshi M. Molecular basis of antibacterial activities in extracts of *Eucommia ulmoides* wood. *Pak J Pharma Sci,* 2014, **27**: 2133-2138
20. Peng WX, Lin Z, Chang JB, Gu FL, Zhu XW. Biomedical Molecular Characteristics of Ybsj Extractives From Illicium Verumfruit. *Biotechnology & Biotechnological Equipment,* 2013, **27**(6): 4311-4316
21. Xiao ZP, Peng ZY, Dong JJ, Deng RC, Wang XD, Ouyang H, Yang P, He J , Wang YF, Zhu M, Peng XC, Peng WX, Zhu HL. Synthesis molecular docking and kinetic properties of beta-hydroxy-beta-phenylpropionyl-hydroxamic acids as Helicobacter pylori urease inhibitors. *European Journal of Medicinal Chemistry,* 2013, : 212-221
22. Peng WX, Wang LS, Lin Z, Minglong, Zhang ML. Identification and Chemical Bond Characterization of Wood Extractives in Three Species of Eucalyptus Biomass. *Journal of Pure and Applied Microbiology,* 2013, **7**(SI): 67-73
23. Wang LS, Peng WX, Zhang ML, Lin Z. Separation Characteristics of Lignin from Eucalyptus Lignincellulose for Medicinal Biocellulose Preparation. *Journal of Pure and Applied Microbiology,* 2013, **7**(SI): 59-66
24. Peng WX , Lin Z , Chang JB, Gu FL, Zhu XW, Zhang ZF. Immunology Molecular Characteristics of BSJY Extractives from Illicium verum Biomass. *Journal of Pure and Applied Microbiology,* 2013, **7**(2): 1237-1244
25. Peng WX, Wang LS, Zhang ML, Lin Z. Molecule Characteristics of Eucalyptus Hemicelluloses for Medical Microbiology. *Journal of Pure and Applied Microbiology,* 2013, **7**(2): 1345-1349
26. Peng WX, Zhang ZF, Lin Z, Ohkoshi M, Chang JB, Gu FL, Zhu XW. Molecular Characteristics of Biomedical and Bacteriostasis Extractives of Illicium verum Fruit. *Journal of Pure and Applied Microbiology,* 2013, **7**(3): 2017-2024
27. Qi HC, Peng WX, Wu YQ, Wu SB, Xu GJ. Effects of Alkaline Extraction on Micro/Nano Particles of Eucalyptus Camaldulensis Biology. *Journal of Computational and Theoretical Nanoscience,* 2012, **9**(9): 1525-1528
28. Peng WX, Wu FJ, Wang LS, Xu Q. Crystal Structure of 3-(4-bromophenyl)-4- (4-chlorophenylamino) furan-2(5H)-one C16H11BrClNO2. Zeitschrift Fur Kristallographie-New Crystal Structures, 2012, **227**(1): 61-62
29. Peng WX, Le C. Crystal Structure of 3-(3-bromophenyl)-4-(3 5-dichloro-phenylamino) furan-2(5H)-one C16H10BrCl2NO2. Zeitschrift Fur Kristallographie-New Crystal Structures, 2012, **227**(2): 267-268
30. Peng WX, Wang LS, Wu FJ, Xu Q. 3-(4-Bromophenyl)-4-(4-hydroxyanilino) furan-2 (5H)-one. Acta Crystallographica Section E-Structure Reports Online, 2011, **67**(9): O2329-U206
31. Liu QM, Luo YS, Yin SP, Chen SM, Zhang DQ, Peng WX. Liquid Rheology Study on Refined Rapeseed oil. *Journal of Central South University of Technology,* 2008, **15**(1S): 525-528
32. Zhang DQ, Chen SM, Peng WX, Liu QM, Gu ZJ, Fan SG, Deng SY. Rheology study of supercritically extracted tea-oil. *Journal of Central South University of Technology,* 2008, **15**(1S): 506-508
33. Dong-Li Li, Sheng-Bo Ge, Wan-Xi Peng, Qing-Ding Wu, Jian-Guo Wu. Chemical structure characteristics of wood/lignin composites during mold pressing. Polymer Composites, 2015, published online. DOI: 10.1002/pc.23658
34. Peng WX, Wang LS, Xu Q, Wu QD, Xiang SL. TD-GC-MS Analysis on Thermal Release Behavior of Poplar Composite Biomaterial Under HighTemperature. *Journal of Computational and Theoretical Nanoscience,* 2012, **9**(: 1431-1433