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Original Research Paper

Research on the Infrared Spectroscopy of Spent Mushroom Compost

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ABSTRACT

In order to investigate the substance transformation mechanism of spent mushroom composting with different exogenous additives, infrared spectral analysis was used to study the spent mushroom composting, and the change of composting temperature was also considered. The result indicates that three treatments of shiitake mushroom (SSM), oyster mushroom (SOM), 50% oyster mushroom + 50% shiitake mushroom (SM), all showed the same transformation trend. Proteins, carbohydrates and aliphatic compounds decreased, while aromatization increased gradually in the composting process. Infrared spectrum characteristic showed that the number and structure of similar functional groups in composting materials is different, and SM has better effects than others.

INTRODUCTION

In recent years, there has been increasing output of mushrooms in China. However, mushroom residue arouses environmental pollution obviously. More concerns about treatment and utilization of mushroom residue has been shown by researchers. Mushroom residue, which contains variety of metabolites, like crude protein, crude fat, nitrogen free extract in mushroom (Diao 2012), and microbial community, is the organic solid waste left after edible fungus cultivation by microbial decomposition. In addition, more degradation of cellulose material, which has a strong ability of fungi microorganism, lignocellulose degradation enzymes and all kinds of proteasome (Chen 2006, Ball 1995), exist in mushroom. It can be realized that production is a kind of potential energy material with composting and reuse of biological resources (Williams 2001). But there has been little relevant research, especially information about condition of rotten quickly control and related technology of edible mushroom residue. Studies showed that the key factors affecting composting was raw material properties, microbial species and composting conditions (Huang 2003). Thus, two kinds of residue were collected as composting materials to find the change law during composting and composting effect by infrared spectrum characteristics. At present, the researchers focused on exogenous additives as the composting indicators, including temperature, pH, C/N ratio, germination index GI, less on the material structure change in composting.

Infrared spectrum reflect the change of molecular structure in composting with IR absorption. The test is simple, accurate (Williams 1987, Villringer 1993, Xu 2004, Malley 2005), and get good application in waste composting monitoring research (Li 2006, Michel 2006, Albrecht 2008, Duan 2009). Chefetz (1996) and Kang Jun (2010) studied the urban refuse compost and sludge compost with this method. The results show that the difference in organic composition transformation was significant compared with different raw materials and conditions. However, there have been few tests of substance changes and mechanism of mushroom residue compost. Therefore, the objectives of this research were to obtain an overview of the material structure transformation during the process of composting and provide further theoretical basis for the mushroom residue compost reused.

MATERIALS AND METHODS

Compost method: The compost was divided into three treatments: separately make Xianggu mushroom (SSM), separate mushroom (SOM), 50% oyster mushroom + 50% shiitake mushroom (SM) as composting material. All treatments were repeated 3 times.

Each compost piles was measuring 2m long, 1.5m wide, and 1m high. During the first period of the composting, we regulated carbon-nitrogen ratio (C:N) to 25:1 with urea, controlling 55% of water. Composts were turned over every 3 days and samples were taken at 0, 4, 7, 10, 16, 25, 35 days.

Index detected: Temperature: special mercury thermometer was used in each pile pile at 10 a.m., 2 p.m. and an average was applied.

Spectrometry: The dried samples were compressed with KBr into tablets and analysed using a Perkin Elmer Spectrum 100 FT-IR (Shelton, CT, USA) over a scanning wavelength range of 4000-450 cm^{-1} with a spectral resolution of 4 cm^{-1}. For each sample, 32 scans were accumulated for each spectrum.

Data processing: Origin Pro 8 analysis software was used to process the data.

RESULTS AND DISCUSSION

Temperature Change During Composting Process

The trend of temperature change shows a first increase-decrease-a slight increase in the process and different treatments have the same trend (Fig. 1). The high-temperature of all the treatments can reach more than 50°C, keep the period for 5 days and meet the healthy index and come to maturity (Du 2005). Therefore, we divided the change into the following periods: the heating period during 0-4d, the high-temperature period during 4-10d, the cooling period during 10-19d, a slight rebound in temperature after the 19th d, which is known as the second compost stage, and the 35th d came to maturity.

SM treatment at the 8th d up to 69°C, higher than the other, and the high temperature lasts for 6 days (the longest), is the best. SSM takes the second, and SOM was the worst. The same result can be obtained by Wang Wenquan (2011).

It has correlation between temperature and material structure transformation. Because the energy can not be fully transformed and used by microorganisms in the compost, it converts into heat energy. The change of temperature is common criterion suit for compost maturity. It is simple, intuitive, and applied widely. But the change curve of temperature (curve shape) can not reflect internal changes in the compost. We conjecture the reason that caused inconsistency with the temperature is the different material and content in the treatments (Zhang 2009). Combined temperature with infrared spectrum analysis, it can reflect clearly change mechanism in the composting process.

Infrared Spectrum Analysis of Different Composting Treatments

Characteristic peaks of infrared spectrum in the mushroom residue compost: Based on Table 1, there were absorption peaks near the 3400 cm^{-1} (stretching vibration in O–H and N–H), 2920 and 2850 (aliphatic C–H stretching vibration), 2359 and 2338 (CO_2 asymmetrical stretching), 1650 (aromatic ring C=O stretching), weak absorption peaks

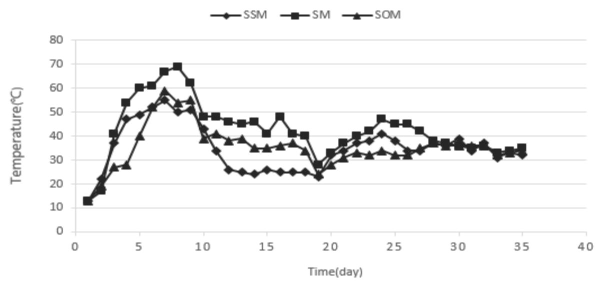

Fig. 1: Temperature change during composting process.

at 1510 (lignocellulosic, characteristic absorption for mushroom residue), the double bond or carbonyl group attached to the $-CH_2$ deformation vibration of lignin and vibration of inorganic NH_4^+, NO_3^- and organic carboxylic acid salt at 1419 and 1427 cm^{-1}; and C-H and C-O absorption bands at 1325 cm^{-1}. Polysaccharide absorption bands appear at 950 and 1170 cm^{-1}, generally caused by starchy fibres of plant materials in organic waste. At 1030 cm^{-1}, it is the Si-O-Si asymmetric stretching vibration, and 875 cm^{-1} is carbonate C-O outside bending vibration. And the characteristic peak of aromatic ring appears at 670 cm^{-1}.

The characteristic absorption peaks described the presence of abundant carbohydrates (lignin, cellulose, hemicellulose) and some proteins, amide compounds, and silicate minerals in the mushroom residue.

Mushroom residue is mainly comprised of nitrogen compounds, carbohydrates and aliphatic compounds. Nitrogen compounds contain crude protein and decomposition products. Carbohydrate contains cellulose, hemicellulose and lignin. Aliphatic compounds mainly refer to crude fat. During the composting process, carbohydrate and aliphatic compounds are mainly decomposed to carbon dioxide, protein and its decomposition products. Nitrogen compounds, like peptides and amino acids, have carbon dioxide, ammonium ion, nitrate ion, amide nitrogen as the decomposition products. Comparing with the sludge and cow dung, clear absorbance was not shown by multiple complex bands for NH_4^+ at 2200-2400cm^{-1}. It indicates that the mushroom residue was low in proteins.

Analysis of infrared spectrum in different composting stages: The differences of absorption peak frequency and position for infrared spectrum reflect the chemical structure changes after composting. Its variation on relative intensity shows special chemicals decomposition. The frequency and position in different treatments were basically identical, which indicate that the materials contain similar functional groups (Fig. 2). It can be concluded from the comparison of changes of infrared spectrum in different stages that the absorption peak has regular changes with the composting process.

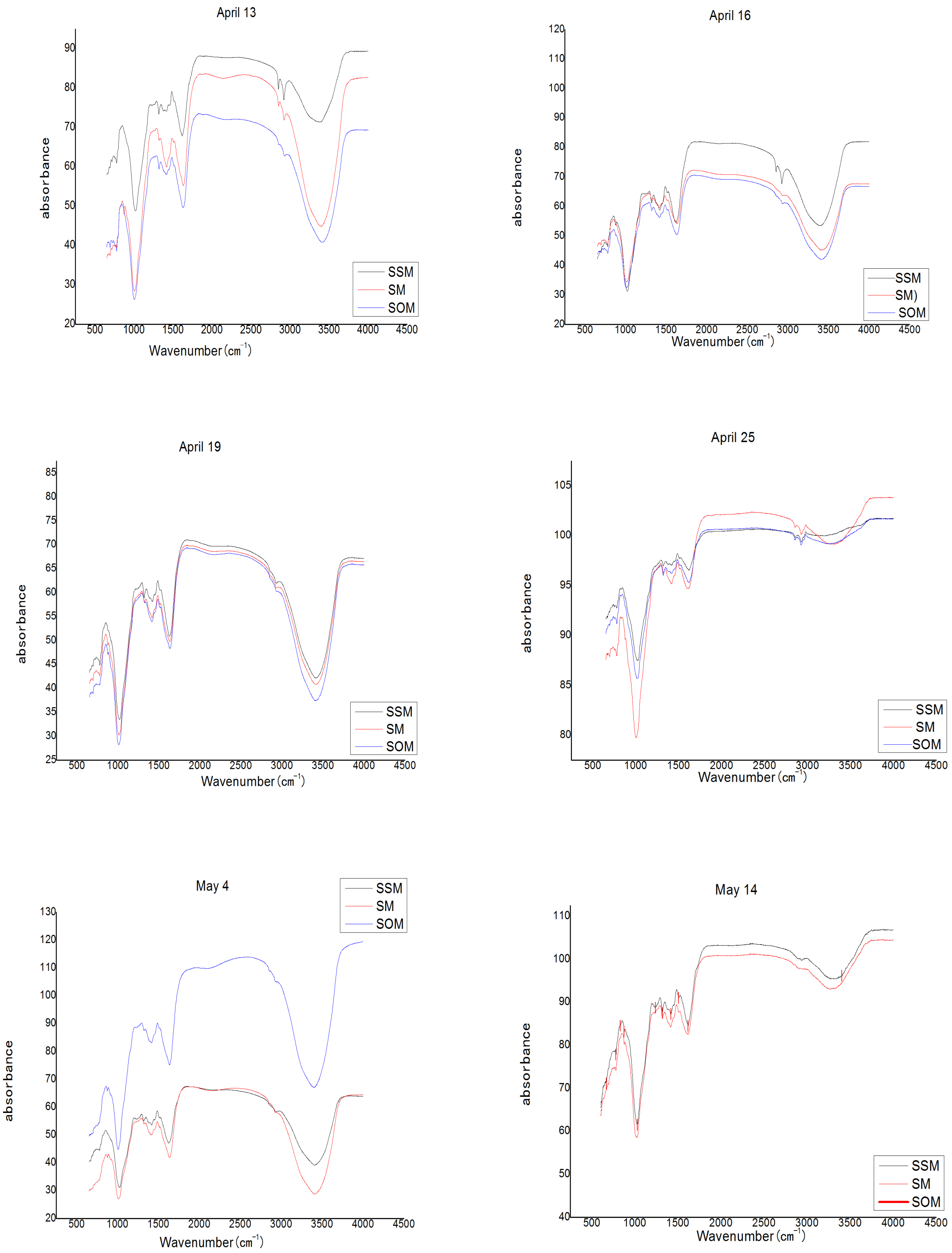

Fig. 2: FTIR spectra of different treatment in different compost stage.

Table 1: Characteristic absorption peak of infrared spectrum and assignment.

Wave Number (cm^{-1})	Assignment
3430-3410	O-H stretching vibration of carbohydrates and moisture; N-H stretching vibration
2920, 2850	The characteristic peak of aliphatic C-H stretching
2359, 2338	Asymmetrical stretching of CO_2
1657, 1645	Amide carbonyl C=O expansion
1564, 1558	Asymmetrical stretching of Aliphatic NO_2; In-plane bending vibration of secondary amides NH
1541, 1547	Asymmetrical stretching of aromatic NO_2
1419, 1425	The double bond or carbonyl group attached to the $-CH_2$ deformation vibration of lignin and vibration of inorganic NH_4^+, NO_3^-, and organic carboxylic acid salt at 1419-1427 cm^{-1}
1242	Stretching vibration of phenols C-O; Stretching vibration of Si-C in organic silicon compounds and characteristic absorption peaks of the lipid and cellulose
1045	Stretching of the polysaccharide C-O
874, 879	Out-plane bending of CO_3^{2-}
665, 671	The characteristic peak of aromatic ring

Table 2: The relative strength of main absorption peak of spectrum.

Time	SSM			SM			SOM		
days	1640/3400	1640/1030	1640/1420	1640/3400	1640/1030	1640/1420	1640/3400	1640/1030	1640/1420
4	0.98	1.41	0.94	1.24	1.81	0.93	1.22	1.76	0.86
7	1.05	1.76	0.95	1.20	1.54	0.91	1.20	1.51	0.90
10	0.91	1.51	0.88	1.22	1.59	0.91	0.92	1.64	0.90
16	0.97	1.10	0.99	0.96	1.18	1.00	0.96	1.11	1.00
25	1.21	1.52	0.89	0.89	1.49	0.83	1.13	1.57	0.91
35	1.21	1.40	1.00	1.46	1.44	1.00	1.29	1.67	1.00

The peaks of -OH and N-H decreased near 3400 cm^{-1} in the heating period and the high-temperature period (1-10days), with lignin related band, 1650-1630cm^{-1}, having a relative decrease. It shows that carbohydrate, protein, soluble sugar and amide compounds material is mainly decomposed at this stage and makes the material to rapid heating. The intensity of asymmetrical stretching of CO_2, 2338 cm^{-1}, 2359 cm^{-1}, gradually increased and promote the decomposition of organic matter by microbes under aerobic conditions. A small peak appeared at 1720 cm^{-1} is the absorption by carbonyl with aldehydes and ketones and carboxylic acid. However, it disappeared quickly on the 19th day. We suggest that the change may be caused with some components or small amount of volatile compounds in the materials.

In the cooling period (10-16 days), the difference in the characteristic peaks were the most obvious, the peak of -OH, N-H at 3400 cm^{-1} and the C-H at 2920 cm^{-1} gradually weakening or disappear. In addition, the lignin, and cellulose-related band at 1510cm^{-1}, 1630cm^{-1}, 1265cm^{-1}, 1325 cm^{-1} decreased obviously, indicating the lignin and fibrin, which are hard to be decomposed, can be changed to the nutrition of the microorganisms. In terms of Fig. 2, the greatest change of peak is SSM. It showed that the *Lentinus edodes* compost has better effect for cellulose decomposition.

In the second composting stage, the optimum temperature promotes medium temperature rapid propagation of microorganisms and a small peak appear in the characteristic peak. The absorption strength continuously increase, associated with the aromatic ring skeleton vibration peak and continuous conversion of lipids to carboxylic acid salts. It shows the accumulation of HA (Duan 2009). With in-plane bending vibration of -OH, stretching vibration of -COO and rocking vibration of aliphatic functional groups CH_2, there were a wide absorption band near the 1430 cm^{-1} and the carbonate absorption near 2520 cm^{-1}. In this band, organic functional groups absorption decreased, but inorganic carbonate content relatively increased and caused the absorption intensity increased with the degradation of organic matter. The band at 1240 cm^{-1} related to stretching vibration of C-O and C-N and weaken as compost glycolysis.

At the end of composting (35th day), the characteristic peaks are more flattening. The peak of aromatic rings increased significantly in 665 and 671 cm^{-1}, proving that protein, carbohydrate, fatty compounds in the composting process is on the decline and aromatization increased. It reflects enhancement of the maturity level.

The ratio of peak height at 1640 cm^{-1} (aromatic carbon) to 3400 cm^{-1} (aliphatic carbon), 1030 cm^{-1} (polysaccharide carbon), 1420 cm^{-1} (carboxyl carbon) can determine the degree of decomposition with different materials in the composting process. It also shows the degree of compost aromatization (Wei 2007). The ratio of 1640/3400 has increased significantly in the three treatments, proving that all the treatments can accelerate the decomposition of protein and small molecular substances, improve the degree of compost aromatization, and obviously speed up the composting process. The result of temperature change also support this point.

The treatment of SSM and SM were relatively superior. 1630/1030 ratio did not change significantly. But the ratio for SM can reach 1.81 in the heating period, promoting degree of degradation for cellulose, lignin and hemicellulose polysaccharide, and speed up the composting process. However, the change of 1640/1420 ratio is not very obvious. Therefore, SM has better effect than the other two groups.

CONCLUSIONS

During composting process, the change of infrared spectrum curves showed the same tendency. It reflects that the decomposition process with microbes in different treatments. But different change intensity of same peak for the groups indicates different content of protein, cellulose, hemicellulose, which were converted in the treatments.

In the experiment, microorganisms decompose sugar, and protein firstly and some difficult decomposability substances secondly, when there is the lack of the easy decomposition material. The results show that the decomposition affects with single use of shiitake in the compost (SSM) is obviously better than the others. Therefore, SM can be considered as the most effective, but it has weak decomposition of cellulose than SSM. We still need further research to find the best proportion and improve the mushroom residue compost effect.

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