Effect of the Composting System of Hickory Shell on the Degradation of Lignocellulose

Jinping Zhang,* Yue Ying, Xuebin Li, and Xiaohua Yao

Three experimental groups were designed to study the effects of different exogenous nutrients on a composting process and the degradation extents of cellulose, hemicellulose, and lignin. Hickory shell was the main raw material, and spent mushroom substrate and composted chicken manure were used as exogenous nutrients. The C/N ratios of these groups were adjusted to 34 by using soybean meal. The study results showed that the duration of high-temperature stage of composting was shortened and the maturity of composting products was improved by adding exogenous nutrients. The seed germination index with spent mushroom substrate and composted chicken manure were 112% and 101%. The addition of exogenous nutrients reduced the composting weight loss and increase the degradation extents of cellulose (⩾64.6%), hemicellulose (⩾82.4%), and lignin (⩾64.3%). In particular, the degradation of compost products with composted chicken manure was higher than that of the composting products with the spent mushroom substrate. In the hickory shell composting system, bacteria played a dominant role in the initial and thermophilic phase, and the lignin degradation is related to the quantity of fungi and actinomycetes in composting process.

Keywords: Hickory shell; Compost; Exogenous nutrient; Cellulose; Hemicellulose; Lignin

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INTRODUCTION

Hickory (*Carya cathayensis* Sarg.) belongs to the family Juglandaceae and the genus *Carya* Nutt. It has a history of 25 million years to 40 million years and is mainly distributed in the Tianmu Mountains (29° to 30°N, 118° to 118°E) at the junction of the Zhejiang and Anhui provinces in China. Lin'an, Zhejiang Province is a central producing area for hickory (Dong *et al*. 2018). The national hickory planting area is 43,300 ha with an annual output of 10000 tons. The hickory fruit consists of pericarp and dried fruit. The pericarp (hereafter referred to as hickory shell) includes the outer and middle pericarps of the fruit, whereas the hard, inner shell and kernel are the dried fruit. Because the mass ratio of the shell to dried fruit is approximately 5:1, the annual yield of hickory shell can reach 50000 ton (Jiang 2008). The literature has shown that disposal of the shell can pollute the air and water, whether it is burned or decomposed in water (Yuan *et al*. 2018). At present, because a scientific and reasonable method to dispose of hickory shells has not been developed, hickory shells are piled or dumped into rivers at will, thus polluting the soil and ecological environment, which has become an inevitable problem in the process of sustainable economic development of hickory producing areas.

Composting is one of the most economic and effective methods to deal with a large amount of waste hickory shell, which not only can solve the issue of environmental pollution, but can also convert hickory shell into fertilizer or a soil regulator. The main components of hickory shell are cellulose, hemicellulose, and lignin. Although it is a good raw material for composting, hickory shell cannot increase temperatures or start composting fermentation under the action of urea with an initial adjusted C/N ratio and inoculating microbes because of the high lignin content and high crystallinity of cellulose. Also, because urea evaporates quickly, exogenous nutrients and inoculating microbes need to be added to increase the microbial quantity and accelerate the composting process (Zhang *et al*. 2018). Meng *et al*. (2017) showed that adding livestock manure to wastes that are not suitable for composting could lead to a high temperature and long duration for composting, which enables the generation of final products with a good stability, high fertilizer efficiency, and good safety. Because the degradation degree of lignocellulose is the key factor limiting the compost maturation process (Xi *et al*. 2002), it is critical to study the initial exogenous nutrients, inoculating microbes, microbial community structure, and macromolecular organic matter changes during the composting process. Studies have shown that exogenous nutrients and microbes can facilitate the decomposition and humification of cellulose, hemicellulose, and lignin in composting materials and accelerate the composting process. As a result, the compost quality is higher than that of compost without exogenous nutrients and microbes (Fang *et al*. 2001; Hart *et al*. 2002; Bolta *et al*. 2003).

In the study, hickory shells were used as raw material, soybean meal was used to adjust the initial C/N ratio, and *Pleurotus abalonus* spent mushroom substrate (hereinafter referred to as spent mushroom substrate) and composted chicken manure were added as exogenous nutrients. To facilitate the composting process of the hickory shell, effective microorganisms (EM, containing more than 80 microbes including *Bacillus*, *Lactobacillus*, *Bifidobacterium*, *Saccharomyces cerevisiae*, photosynthetic bacteria, *Actinobacteria*, *Actinobacillus*, *etc.*) and PC were added to increase microorganisms in raw materials, shorten composting period and improve the composting quality (Xu *et al.* 2015). The effects of exogenous nutrients on changes of the cellulose, hemicellulose, and lignin in the process of hickory shell composting, as well as the relationship between the dynamic changes in the microorganisms and the three main components in composting process were investigated in this study. It was expected that the result of this study would provide the theoretical and technical basis for the rapid composting of hickory shell containing high lignin.

EXPERIMENTAL

Materials

The raw materials used in this study were as follows: compost raw material hickory shell (< 3.5 cm) (collected from Lin'an district, Hangzhou city, Zhejiang Province, China), soybean meal (Henan province, China), spent mushroom substrate of *Pleurotus abalonus* (Hangzhou, Zhejiang Province), composted chicken manure (air dried after being composted, Anhui province, China), planting special EM bacteria seed (Effective microorganisms, EM), containing more than 80 microbes including *Bacillus*, *Lactobacillus*, *Bifidobacterium*, *Saccharomyces cerevisiae*, photosynthetic bacteria, *Actinobacteria*, *Actinobacillus*, *etc*. (Henan Nanhua Qianmu Biotechnology Co., Ltd.), and PC (*Phanerochaete chrysosporium*, CICC40299, China Center of Industrial Culture

Collection, the suitable growth temperature is 28 to 39 °C). The main properties of raw materials are shown in Table 1.

Table 1. Properties of the Compost Materials

Component	Cellulose (%)	Hemicellulose (%)	Lignin (%)	C (%)	N (%)
Hickory shell	20.63	22.48	49.78	45.4	0.72
Soybean meal	35.28	24.09	13.51	41.4	6.64
Abalone spent mushroom substrate	15.96	8.86	32.26	28.3	1.54
Composted chicken manure	29.71	13.43	25.87	30.0	3.00

Methods

Composting methods

The composting process was performed in an eco-composting box (73×115×80cm, 220L) (Biolan, EURA, Finland) that was thermally insulated and efficiently ventilated. Three experimental groups were set up. Groups A contained composted chicken manure (the dry weight ratio of composted chicken manure to hickory shell is 1:20), Group B contained spent mushroom substrate (the dry weight ratio of spent mushroom substrate to hickory shell is 1:20), and Group CK was without composted chicken manure or spent mushroom substrate. Soybean meal was added to these three groups to adjust their initial C/N ratios to 34. After adding 1.5% EM microbial agent, tap water was added to adjust the initial moisture content of composting to 55%. The PC microbial agent, 3% of the initial weight of mixture (A, B, CK)(41±1kg, dry weight) was added when the compost temperature dropped below 40 °C. The materials was mixed and turned manually and each group stirred for 20 minutes. Then the mixture (41 ±1kg, dry weight) was loaded into the compost barrel to start aerobic composting fermentation. The inlet air valve of the eco-composting box was kept fully open, equivalent to open fermentation. The composting temperature and room temperature were recorded at every 3:00 pm for 42 days. Turning frequently and sampling method at day 0, 3, 6, 9, 12, 18, 24, 30, 42 was according to Zhang (2015). A portion of the homogenized samples (100g, fresh weight) was stored at -20 °C for microbiological analysis as fresh sample , a portion (100g, fresh weight) was used for seed germination index on the day of sampling and the remainder was dried at 65 °C as dried sample.

Testing index and method: pH and electrical conductivity

The fresh shells were extracted with deionized water at a water to sample ratio of 10:1 (V (mL):W (g)) by shaking at 200 rpm for 1 h at room temperature. Next, the pH was measured with a 2F pH meter (Inesa Scientific Instrument Co. Ltd., Shanghai, China), and the electrical conductivity (EC) (ms/cm) was measured with a DDS-307 conductivity meter (Inesa Scientific Instrument Co. Ltd.).

Seed germination index (Tiquia and Tam 1998)

Twenty grams of fresh sample and 200 mL of distilled water were mixed and shaken well for 1 h. Then, the mixture was extracted by immersing it at 30 °C for 24 h. After filtration, 6 mL of the filtrate were aspirated and added to a 9-cm dish covered with filter paper. Subsequently, 20 plump cabbage seeds were sowed on each petri dish and placed in an incubator at 20 °C ± 1 °C.

The seed germination percentage was measured after 24 h. Each treatment was repeated three times, and distilled water was used as the control. Equation 1 was used to calculate the germination index (GI),

$$GI\ (\%) = \frac{G_t \times L_t}{G_c \times L_c} \times 100 \tag{1}$$

where G_t is the seed germination percentage (%) of the raw material extractive, L_t is the length (cm) of the seed root cultivated by the raw material extractive, and G_c and L_c are the seed germination percentage (%) and control length (cm) of the seed root cultivated in water, respectively.

Cellulose, hemicellulose, and lignin contents

The cellulose, hemicellulose, and lignin contents were determined in accordance with the national standards GB/T 2677.10 (1995), GB/T 2677.9 (1994), and GB/T 2677.8 (1994), respectively. Three parallel measurements were performed for each sample, and the average mass percentage of each major component was calculated according to the data obtained.

Weight loss and degradation (Liu 2006)

The fresh weight of the compost at each turning over was recorded as W_x (g). At each turning over, the moisture content (M_x, %) of the sample was determined. The cellulose, hemicellulose, and lignin contents in the sample were determined and recorded as a_x, b_x, and c_x (%), respectively. The x represents the number of turning overs. The initial dry weight of the compost was recorded as W_0 (g).

The calculation methods for the weight loss and lignin degradation extents of cellulose, hemicellulose, and lignin contents were as follows:

$$\text{Weight loss}\ (\%) = \frac{W_0 - W_x \times M_x}{W_0} \times 100\% \tag{2}$$

$$\text{Cellulose degradation}\ (\%) = \frac{W_0 \times a_0 - W_x \times M_x \times a_x}{W_0 \times a_0} \times 100\% \tag{3}$$

$$\text{Hemicellulose degradation}\ (\%) = \frac{W_0 \times b_0 - W_x \times M_x \times b_x}{W_0 \times b_0} \times 100\% \tag{4}$$

$$\text{Lignin degradation}\ (\%) = \frac{W_0 \times c_0 - W_x \times M_x \times c_x}{W_0 \times c_0} \times 100\% \tag{5}$$

Microbial counting method (Ding *et al.* 2014)

Ten grams of compost sample were added to 90 mL of sterile water and vibrated sufficiently on an oscillator to disperse the microbial cells in the sample. After treatment, the samples were diluted with sterile water to a series of concentrations (10^{-2} to 10^{-8}). One half of a milliliter of diluted microbial solution was transferred using a pipette and then dripped on a flat plate with the aseptic operation. The microbial solution was evenly coated with three plates at the same time for each dilution. After inoculation, the dishes were placed in a constant temperature incubator to observe the growth of colonies, record the types of microorganisms and the number of colonies, and calculate the number of microorganisms. The culture medium, incubation temperature, and incubation time of the different microorganisms are shown in Table 2.

Table 2. Culture Temperature, Time, and Medium of the Microbes

Type of microbe	Dilution of microbial suspension	Culture temperature (°C)	Culture time (d)	Culture medium
Bacteria	10^{-6}, 10^{-7}, 10^{-8}	30	2	Beef-protein Medium
Fungus	10^{-4}, 10^{-5}, 10^{-6}	28	3	Martin's Medium
Actinomycetes	10^{-5}, 10^{-6}, 10^{-7}	28	3	Gause 1 Medium

RESULTS AND DISCUSSION

Analysis of the Composting Temperature Variation

Compost temperature change is considered to be one of the most convenient and rapid physical indicators for evaluating compost stability. When it is close to the environmental temperature, it shows that compost is stable (Xu *et al.* 2016). Because temperature change is closely related to microbial reproduction and decomposition of organic matters, the temperature is one of the important parameters in the composting process. According to the temperature changes, composting can be divided into four stages, namely, initial, thermophilic, mesophilic and mature phase (Bustamante *et al.* 2008). In particularly, the thermophilic phase (＞50 °C) is favorable for killing insects eggs and some pathogenic microorganisms in composting materials, which promotes rapid degradation of organic matters in composting and realizing the stability and harmlessness of composting (Szanto *et al.* 2007; Tang *et al.* 2007; Bernal *et al.* 2009; Rashad *et al.* 2010). The three groups was turned over at day 7, day 14, and day 28, which made the temperature noticeable drop.

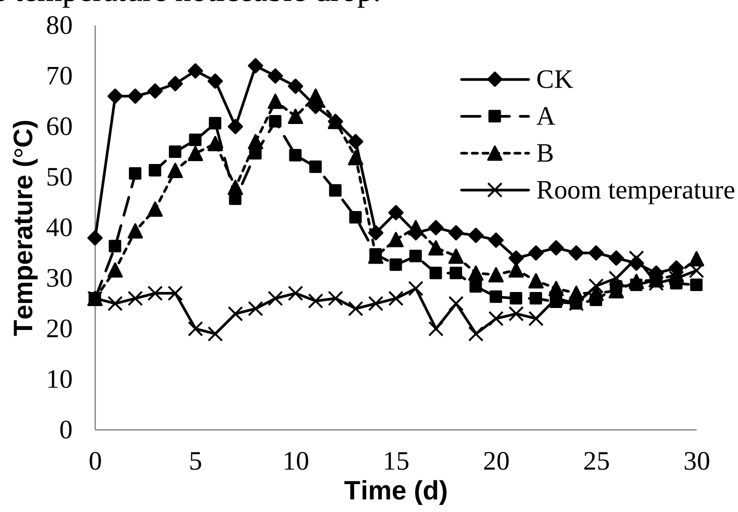

Fig. 1. Temperature variation in the composting process

Figure 1 shows that Groups CK and A entered the thermophilic phase on the second day (>50 °C), while group B reached 50 °C on the fourth day when microorganisms decomposed original soluble organic matter in the groups (Zhang 2015). The thermophilic retention times for groups CK, A, and B (> 50 °C) were 13 d, 9 d, and 10 d. The highest temperatures of the three groups were 72 °C, 61 °C, and 66 °C, respectively. The products of the groups accorded with the hygienic requirements (GB 7959-2012) for more than three consecutive days above 55 °C, *i.e.* it will be free of weed seeds and pathogens. And then the temperature dropped gradually to room temperature, indicating the onset of the mature phase. The fall of temperature indicated reduction of microbial activity, which might have been caused by the degradation of most of the organic matter and the death of the majority of microorganisms which were heat-labile during the thermophilic phase microbial activity.

Comparing the thermophilic phase of groups A and B to group CK, the slower rise in temperature and shorter thermophilic phase in Group A and B indicated that the addition of composted chicken manure and spent mushroom substrate impeded decomposition of this compost mixture. This result was likely made possible by the differences in cellulose, hemicellulose, and lignin of exogenous nutrients (soybean meal, composted chicken manure, and spent mushroom substrate). Hemicellulose is the most easily decomposable components of the lignocellulose; therefore it could greatly promote microbial activity and subsequent heat generation (Zhu *et al.* 2012). Thus, higher hemicellulose content made group CK the faster rise in temperature in initial phase, followed by group A and slowest temperature rise in group B. The content of lignin and cellulose likely affected the duration of thermophilic phase, for what the group CK and B had longer thermophilic phase.

Change in the pH and EC

In Fig. 2, the pH values showed a trend of first rising and then decreasing. The initial pH of Group CK, Group A and Group B were 7, 7.4, and 8.1, respectively. At the rising stage of pH , the change of Group B was not obvious compared with the other two groups. From day 9 to day 18, the pH was generally stable. Then pH of Group A dropped at first at day 18, 6 days earlier than the two groups dropped at day 24, which were likely made possibly by the higher lignin content and lower cellulose content. The final pH was about 7. Although there some difference, all the groups shows high pH values in thermophilic phase (Li *et al.* 2010).

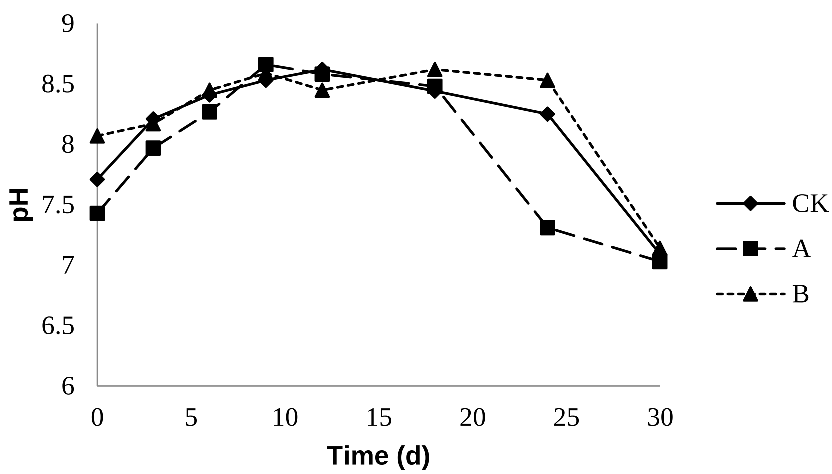

Fig. 2. Changes in the pH value for each group

The electronic conductivity (EC) reflected the soluble salt content in the compost. Water-soluble salt in compost is one of the important factors of crop toxicity, also used as a necessary condition for compost maturation (Huang 2011). In Fig. 3, the EC of Group B declined rapidly and the EC values reached peaks on day 3 (Group CK and Group A) and day 9 (Group CK and Group B), respectively. Subsequently, the EC values were relatively stable. At the end of the compost, the EC values were 105.0 μS/cm (Group CK), 128.4 μS/cm (Group A), 150.5 μS/cm (Group B), conforming to crop safety standard (EC≤9.0ms/cm) (Nie 2000).

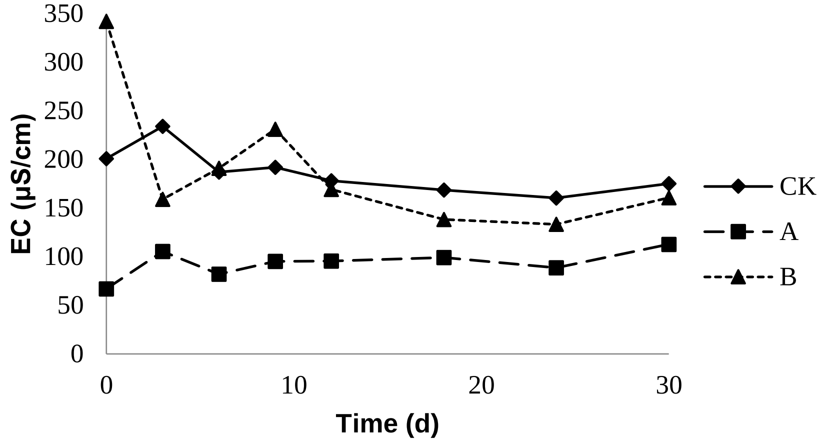

Fig. 3. Changes in the EC for each group

Change in the Seed Germination Index

The seed GI is the most commonly used parameter to evaluate the maturity and biological toxicity of compost products, and it can directly reflect the effects of compost products on seed germination and growth (Chan *et al*. 2016). Figure 4 shows that the GI of the seeds of each group decreased from 0 d to 3 d and then increased gradually.

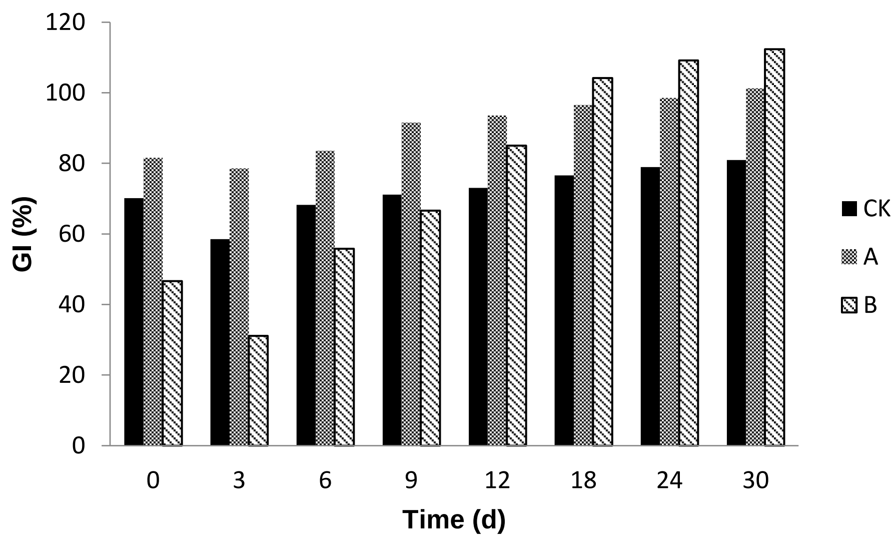

Fig. 4. Change in the seed GI for each group

The decrease in the seed GI was attributed to the strong microbial activities during the early stage of composting, which produced a large number of harmful substances, such as NH_3 and volatile fatty acids, that remarkably inhibited the seed germination (Yuan *et al*. 2016). As composting progressed, some of the NH_3 and volatile fatty acids were converted into volatile gas under the high temperature, while the other part degraded and synthesized new substances (Bao *et al.* 2008; Jiang *et al.* 2016). As a result, the seed germination increased. The decrease in the seed GI for groups CK and B from 0 d to 3 d was notably greater than that for group A, which may have been related to the lower protein content in the composted chicken manure in group A. The final seed germination index of the compost products for groups CK, A, and B were 81.0%, 101.3%, and 112.4%, respectively. According to the criterion for the seed GI where a value greater than 85% when composting indicates full decomposition (Zhang 2004), groups A and B met the criterion for maturity and group B was likely more suitable for plant growth.

Weight Loss and Degradation

Figure 5 shows that the weight loss of each group during the initial seven days was the largest, which was approximately 60%. This period corresponded to the temperature increasing stage and initial part of the high temperature stage. Microorganisms actively decompose proteins, sugars, starches, and other organic matter that can be readily decomposed (Bernal *et al.* 2009). During day 7 to day 14, composting was still in the high temperature stage, but the weight loss of the compost was remarkably reduced compared with the previous seven days, which indicated that after the early vigorous degradation activities, there were not many easily degradable substances (starch, polysaccharides, *etc.*) in the compost and the remaining substances, such as cellulose and lignin, were degraded slowly and with difficulty. After day 14, the weight of the compost hardly changed, which may have been because of the almost complete degradation of the available organic matter, induced microbial activity, or accumulation of certain substances in the compost that inhibit microbial activity. The final mass loss of these three compost groups was in the order CK, A, and B, from large to small. The weight loss over the same period was reduced by adding chicken manure and spent mushroom substrate. Also, the weight loss of the compost with the addition of spent mushroom substrate was less than that of the compost with the addition of the same amount of composted chicken manure.

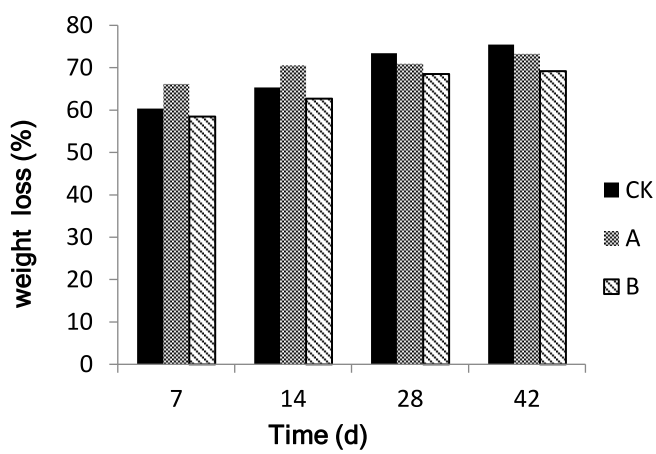

Fig. 5. Weight loss of each group during composting

Degradation of the Cellulose, Hemicellulose, and Lignin

Cellulose, hemicellulose, and lignin are the main components of hickory shell. Improving the degradation of these three components is key to enhancing the composting quality. Figure 6 shows that degradation of cellulose, hemicellulose, and lignin in the first 7 days accounted for 70% to 90% of the total degradation throughout the composting process and it was occurred during thermophilic phase. As it was said in temperature change, high temperature indicated high quantity and activity of the microorganisms. So the sufficient nutrients of the compost mixture made microorganisms reproduce and grow rapidly and the microorganisms led to a massive degradation of lignocellulose during the seven days. After day 7, the temperature increased further and exceeded 63 °C, and the microbial activity decreased rapidly (Figs. 7, 8, and 9). At day 7, the cellulose, hemicellulose, and lignin degradation for Group A were higher than those for the other two groups. Also, the weight loss, seed GI, and maturity of Group A were the highest (Figs. 4 and 5), which was related to composted chicken manure in Group A that contained more easily decomposable components and the higher composition of microbes. (Figs. 7 to 9). At day 7, the cellulose and lignin degradation in group CK were the lowest, while the hemicellulose degradation was similar to that of the other two groups. which was likely caused by fewer bacteria and fungi in Group CK than in the other two groups. On the one hand, compared with chicken manure in Group A, the materials in Group CK contained less additional microbes. On the other hand, the rapid temperature increase, highest temperature (71 °C), and long period of high temperature for group CK resulted in activity reduction or even death of a large number of microbes (Fig. 7-9). At day 14, the cellulose degradation for the three groups was more than 60.4%, which hardly changed at the end of composting. Therefore, the degradation of cellulose in the three groups occurred mainly from 1 d to 14 d. According to Fig. 6, the hemicellulose degradation in the three groups occurred mainly from day 1 to day 7. The lignin degradation in groups A and B was much higher than that in group CK. The main reasons were as follows: first, some bacteria and fungi were inactivated or died because the highest temperature in group CK was higher, and the high temperature lasted for a long period; second, a high temperature inhibits the activity of lignin-degrading enzymes. At the end of composting, the cellulose and hemicellulose degradation in the three groups were almost the same. The lignin degradation in the experimental group with chicken manure and spent mushroom substrate were much higher than that in the control group CK. It was evident that chicken manure and spent mushroom substrate could improve the lignin degradation during composting. In the composting test up to day 14, each group had the same amount of lignin degrading PC bacteria added when the composting temperature decreased to 40 °C. At the end of composting up to day 42, the lignin degradation of groups CK, A, and B were increased by 8.1%, 2.8%, and 5.4%, respectively. Because their lignin degradation extents did not increase remarkably, it was not certain that PC promoted the degradation of lignin. Therefore, the addition of the lignin-degrading PC bacterium in this experiment was of no importance.

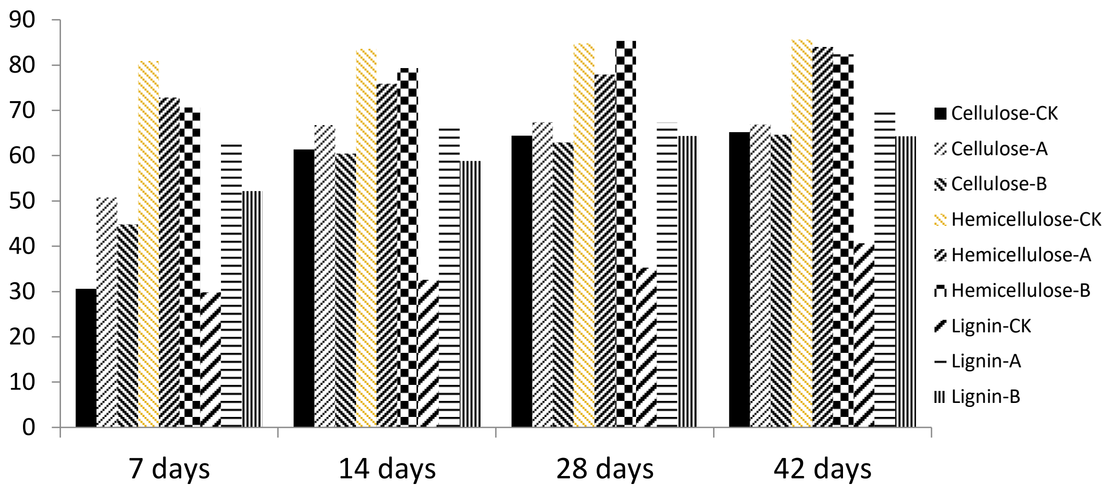

Fig. 6. Cellulose, hemicellulose, and lignin degradation for each group

Correlation of the Microbial Population Changes with the Cellulose, Hemicellulose, and Lignin

Because composting is essentially the process of microbial degradation of organic matter, the microorganisms in compost are closely related to the changes in the organic matter composition, content, and temperature (Wan *et al*. 2009). Figures 7, 8, and 9 show that the number of bacteria, fungi, and actinomycetes in the composting process had a trend where they increased, decreased, increased, and trended towards being stable, which was consistent with the temperature change trend.

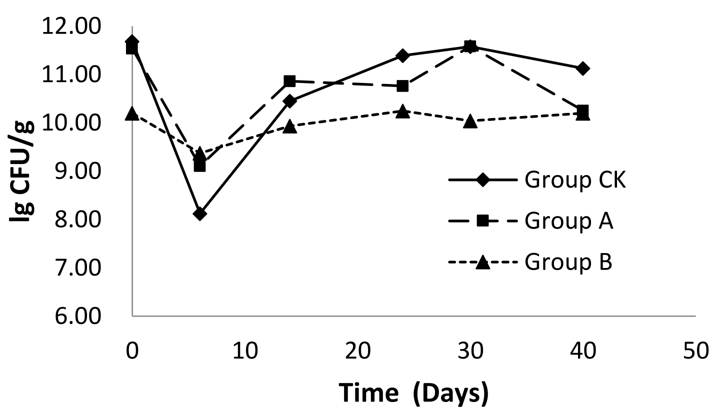

Fig. 7. Changes in the bacterial population during composting

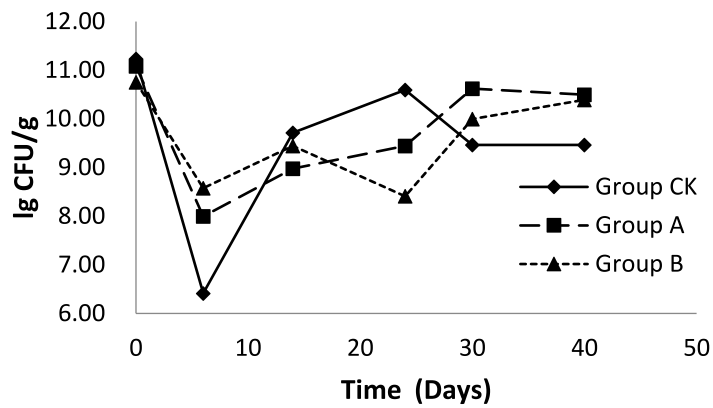

Fig. 8. Changes in the fungal population during composting

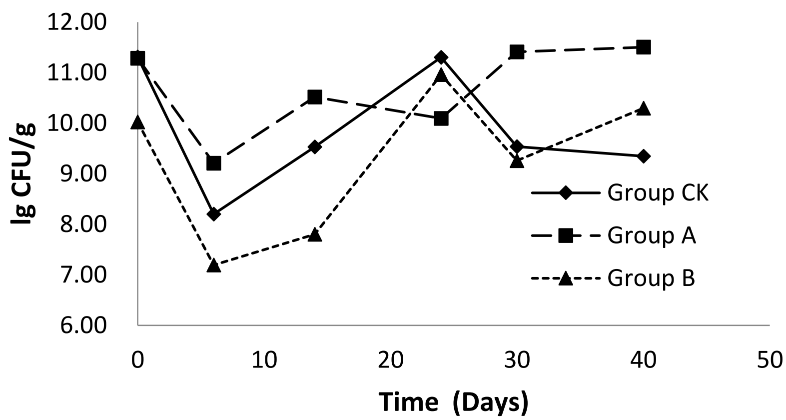

Fig. 9. Changes in the actinomycetes population during composting

Bacteria are the main microorganisms that degrade organic matter and produce heat in the composting process. During the initial phase, a large number of bacteria decomposed organic matter, which caused the temperature of the compost to increase rapidly. The composting temperature increased to above 55 °C on the fourth day to fifth day. At this time, many bacteria were not tolerant to the high temperature and the number of them decreased. Throughout the composting process, the number of bacteria was always larger than fungi and actinomycetes in the groups, especially when the temperature was increasing and high. So bacteria played a dominant role in the initial and thermophilic phase, which generates large amounts of heat. Most of the fungi's maximum growth temperature does not exceed 55 °C. Therefore, as the temperature increased to above 50 °C, the number of fungi decreased rapidly. The growth of actinomycetes was also inhibited by the high temperature (Wan *et al.* 2009). In the temperature decreasing stage (14 d in groups CK and B, and 12 d in group A), the number of the microorganisms increased slowly, and it tended to be stable in the maturation stage. Therefore, the decomposition of cellulose, hemicellulose, and lignin mainly occurred in the first 7 days. The decomposition of organic matter was slow and the products were stable in the middle and late stages because of the death of the degrading bacteria and the lack of nutrients.

Figures 7 to 9 show that the initial number of bacteria, fungi, and actinomycetes in Group B was less than the other two groups, which led to the slower rise in temperature, and indicated the spent mushroom substrate materials had less microorganisms itself compared with soybean meal and composted chicken manure. The number of fungi in groups A and B was remarkably higher than that in group CK in the day 7, which was the main reason that the lignin degradation of groups A and B were notably higher than that of group CK. This may have been because the nutrients in the composted chicken manure (Tao *et al.* 2014) and spent mushroom substrate (Wei *et al.* 2010) and the lower temperature of Group A and B in the initial and thermophilic phase provided suitable environment for fungi growth and activity. From day 7 to day 14, the number of actinomycetes in group A was higher than that in group B, which was the main reason that the lignin degradation of group A was higher than that of group B. In summary, the microorganisms that affected the lignin degradation in the composting process were mainly the fungi and actinomycetes.

CONCLUSIONS

1. The results of this study showed that hickory shell could be used as a raw material for composting by adjusting the initial C/N ratio of composting with soybean meal, thus initializing the composting fermentation and heating up of the hickory shell. The addition of spent mushroom substrate and composted chicken manure as exogenous nutrients could reduce the duration of the high temperature stage for the matured compost, but it increased the degradation of lignin and maturity of compost products. For achieving harmless compost products (GI≥85%), Group A spent 9 days and Group B spent 12 days, but the products of Group B were more suitable for seed growth when the composting time was more than 20 days . The GI of groups with spent mushroom substrate and composted chicken manure were 112% and 101% at day 42, respectively.

2. The weight loss of the hickory shell compost mainly occurred in the first 7 days, which accounted for approximately 60% of the weight loss of the whole process. This result indicated that the addition of spent mushroom substrate and composted chicken manure reduced the weight loss of the compost. The hemicellulose and cellulose degradation of the compost products with composted chicken manure and spent mushroom substrate were more than 82.4% and 64.6%, respectively. Adding composted chicken manure and spent mushroom substrate improved the degradation of cellulose, lignin, and hemicellulose. The cellulose and lignin degradation of group A with composted chicken manure was higher than those of group B with spent mushroom substrate.

3. In the hickory shell composting system, bacteria played a dominant role in the initial and thermophilic phase, and the main factors that affected the degradation extent of lignin during composting were the fungi and actinomycetes.

4. High temperature (>55 °C) is the necessary condition for maturity, but the excessive temperature in composting process is not conducive to the growth of microorganisms and the degradation of substances, so the temperature of thermophilic phase should be controlled. Adding exogenous nutrients, such as spent mushroom substrate or composted chicken manure, is a way to control the temperature.

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