COCONUT FIBER AS CASING MATERIAL FOR MUSHROOM PRODUCTION
Fibra de Coco como Material de Cobertura en la Producción de Champiñón

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SUMMARY

The use of coconut fiber as casing material in mushroom production, as an alternative to decrease the use of the endangered forestal "black soil" [humic Andisol (Soil Taxonomy); Andosol (WRBS FAO-UNESCO); Aplustand pachico (Soil Survey Staff)], from forest areas of Huitzilac, Morelos State, Mexico, was the subject of this investigation. Coconut fiber, a lignocellulose by-product, was physically and chemically analyzed and evaluated in a commercial mushroom production facility to determine its feasibility as casing material. These analyses indicated that coconut fiber has a series of physicochemical properties which actually enhance the characteristics of "black soil" when mixed in a ratio of 50:50. Productivity trials carried out using casing mixtures of "black soil" as much as 85% of coconut fiber indicated that such mixtures produced the same yields as "black soil" alone.

Index words: *mushrooms cultivation,* Agaricus bisporus *Lange.*

RESUMEN

Esta investigación tuvo como objetivo utilizar la fibra de coco como material de cobertura en la producción de champiñón, como alternativa para disminuir el uso del "suelo negro" de áreas forestales de Huitzilac, Morelos [Andisol húmico (Soil Taxonomy); Andosol (WRBS FAO-UNESCO); Aplustand pachico (Soil Survey Staff)], reduciendo así el impacto antropogénico que coloca a estos suelos y a la biodiversidad que albergan en peligro de extinción. La fibra de coco, de naturaleza lignocelulósica, se analizó y se evaluó física y químicamente en un sistema de producción comercial de champiñones para determinar su potencial y factibilidad de uso. Los análisis indicaron que la fibra de coco posee propiedades fisicoquímicas que se acercan significativamente a las del "suelo negro" cuando se mezclan ambos materiales en una proporción 5:5. Los experimentos de productividad realizados demostraron que en las mezclas de "suelo negro", donde la fibra de coco se adicionó hasta en 85%, el rendimiento fue igual al obtenido con "suelo negro" únicamente.

Palabras clave**:** *materiales de cobertura, cultivo de champiñones,* Agaricus bisporus *Lange.*

INTRODUCTION

Mushroom cropping depends on a particular set of physical, chemical and biological factors, which interact during the growing and fructification processes. Achieving commercially adequate production levels depends on the balance of these factors (Hayes, 1981). The use of a supportive casing material in which the sporophores develop and grow is a fundamental requirement of the production process (Hayes, 1981). Peat and "black soil" have been the casing materials most widely used by commercial mushroom production plants. For instance, in the Highland Plateau of Central Mexico, mushroom producers require about 10 000 cubic meters of "black soil" per year to produce 60 tons of fruiting bodies per day. However, both materials are virtually non-renewable natural resources due to their very long generation period of thousands to millions of years and, therefore, should be husbanded to the maximum (Rangel *et al.*, 1996). Utilization of "black soil" of volcanic origin represents a high risk of erosion of mountainous wooded soils from which it is mined (Palacios-Mayorga and Gama-Castro, 1994). The excessive exploitation of forest soils in recent years represents a danger for forest survival, since these soils are still used for ornamental plants and forest species propagation at the nurseries by the polybag system, in which 700 m^3 of forest soil are needed to produce one million trees. The search, then, for alternative casing

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materials is a pressing task for mushroom producers (Yeo and Hayes, 1978; Hayes *et al*., 1978).

In Mexico, "black soil" [Humic Andisol (FAO-UNESCO, 1990)] added with calcium carbonate or lime has been the most frequently used formulation as casing material for mushroom production. Recently, several tests have been carried out in our laboratories to evaluate various lignocellulose by-products to determine their feasibility as substitutes for "black soil" (Flores *et al.*, 1993; Rangel *et al*., 1996). Coconut fiber is a residue of coconut processing for production of copra and oil. This by-product has been underutilized with only a fraction of its constant production being used in the manufacture of products such as rope, carpet padding, automobile seats and floor mats (SAGAR, 1994). It has also been used as a substrate for growing ornamental plants. In a previous report, coconut fiber mixed with peat was tested as casing material, resulting in competitive production when compared to peat casing material (Border, 1993).

Nevertheless, there is no detailed information available on the physical and chemical properties, which appear to allow coconut fiber to function as casing material either alone or in combination with other substrates, e.g. "black soil". The objectives of this investigation were to characterize physically and chemically coconut fiber, as well as to evaluate its commercial potential as casing material, single or combined, in mushroom cropping when compared with "black soil".

MATERIALS AND METHODS

Materials for Preparation of Casing Media

To evaluate the real potential use of coconut fiber as basic ingredient of a casing medium, two available types of this by-product were selected. Unprocessed coconut fiber (UCF) was obtained from a copra production plant located in Colima, Mexico. Commercial coconut fiber (CCF), commonly used as substrate for ornamental plant production, was obtained from nurseries in the outskirts of Mexico City. The mushroom farm where production tests were performed, supplied the "black soil" (BS) used in the study. This was collected from the mountainous forest areas of the Huitzilac Municipality, State of Morelos. It was either used alone (BS) or supplemented with calcium carbonate at a rate of 100 kg m^{-3} (BSC) and at a rate of 200 kg m^{-3} (BS2C) or with calcium hydroxide at a rate of 25 kg m^{-3} (BSL). These materials were used alone or in volumetric mixtures with coconut fiber as casing media making a total of nine treatments.

Physicochemical and Chemical Analyses of Coconut Fiber and "Black Soil"

Mixtures of each type of coconut fiber with equal volumes of BSC were prepared; that is, BSC:CCF (50:50) and BSC:UCF (50:50). These two mixtures and each individual material were analyzed according to the methods reported by Rangel *et al*. (1996). The following properties were determined: porosity (obtained by dividing the difference of bulk and particle densities); particle size of coconut fiber [using Wentworth screens, according to US Standard (Soil Survey Staff, 1951)]; soil texture (determined according to Bouyoucos, 1963); permeability (determined with the aid of a transparent plastic cylinder with a filter paper); water holding capacity (determined using metallic cylinders covered with filter papers, where materials were moistened by capillarity and drained for 12 h); pH (potential and real, 1:3 w/v, in 0.01 M $CaCl_2$ or in distilled water, respectively); electrical conductivity (determined in a "saturation extract" using a Wheatstone conductimeter); soluble cations in saturation extract (Na and K by flamometry, Ca and Mg by titration with 1*N* EDTA according to Jackson, 1970); organic matter (Walkley and Black, 1974); total nitrogen was determined by the Kjeldahl method (AOAC, 1980).

Production Trials with Experimental Casing Media

Production tests were carried out using 12 plastic bags with 35 kg of fully colonized compost for each casing medium, which were individually cased and randomly distributed in a 250 m^2 commercial production room. Conditions for incubation, fruiting and harvesting were the same as those used for industrial production. The mixtures were: unprocessed coconut fiber (UCF); "black soil"+25 kg of lime (calcium hydroxide) m^{-3}; "black soil"+100 kg of $CaCO_3$ m^{-3} (BSC); "black soil"+ unprocessed coconut fiber, (BSC+UCF) at the ratios of 50:50 and 25:75. For each casing medium, daily production of mushrooms was registered and reported as accumulated mushroom weight per 35 kg of substrate. The average weight of harvested mushrooms per casing material was also recorded.

Using Statistical Package (SPSS, 2005) software, significant differences among mushroom production in each casing material were established by variance analysis of experimental data, and the best treatments were identified with Duncan's test ($\propto = 0.05$).

RESULTS AND DISCUSSION

Physicochemical Characterization

Differences were observed among BSC and both coconut fiber substrates UCF and CCF (Tables 1 and 1A). Porosity is a very important factor in determining the economic potential of a casing material since both mycelium and nutrients should have an easy access to the upper part of the casing layer in order to promote good development of the fruiting bodies. Porosity was larger in lignocellulosic residues (89.7% in CCF and 88.6% in UCF) than in "black soil" (59.8%). This is probably result of the large amount of middle-sized particles present in both types of coconut fiber (0.25 mm and 0.50 mm), while the BSC displayed a higher concentration of smaller particles (less than 0.05 mm). Porosity was not affected by the minor

Table 1. Physical and chemical properties of casing materials.

Properties	Units	Casing materials†					
		BS	BSC	CCF	UCF	BSC:UCF (50:50)	BCS:CCF (50:50)
Porosity	%	59.84	61.86	89.70	88.60	64.70	75.86
Size particles	%						
2.00 mm		4.26	5.06	11.56	4.50	3.30	6.63
1.00 mm		6.46	6.92	16.44	17.30	6.98	7.88
0.50 mm		9.32	7.52	26.81	29.10	10.56	10.52
0.25 mm		36.00	15.28	43.14	24.80	15.86	15.19
0.10 mm		18.58	14.98	0.83	14.20	15.32	15.27
0.05 mm		21.66	48.72	1.19	10.00	47.84	42.27
Textural analysis	%						
Sand		49.10	45.46	-	-	-	-
Silt		34.54	40.00	-	-	-	-
Clay		16.36	14.54	-	-	-	-
Permeability coefficient	$cm\ h^{-1}$	5.32	3.37	102.73	-	23.31	65.27
Water-holding capacity	%						
Drainage at atmospheric		43.37	42.88	78.77	92.90	57.36	46.03
Field capacity (33 KPa)		53.97	65.57	-	-	-	-
PWP (1500 KPa)		22.10	27.76	-	-	-	-
Available water		31.87	35.81	-	-	-	-
pH							
Potential		5.42	7.58	5.47	5.50	7.42	7.62
Real		6.21	8.08	6.07	5.92	7.86	7.70
Electrical conductivity‡	$dS\ m^{-1}$						
Supernatant		0.20	0.44	2.94	2.16	1.05	2.45
Total suspension		0.18	0.49	2.94	2.14	0.77	2.15
Saturation extract		0.33	0.50	-	-	1.83	6.48
Soluble cations	$mg\ L^{-1}$						
Na^+		0.35	6.00	6.45	14.60	3.50	7.30
K^+		0.03	1.70	1.50	5.00	4.20	77.50
Ca^{2+}		2.40	100.00	0.38	0.93	24.00	35.00
Mg^{2+}		0.90	84.00	1.50	1.00	4.75	6.50
Organic matter	%	10.15	10.82	73.08	79.51	17.91	17.25
Carbon/Nitrogen ratio		11.30	14.00	72.30	66.60	18.50	17.80

† BS = "Black Soil"; BSC = "Black Soil" + 100 kg calcium carbonate m^{-3}; CCF = commercial coconut fiber; UCF = unprocessed coconut fiber.
‡ Detected in a 1:3 solution (w/v).

Table 1A. Physical and chemical properties of coconut fiber.

Properties	Unit	CCF	UCF
pH		6.0	6.2
Electrical conductivity	dS m^{-1}	0.12	0.14
Total dissolved solid	mg L^{-1}	5730	7000
Soluble cations	nmol L^{-1}		
Ca^{2+}		12.0	12.0
Mg^{2+}		16.0	20.0
Na^{+}		36.6	37.0
K^{+}		213.3	212.3
Soluble anions	nmol L^{-1}		
CO_3^{2-}		ND	ND
HCO_3^{-}		14.0	14.0
Cl^{-}		230.0	240.0
SO_4^{2-}		30.0	25.0

CCF = comercial coconut fiber (processed); UCF = unprocessed coconut fiber; ND = not detected.

differences between the two types of coconut fiber in the largest particles (2 mm), CCF with 11.6% as opposed to 4.5% in UCF, and in the smallest particles (less than 0.05 mm), 1.2% in CCF as compared to 10% for UCF.

Since both types of coconut fiber had a similar porosity, permeability was determined only in CCF, which showed an extremely high value, 102.7 cm h^{-1}, compared with the very low permeability of "black soil", 3.4 cm h^{-1} for BSC. Water-holding capacity was determined as the weight (g) of water retained by 100 g of wet sample. It is a parameter closely related to porosity and permeability, as well as to the physical and chemical nature of the material, and it is of basic importance for a good mushroom crop. Water-holding capacity was significantly higher for both types of fiber (78.8% and 92.9% for CCF and UCF, respectively) than for BSC (42.9%, when the percolation was performed at normal atmospheric conditions). However, despite the high water-holding capacity of coconut fiber in a weight basis, its very low density limits the amount of material that can be cased on the mushroom culture and special care is needed to avoid uncontrolled drainage from the casing layer to the substrate.

Determinations of pH, either soil-water 1:2.5 (ordinary pH) or soil-KCl 1:2.5 (potential pH, the crude measure of ion exchange), indicated slightly acid values for both types of coconut fiber; 5.50 and 5.92, respectively. The corresponding slightly basic values shown by BSC (7.6 and 8.1) are better suited for the growth of the mushroom mycelium, since at a neutral pH the growth of competing organisms is higher. Addition of calcium carbonate or calcium hydroxide to mixtures of coconut fiber would easily correct this value. Electrical conductivity values, in overflow or in suspension, were higher for coconut fiber, 2.94 dS m^{-1} for CCF and 2.1 dS m^{-1} for UCF, than for BSC (0.44 and 0.49 dS m^{-1}). Nevertheless, these values indicate a content of soluble salts below those levels causing inhibition of fruiting (Hayes, 1981). Insofar as soluble cations are concerned, sodium and potassium concentrations were generally higher in both types of coconut fiber than in BSC (Tables 1 and 1A). It should be pointed out that potassium concentration in CCF was very high (127.5 mg L^{-1}), especially as compared to that of BSC (1.70 mg L^{-1}), although it still falls below the level that is considered inhibitory for mushroom production (Hayes, 1981). The remarkable difference in potassium concentration between the two types of coconut fiber, CCF and UCF, likely indicates that the former one has been supplemented with some fertilizer to enhance yields of vegetables. In contrast, the two remaining ions, calcium and magnesium, are found in greater concentrations in both types of "black soil" (BS and BSC) than in either type of coconut fiber. Organic matter content in the lignocellulosic residues (73.1% for CCF and 79.5% for UCF) is remarkably higher than in "black soil" (around 10%). As expected, the C/N ratio in coconut fiber is much higher than in "black soil". The presence of low levels of nitrogen and unavailable carbon sources in coconut fiber makes it suitable as a casing material, since transition from vegetative growth to fruiting is promoted by casing media with a low content of readily digestible nutrients (Hayes, 1981).

By mixing equal volumes of coconut fiber with BSC, most of the physicochemical parameters of the resulting mixtures approximate to those of single BSC. The mixtures exhibit improved properties as casing material even in regard to the three parameters that resemble more those of the coconut fiber than those of "black soil", *i.e.* permeability coefficient, electrical conductivity and soluble ions. With respect to the last variable, even in the mixture with BSC, CCF shows higher content of soluble ions than the mixture with NCF. Due to the possibility that CCF has been supplemented with some kind of fertilizer, which could negatively influence production of sporophores, its use as casing material is ruled out. Just as reported from previous research (Rangel *et al.*, 1996), the differences found between the values for BSC and BS can be attributed to the added calcium carbonate, which creates a more adequate environment for mushroom development and fructification.

Mushroom Production with Coconut Fiber Containing Casing Media

Based on its favorable physicochemical properties as casing media, UCF alone and in a 50% volumetric mixture with BSC were selected for an initial production trial. In order to reduce as much as possible the proportion of BSC, a casing formula with a higher proportion of coconut fiber, *i.e.* 75%, was also included in this test. As control casings, UCF and BSC ("black soil" supplemented either with 100 kg m^{-3} calcium carbonate) or BSL ("black soil" supplemented with 25 kg m^{-3} calcium hydroxide as masonry lime) were used.

Accumulated mushroom production after seven weeks of cropping, productivity in relation to the control (BSL) and the average weight per mushroom produced with each type of casing material, are shown in Table 2. Statistical analysis of production data allowed classification of the tested casings in four groups. UCF alone showed the lowest accumulation production. Though BSC and its 50% mixture with coconut fiber (BSC+UCF) showed higher values, 45% and 55%, they are separated in the second group, with lower productivity than the control (BSL). The mixture with the highest proportion of coconut fiber, 75%, exhibited the highest productivity with 27% more mushrooms than the control commercial casing: BSL. Although casing with 100% coconut fiber (UCF) failed to produce good yields, with this first trial it was possible to establish a marked improvement of productivity when its proportion in the casing mixtures with soil was increased up to 75%. Concerning the average weight of mushrooms, the lightest fruiting bodies were produced with "black soil", either lime (11.54 g) or carbonate supplemented (11.77 g). Though heavier mushrooms were harvested from the coconut fiber containing casings, 17.03 g for UCF, 14.7 g for the 50% mixture and 14.53 g for the 75% mixture, no statistically significant differences could be established among the various tested casings.

The very low yields obtained with the 100% coconut fiber casing indicated a need for compensation of the resulting loose structure conferred by coconut fiber. Therefore, the rate of calcium carbonate supplementation was doubled and also tested with the 75% mixture aiming to maintain as much as possible the physical and chemical properties provided by "black soil", even at the low proportions of soil used. In this second test, in spite of a higher accumulated production obtained with the 75% mixture, 9% more than the control casing (BSL), no statistically significant differences were detected, either with the other two tested mixtures or with BSC (Table 3). The addition of the larger amount of calcium carbonate did not result in an increased productivity. In fact, it was even lower than the productivity of the control (BSL) and of the mixtures based on BSC.

Though no statistical differences were found in the average weight of mushrooms produced in this second test among the different casings, they were larger than those produced in the first trial. However, it cannot be assumed that mushroom production was carried out under better conditions in the second trial because of the contradicting results obtained with the various casing materials. So, with the control casing (BSC), a significantly larger production was obtained in the second

Table 2. Mushroom production with coconut fiber containing casing materials (Experiment 1).

Casing materials†		Accumulated mushroom production of compost phase II	Productivity	Average weight per mushroom produced
		g kg^{-1}	%	g
UCF	(100)	11.74 ± 16.34 a‡	22	17.03
BSC		24.11 ± 10.37 b	45	11.77
BSC+UCF	(50:50)	29.69 ± 18.83 b	55	14.70
BSL		53.63 ± 18.03 c	100	11.54
BSC+UCF	(25:75)	67.97 ± 11.91 d	127	14.53

† UCF = unprocessed coconut fiber; BSL = "Black Soil" + Lime (25 kg calcium hydroxide m^{-3}); BSC = "Black Soil" + $CaCO_3$ (100 kg calcium carbonate m^{-3}); BS2C = "Black Soil" + $CaCO_3$ (200 kg calcium carbonate m^{-3}).

‡ Different letters in the same column indicate significant differences among the various casing materials (Duncan, $P \leq 0.05$).

Table 3. Mushroom production with coconut fiber containing casing materials (Experiment 2).

Casing materials†	Accumulated mushroom production of compost phase II	Productivity	Average weight per mushroom produced
	g kg^{-1}	%	g
BSL	47.89 ± 25.31 a‡	100	19.53
BSC	43.74 ± 24.14 a	91	22.19
BSC+UCF (25:75)	52.00 ± 21.37 a	109	19.29
BSC+UCF (15:85)	48.26 ± 27.83 a	101	19.70
BS2C+UCF (25:75)	42.46 ± 25.14 a	89	20.73

† UCF = unprocessed coconut fiber; BSL = "Black Soil" + Lime (25 kg calcium hydroxide m^{-3}); BSC = "Black Soil" + $CaCO_3$ (100 kg calcium carbonate m^{-3}); BS2C = "Black Soil" + $CaCO_3$ (200 kg calcium carbonate m^{-3}).
‡ Similar letters in the same column indicate no significant differences among the various casing materials (Anova, $P \leq 0.05$).

Table 4. Analyses of mushroom production with "black soil" and unprocessed coconut fiber as casing material (Experiments 1 and 2).

Experiment	Casing materials	Accumulated mushroom production of compost phase II
		g kg^{-1}
1	"Black Soil" + $CaCO_3$ (100 kg calcium carbonate m^{-3})	24.14 ± 8.86 a†
2	"Black Soil" + lime (25 kg calcium hydroxide m^{-3})	47.89 ± 25.31 b
2	"Black Soil" + $CaCO_3$ (100 kg calcium carbonate m^{-3})	43.74 ± 24.14 b
2	Black Soil + unprocessed coconut fiber (25:75)	52.00 ± 21.37 b
1	BSL = "Black Soil" + Lime (25 kg calcium hydroxide m^{-3})	53.63 ± 19.49 bc
1	Black Soil + unprocessed coconut fiber (25:75)	66.54 ± 12.31 c

† Same letters in the same column are not statistically different (Duncan, $P \leq 0.05$).

experiment, which almost doubled that obtained in the first trial. But on the contrary, no difference between the two tests was observed with the other control casing (BSL) and, moreover, the yield of the 75% mixture was statistically higher in the first test (Tables 3 and 4). These observations confirm the complexity of the process for mushroom production, therefore, to evaluate new types of casing their performance has to be analyzed by comparison with a control casing. In this study, calcium hydroxide supplemented "black soil", the casing mixture locally used for commercial production, was employed for such purpose.

According to the results of this investigation, a productive casing material can be prepared by adding coconut UCF to BSC; the good performance observed with the 85% mixture point it out as a good alternative to reduce consumption of "black soil" and yet maintain mushroom productivity. As we can observe in Figure 1, treatment with 100% of "black soil" as casing material (bag 27) and treatment mixture 85% UCF - 15% BSC as casing material (bag 30) were similar in yield. Herewith, an actual improvement of certain physical and chemical properties of casing materials, which are of prime importance for mushroom formation, can be accomplished documenting previous empirical reports about the potential use of coconut fiber for the formulation of casing media (Border, 1993).

CONCLUSIONS

- Porosity and texture (particle size distribution in the mixture), as well as the water holding capacity, are markedly improved by addition of coconut fiber (UCF), while pH, electrical conductivity, and the contents of soluble cations remain statistically unaltered. These changes altogether provide an enhanced environment for the development and growth of the fruiting bodies.
- The lime supplemented "black soil", extensively used for commercial production in Mexico, can be substituted by mixtures containing as much as 85% of UCF with no impairment in yield. In this way, by decreasing the requirements of forest "black soil", its depletion from

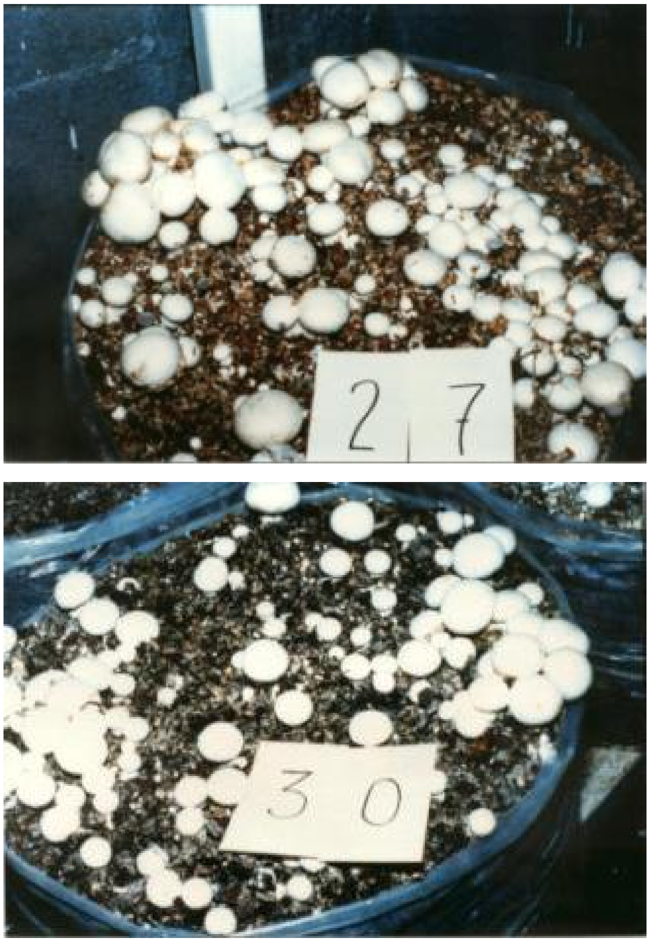

Figure 1. Culture of mushrooms in plastic bags; with Number 27 using only "black soil" as casing material, and Number 30 using casing mixture of "black soil" with 85% of coconut fiber. Statistically, both treatments were similar in yield.

the temperate central forests of Mexico can be significantly reduced.

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