

Effect of Food Waste Compost on the Antler-Type Fruiting Body Yield of *Ganoderma lucidum*

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Abstract The effects of the composition of a mixture containing food waste compost (FWC), rice bran (RB), and oak sawdust (SD) on the antler-type fruiting body (FB) yield of *Ganoderma lucidum* were studied. Experiments were performed using 0 (control), 5, 10, 15, 20, 25, 30, 35, and 40% (w/w) FWC added to a basal growth medium consisting of 20% (w/w) RB and 80% (w/w) SD. The content of 15% FWC gave the highest FB yield (27.0 ± 1.3 g/bottle), which was 44% higher than the yield (18.6 ± 2.8 g/bottle) of the control treatment. However, FWC contents of 20~40% showed reduced yield (2.4~23.0 g/bottle), partly because FWC had a high Na concentration (0.6%). These results demonstrate the potential for use of FWC as a component of a growth medium for production of *G. lucidum* FBs.

Keywords *Ganoderma lucidum*, Lingzhi, Medical mushroom, Nutrient, Organic waste

Mushroom research and production have received increased attention in recent years because of the recognition that mushrooms are a nutritious food with health-stimulating properties and medicinal effects [1]. In Korea, China, Japan, and Taiwan, *Ganoderma lucidum* has long been a popular traditional or Oriental medicine used for treatment of various human diseases including hepatitis, hypertension, hypercholesterolemia, and gastric cancer [1, 2]. This species normally forms shelf-like fruiting bodies (FBs) on tree-trunks, but when grown in darkness and poor ventilation conditions some strains produce an antler-type FB [3] that is rarely found in the wild.

In modern production systems, *G. lucidum* is cultivated on a mixture of sawdust (SD) and wood-chips in bottles or bags [3]. During *G. lucidum* production, raw materials and the preparation of selective compost for FB production are major cost inputs. Therefore, growers are seeking ways to

reduce their production costs by increasing bio-efficiency [4]. Recently, the addition of food waste to the *G. lucidum* growth medium has been considered because this practice has the dual benefits of increasing FB yield and disposing of organic wastes [1].

In Korea, large amounts of food wastes are produced. Currently, such waste is recycled as fertilizer. Food waste compost (FWC) is a nutritionally rich and complex product low in toxic constituents that can be fed to heterotrophic organisms such as fungi [5].

A mixture of SD and rice bran (RB) is one of a variety of possible substrates for mushroom production. Therefore, several types of mushrooms including *G. lucidum* are commercially cultivated in SD media consisting of a mixture of SD and RB. However, little information is available regarding how addition of FWC to growth media affects mushroom production. Thus, the objectives of this study were to evaluate the applicability of FWC as a substrate for *G. lucidum* cultivation and estimate the FWC content at which FB production is greatest.

MATERIALS AND METHODS

***Ganoderma* strain.** A subculture of *G. lucidum* mother culture in media of 80% (w/w) oak SD and 20% (w/w) RB was obtained from a mushroom farm in Chuncheon, Korea.

Substrate preparations and experimental set-up. FWC was obtained from a food waste treatment plant in Wonju, Korea. The FWC was produced by aerobic composting using municipal-source separated food waste

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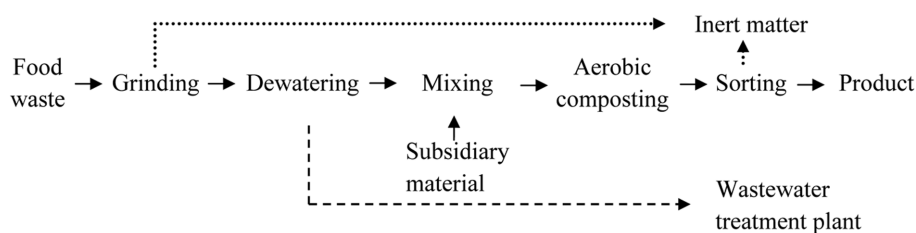


Fig. 1. Schematic of food waste treatment plant in Wonju, Korea.

Table 1. Composition of cultivating media in this experiment and their C/N ratio, NaCl, and Ca contents

Parameter	Control	FWC 5	FWC 10	FWC 15	FWC 20	FWC 25	FWC 30	FWC 35	FWC 40
FWC (%)	0	5	10	15	20	25	30	35	40
SD 80% + RB 20% (%)	100	95	90	85	80	75	70	65	60
C/N ratio	59	51	45	40	36	33	30	28	16
NaCl (%)	0.01	0.09	0.16	0.24	0.32	0.39	0.47	0.55	0.62
Ca (g/kg)	2.67	4.37	6.07	7.77	9.47	11.17	12.87	14.56	16.26

FWC, food waste compost; SD, sawdust; RB, rice bran.

(Fig. 1). RB and oak SD were obtained from companies in Chuncheon, Korea. The oak SD had been stored for more than six months outdoors.

Experiments were performed to evaluate the effects of FWC contents of 0, 5, 10, 15, 20, 25, 30, 35, and 40% (w/w) on mycelial growth rate and FB production. Treatment conditions were denoted as the control, FWC5, FWC10, FWC15, FWC20, FWC25, FWC30, FWC35, and FWC40, respectively (Table 1). The rest of the medium consisted of 80% (w/w) SD and 20% (w/w) RB. All treatments were replicated four times.

Consistent with the established practice [6], the water content of the mixture of SD, RB, and FWC was maintained at 60~65%. Homogenized substrates (800 g) were placed into 850 mL bottles (polyester, 8 cm diameter × 17 cm height), then sterilized in an autoclave for 40 min at 121°C. The sterilized substrates were subsequently inoculated with 5 ± 1 g of fully colonized spawn from the selected strain, after which they were kept in a darkened spawn running room at 23 ± 2°C and 60% relative humidity (RH) for 37 day until inducing FB primordium. To determine the mycelium growth, the length of mycelia was measured after 30 days of incubation. After completion of spawn running, FBs were allowed to develop at 28 ± 2°C and 80% RH in the darkened growing room. To maintain water content at the desired level, water was applied as fine mist. Adequate ventilation was provided manually to maintain the optimum CO₂ concentration [7]. FBs in each bottle were harvested manually and weighed. All procedures were conducted at the mushroom farm in Chuncheon, Korea.

Analytical methods. pH was determined in 1:5 (w/v) sample:water extracts using a pH electrode (Model 735P; Istek, Inc., Seoul, Korea). The water content of SD, RB, and FWC was determined after drying to a constant weight at

105°C in a hot air oven for 5 hr. Organic matter (OM) content was determined after combustion in a muffle furnace at 550°C for 2 hr. The dry weight of the FB was determined after drying to a constant weight at 70°C in a hot air oven for 5 hr. Total nitrogen (T-N) was determined using the Macro-Kjeldahl method [8, 9], and the C/N ratio was calculated from this value and the associated OM value, assuming that OM contains 58% carbon [10, 11].

Mineral contents were measured in dried samples (1 g) after mineralization using 10 mL of a mixture of 60% HClO₄ (9 mL) and 98% H₂SO₄ (1 mL). Phosphorus content was measured colorimetrically using ultraviolet (UV) spectrophotometry (Cary 3; Varian, Harbor City, CA, USA) at 470 nm. K, Ca, Mg, and Na concentrations were analyzed using atomic absorption spectrophotometry (AAS, nov AA300; Analytik Jena AG, Jena, Germany) in an air-acetylene flame.

Concentrations of heavy metals (Pb, Zn, Cu, Cd, and Ni) were determined from 0.5 g samples after digestion for 5 min at 175°C in 10 mL of 70% HNO₃ solution in a microwave accelerated reaction system (CEM, Matthews, NC, USA) equipped with temperature and pressure sensors within the cavity and a turntable with pressure sealed vessels (Omni) of 100 mL each [12]. The heavy metals in the digested samples were analyzed by AAS.

RESULTS AND DISCUSSION

Characteristics of food waste compost, sawdust, and rice bran. The pH was higher in the FWC (7.4 ± 0.1) than in the SD (6.9 ± 0.1) and the RB (6.6 ± 0.1) (Table 2). The water content was 19.5 ± 0.1% in FWC, 15.9 ± 0.2% in SD, and 10.8 ± 0.1% in RB.

The OM in the FWC was 68.3 ± 0.6% (39.6% total carbon [T-C]) and 78.7 ± 0.3% (45.7% T-C) in the RB. T-N

Table 2. Chemical characteristics of food waste compost, sawdust, and rice bran used in this experiment

Parameter	Content		
	Food waste compost	Sawdust	Rice bran
pH	7.4 ± 0.1	6.9 ± 0.1	6.6 ± 0.1
Water content (%)	19.5 ± 0.1	15.9 ± 0.2	10.8 ± 0.1
OM (%)	68.3 ± 0.6	80.3 ± 0.1	78.7 ± 0.3
T-C (%)	39.6	46.6	45.7
T-N (%)	3.10 ± 0.21	0.08 ± 0.01	3.55 ± 0.64
C/N ratio	12.8	615.9	12.9
P (g/kg)	2.68 ± 0.02	0.27 ± 0.01	20.81 ± 0.23
K (g/kg)	0.90 ± 0.01	0.34 ± 0.02	2.07 ± 0.01
Ca (g/kg)	25.22 ± 0.25	3.26 ± 0.21	0.34 ± 0.01
Mg (g/kg)	1.58 ± 0.02	0.33 ± 0.03	4.52 ± 0.05
Na (g/kg)	6.05 ± 0.01	ND	0.19 ± 0.01
Pb (mg/kg)	ND	ND	ND
Zn (mg/kg)	32.7 ± 3.5	12.4 ± 6.9	66.3 ± 6.2
Cu (mg/kg)	11.9 ± 1.5	4.6 ± 2.2	7.0 ± 1.0
Cd (mg/kg)	0.41 ± 0.01	0.41 ± 0.01	0.42 ± 0.01
Ni (mg/kg)	ND	ND	ND

OM, organic matter; T-C, total carbon; T-N, total nitrogen; ND, not detected.

in the FWC was 3.10 ± 0.21% and 3.55 ± 0.64% in the RB. Therefore, the C/N ratio was 12.9 in the RB and 12.8 in the FWC. The FWC contained a good supply of mushroom nutrients and a high OM content so that the RB could partly be replaced by FWC.

Minerals such as Mg, Ca, Cu, and Zn are required by fungi for growth [13]. The P, K, and Mg contents were lower in the FWC than in the RB. However, the Na content in the FWC (6.05 ± 0.01 g/kg) was more than thirty times higher than that in the RB (0.19 ± 0.01 g/kg), which might have reduced FB yield [14]. The FWC had higher Cu content but lower Zn content than the RB. The Ca content in the FWC (25.22 ± 0.25 g/kg) was more than seven times higher than that in the SD (3.26 ± 0.21 g/kg) and more than 70 times higher than that in the RB (0.34 ± 0.01 g/kg), which may have increased the FB since this mineral is in high demand by FB [13, 15, 16]. Pb and Ni were not detected in the FWC, SD, or RB.

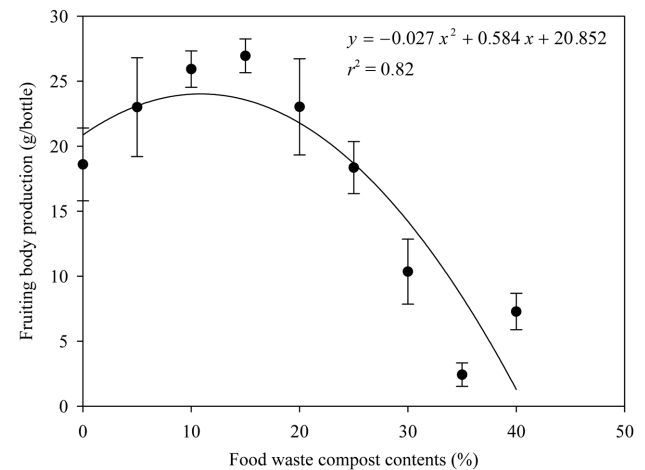
Mycelial growth and fruiting body production. The mycelial growth in the control, FWC5, FWC10, FWC15, FWC20, FWC25, FWC30, FWC35, and FWC40 tended to decrease as FWC content increased (Table 3). The mycelial growth in FWC5, FWC10, FWC15, and FWC20 was not significantly different than that in the control ($p > 0.05$), but the mycelial growth in FWC25, FWC30, FWC35, and FWC40 was significantly lower than that in the control ($p < 0.01$).

FB production (dry weight) increased with FWC content to a maximum at 15% FWC content, and then decreased at higher FWC (Table 3, Figs. 2 and 3). Regression analysis indicated that 11% FWC content would yield the greatest

Table 3. Mycelial growth (23°C) and fruiting body production (28°C) on the substrate containing food waste compost

Treatment	Mycelium growth (cm/30 days)	Fruiting body production ^a (g/bottle)
Control	15.8 ± 1.7	18.6 ± 2.8
FWC5	16.0 ± 2.0	23.0 ± 3.8
FWC10	15.4 ± 1.7	25.9 ± 1.4
FWC15	14.3 ± 3.7	27.0 ± 1.3
FWC20	14.3 ± 3.8	23.0 ± 3.7
FWC25	12.2 ± 2.2	18.4 ± 2.0
FWC30	11.9 ± 1.6	10.4 ± 2.5
FWC35	10.8 ± 1.6	2.4 ± 0.9
FWC40	11.3 ± 2.6	7.3 ± 1.4

^aDry weight.

**Fig. 2.** Effect of food waste compost content in the sawdust media on the yield of fruiting body (dry weight) of *Ganoderma lucidum*.

FB production (Fig. 2). Addition of more than 25% FWC caused FB production to be lower than in the control, possibly due to inhibition by Na [14, 15]. Na content increased as the FWC content increased, but the calculated C/N ratio decreased as the FWC content increased (Table 1). Therefore, FB yield was higher with FWC supplementation when the C/N ratio and Na content were maintained within optimum ranges [1, 14] than when the C/N ratio and Na content exceeded these ranges.

Ca has important functions in regulation of the growth of hyphal apices and the formation of branches. FB production is higher on substrates amended with Ca than on those that contain no additional Ca [13]. In this study, the Ca content increased as the FWC content increased (Table 1); therefore, FB production can be increased when FWC containing high Ca content is used as a growth medium.

Treatment FWC15 gave the highest FB yield, whereas FB production in FWC25, FWC30, FWC35, and FWC40 was not better than in the control, FWC5 or FWC10. Therefore, FWC addition can increase FB production, but too much FWC can reduce it.

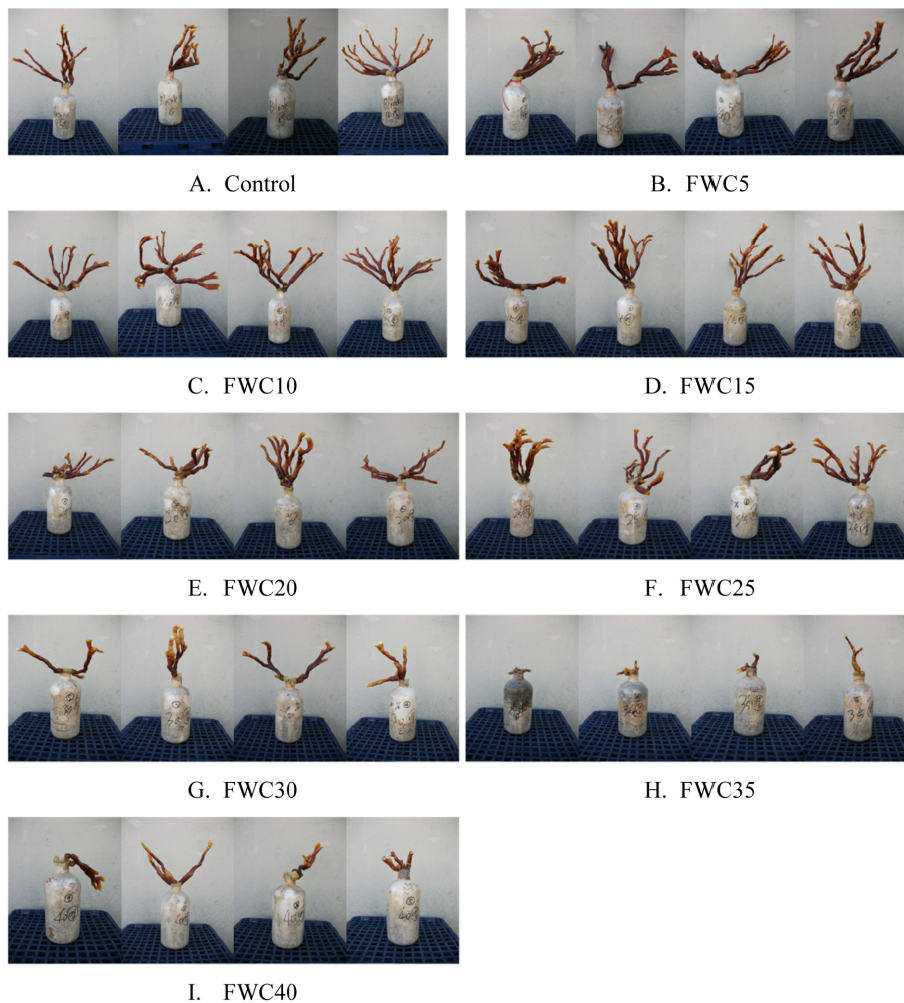


Fig. 3. Fruiting body of *Ganoderma lucidum* with food waste compost (FWC) content of 0% (A), 5% (B), 10% (C), 15% (D), 20% (E), 25% (F), 30% (G), 35% (H), and 40% (I) (w/w).

As mushroom production becomes more competitive and profit margins decrease, growers willing to optimize their production media may have an advantage in the marketplace. Ultimately, consumers will benefit from increased mushroom yields by having mushrooms available at a lower price [13].

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