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Enhancement of nutritive value of tea leaf waste by solid-state fermentation with *Lentinus sajor-caju*

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ABSTRACT

Nutritional value of tea leaf waste was improved significantly ($p < 0.05$) by solid-state fermentation for 8 weeks with a white rot fungus, *Lentinus sajor-caju*. The proximate analysis revealed that crude protein, ash, cellulose-lignin ratio and reducing sugar contents were increased by 2001.53, 117.62, 31.38, and 619.10%, respectively. In contrary, crude fiber, lipid, carbohydrate, lignin, cellulose and hemicelluloses contents were decreased by 40.70, 71.87, 47.65, 35.63, 15.26, and 61.03%, respectively. Ascorbic acid and carotenoids were also increased by 129.17 and 398.79%, respectively. At 7 weeks of fermentation, the crude tea leaf waste extract showed very high endoglucanase, exoglucanase, cellobiase and amylase activity, moderate pectinase and poor xylanase activity. Furthermore, In vitro dry matter digestibility was increased by 50.35% at the end of fermentation. Therefore, it was concluded that *L. sajor-caju* efficiently degraded tea leaf waste and improved its nutritive value.

Key words: Solid-state fermentation, *L. sajor-caju*, tea leaf waste, protein, lignocellulose

Introduction

Lignocellulosic wastes (LCW) are composed of cellulose, hemicellulose, and lignin. These abundant and largest renewable fermentable carbohydrates have a great potential for the production of protein rich food, feed, fuel and other industrially important products (Pandey et al., 2000; Mukherjee et al., 2004; Mtui & Nakamura, 2005; Foyle et al., 2007). However, the main impediment to produce valuable materials from LCW through biodegradation is the structure of lignocelluloses which has evolved to resist degradation due to crosslinking between the polysaccharides (cellulose and hemicellulose) and the lignin via ester and ether linkages (Yan & Shuya, 2006; Xiao et al., 2007; Rubin, 2008). The

degradation can be achieved by single or combined implementation of mechanical, physico-chemical or biological treatments (Mosier et al., 2005; Hendriks & Zeeman, 2009).

Microbial conversion of lignocelluloses to energy and nutritionally enriched ruminant feed is becoming popular day-by-day. White rot fungi, capable of degrading lignin, cellulose and hemicelluloses, have already been reported for efficient bioconversion of many lignocellulosic wastes. Although tea is the most popular beverage in Bangladesh, like other countries, leaf waste of this popular drink has almost no use and just throughout with other kitchen waste. Until now, there are only a few reports evaluating the nutritive value of tea leaf waste and even fewer reports

attempting augmentation the value by bioconversion. However, combination of chemical and biological treatment is expected to improve the nutritional quality of this useless-lignocellulosic waste. In the present study, CaCO₃-pretreated tea leaf waste was used for Solid-state fermentation (SSF) by *L. sajor-caju* to enhance delignification and in vitro dry matter digestibility in addition to several nutritional parameters. We further checked the rise of antioxidative properties and enzyme activities of crude tea leaf waste extracts because of SSF.

Materials and Methods

Pretreatment of substrates

Cellulosic materials collected from different sources were first cleaned off all dirt and unwanted materials. Then they were sun dried, cut into tiny pieces between 2–3 cm and stored at 5°C until used. 500 g of untreated tea leaf waste was soaked with a calcium carbonate solution (0.27% CaCO₃ in distilled H₂O). The substrates were left in soaking condition overnight. Then the lime solution was drained out by tap water. Treated substrates were then spread over aluminum foils and allowed to dry overnight at 60°C.

Collection and storage of *L. sajor-caju*

Stock culture of *Pleurotus sajor-caju* was obtained as Potato dextrose agar (PDA) slant from Microbiology and Industrial Irradiation Division of Bangladesh Atomic Energy Commission. The culture was maintained on PDA slant medium at 4°C and sub-cultured every 15 days.

Solid-state fermentation

L. sajor-caju was sub cultured from stock PDA slant to PDA plate. After 7 days of incubation at 30°C three pieces of mycelia growth (about 1 cm in diameter) were inoculated in 100 ml Erlenmeyer flask containing 50 ml PDB. The flask was incubated at 30°C at 150 rpm for 7 days and then the inoculum was transferred in pre-sterilized 30 g substrates (into 1000 ml Erlenmeyerflask) and incubated at 30°C for 8 weeks.

Analytical methods

Biochemical analyses: Tea leaf waste with different periods of fermentation were collected aseptically, oven dried at 60°C and used for biochemical analysis. The substrate without CaCO₃ treatment and SSF was used as control and also dried overnight at 60°C before biochemical analyses. Ash, fat, crude fiber and moisture contents were determined following the methods of A.O.A.C (1980), while the crude protein contents (N×6.25) were determined using micro-kjeldahl method (ISO 20483 2006). The carbohydrate content was determined by the method of Dubois et al. (1956).

Gravimetric determination of lignin, cellulose and hemicellulose of the substrates were estimated according to Sun et al. (1996) and Adsul et al. (2005). In brief, a considerable weight of air-dried moldy substrate was fragmented into small pieces and suspended in 200 ml 1.0% (w/v) aqueous solution of NaOH. The mixture was autoclaved at 121°C for 1.0 h in 500 ml Erlenmeyerflask. The residues were collected and extremely washed by tap water until neutral pH; then dried at 80°C for 48 h and weighted. The loss of weight corresponded to lignin content. For determination of cellulose and hemicellulose, a considerable weight of air dried delignified substrate (after lignin determination) was milled and screened to about 0.1 cm and suspended in 100 mL sulfuric acid 1.0% (v/v). The mixture was then autoclaved at 121°C for 1.0 h in 250 ml Erlenmeyer flask. The residues were collected and washed extensively with tap water until neutral pH, dried at 80°C for 48 h and then weighted. The difference between started weight and residual weight corresponded to hemicellulose fractions; while, residual weight after acid hydrolysis corresponded to cellulose content.

The cellulose to lignin ratio was also determined. Reducing sugar contents in control and fermented substrates at their various stages of fermentation were determined by the dinitrosalicylic acid (DNS) method (Miller, 1959).

The crude enzyme solution was obtained by soaking 1 g moldy substrate with 10 ml 0.01 M acetate buffer (pH 5.5). The mixture was shaken for 2.0 h and centrifuged at 5000 rpm for 10.0 min to remove cells and residual substrate. The clarified extract representing crude enzyme was used for assaying endoglucanase (CMCase, EC 3.2.1.4), exoglucanase (avicelase, EC 3.2.1.91), xylanase (EC 3.2.1.8), (Saddler et al., 1987), pectinase (EC 3.2.1.15) (Shimizu & Kunoh, 2000), cellobiase (EC 3.2.1.21) (Lowe et al., 1987) and amylase (EC 3.2.1.1) (Pandey et al., 2000) activities. Enzyme assays were carried out in triplicate. The enzymatic activities were expressed as international units (IU), defined as the amount of enzyme required for production of 1 μmol product/min, and were reported as IU/g substrate used in the SSF as described by Shrivastava et al. (2011).

Quantification of antioxidants: Amount of ascorbic acid was quantified by spectrophotometric method after extraction with 3% HPO₃ as described in the Methods of Vitamins Assay (1966). Total carotenoids were extracted in 80% acetone and absorption was taken at 663, 645 and 480 nm. Finally the amount of carotenoids was calculated using the following formula as described by Hiscox & Isrealstam (1979).

$$\text{Total carotenoid mg/g of sample} = A_{480} + (0.114 \times A_{663}) - (0.638 \times A_{645}) \times V/1000 \times W$$

A = Absorption at given wavelength, V = Total volume of sample in extraction medium (ml) and W = Weight of the sample (g)

In-vitro dry matter digestibility (IVDMD): Dry matter digestibility was assessed following the methods of Tilley & Terry (1963) and Minson & McLeod (1972) and expressed as loss of dry matter. Ruminant fluid was obtained from a lactating goat after 4 h feeding on a mixed ration consisting of 75% grass forage and 25% grain mixture (20% ground corn, 4% soybean meal, 1% vitamin and mineral mix).

Statistical analysis

Data from different biochemical analyses of non-fermented and fermented samples at different periods were subjected to one-way analysis of variance (ANOVA) followed by Duncan's multiple range tests. Analyses were performed using statistical applications and differences and were considered significant at an alpha level of 0.05. The statistical program used was stat viewR 5.0 (Mind Vision Software, Abacus, Concepts, Inc. Berkeley, CA, USA).

Results and Discussion

Changes in the proximal composition during SSF

The proximal composition of tea leaf waste was changed significantly after solid-state fermentation ($p < 0.05$) compared to non-fermented one (Table 1). The crude fiber content decreased 40.70% after 8 weeks fermentation indicating secretion of cellulose/hemicellulose-degrading enzymes by the fungus during fermentation (Lateef *et al.* 2008). The protein content of fermented tea leaf waste was increased by 2001.53% referring enormous increase of the fermenting fungal growth on the lignocellulosic waste. The finding supports similar improvement for lignocellulosic wastes reported elsewhere (Murata & Miyamoto, 1967; Bender, 1970; Odunfa, 1983; Hammond & Wood, 1985; Matsuo, 1997; Leifa *et al.*, 2001; Iyayi & Aderolu, 2004; Iluyemi *et al.*, 2006; Moore *et al.*, 2007; Das & Mukherjee, 2007; Akinyele *et al.*, 2011). Besides fungal growth, secretion of certain extracellular enzymes also contributed to the increase of protein (Kadiri, 1999). The ash content was also increased 117.62% at the end of fermentation. Since the ash content determination is a measure of mineral levels in the substrates, it can be inferred that SSF contributed to the elevation of mineral levels in the fermented products. The improvement of ash content due to enhanced decomposition of total organic carbons to carbon dioxide by SSF was in accordance with the report of Sanni & Ogbonna (1991), Bressani (1993), O'Toole (1999). In contrary, Fadahunsi & Sanni (2010) and Akinyele *et al.*, (2011) reported a decrease of ash content due to SSF of agricultural wastes. Generally, fermentation led to the reduction in the crude fat content. Here, the reduction was

71.88% after 8 weeks SSF. In a similar study, the fat content of okara was reduced from 15 to 9% by fermentation with *Neurospora intermedia* (Matsuo, 1997). Earlier studies showed a decrease in the fat content of different lignocellulosic substrates fermented with different microorganisms. During SSF, lipolytic strains assimilate lipids from substrates for biomass production and cellular activities leading to a general reduction of the overall lipid content (Lateef *et al.*, 2008; Iluyemi *et al.*, 2006; Sanni & Ogbonna, 1991; Das & Weeks, 1979; Ejiofor *et al.*, 1987). The carbohydrate content of tea leaf waste was also decreased (47.66%) significantly because of the SSF. Carbohydrates are used through different biochemical processes by microorganisms to produce simple sugars during bioconversion of lignocelluloses (Howard *et al.*, 2003; Akinyele, 2011).

The reducing sugar content of tea leaf waste was increased significantly and correlated directly with the increase of biomass and decrease of carbohydrates during 8 weeks fermentation period (Table 2). The reducing sugar content of fresh tea leaf waste was found to increase up to 7 weeks of fermentation indicating enzymatic degradation of cellulose, hemicellulose and pectin fractions of the substrate (Sherief *et al.*, 2010). However, the decreased free sugar content after 7 weeks fermentation can be explained by decreased rate of the degradation as compared to the rate of free sugar metabolism by *L. sajor caju*. These findings were supported by the findings of Sanni & Ogbonna (1991) where they reported a sharp decrease of enzymatic activity at 24 h of fermentation during the production of "Owoh" from cotton seed.

Degradation of lignin, cellulose and hemicelluloses

The chemical pretreatment of tea leaf waste with CaCO_3 prior to SSF enhanced the delignification and resulted in a decrease of lignin content from 27.90% of total dry weight to 24.27% (13.01% loss). While comparing the content of lignin, hemicellulose and cellulose during SSF, a significant decrease ($p < 0.05$) of all these compounds was observed. However, cellulose to lignin ratio (C/L ratio) of fermented agro-industrial wastes was significantly increased ($p < 0.05$) compared with their non-fermented samples. The percentage of lignin content was decreased by 35.62% (Table 2) for SSF indicating the ability of *L. sajor-caju* to bulk of ligninases production such as laccases and peroxidases (Leonowicz *et al.*, 1999; Baldrian *et al.*, 2005; Hoegger *et al.*, 2007) while fermenting tea leaf waste. The finding was in accordance with the previous reports of Vega *et al.* (2005), Lechner & Papinutti (2006) and Sherief *et al.* (2010) where lignolytic activities of fermenting microorganisms were found during biodegradation of rice straw, saw dust, wheat straw, coffee pulp and banana leaves. The percentage of cellulose was

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Table 1. Proximal composition (% of dry substrate) of tea leaf waste at various periods of solid state fermentation with *L. sajor-caju*. (Results are expressed as mean \pm SD (standard deviation) of three independent experiments. Values in the same column with different alphabets are significantly different at $p < 0.05$).

Cultivation period	Crude fibers	Protein	Ash	Lipids	Carbohydrates
Week-0	5.11 \pm 0.04h	1.96 \pm 0.12a	5.9 \pm 0.14a	0.985 \pm 0.09g	80.01 \pm 0.23i
Week-1	4.71 \pm 0.03g	6.52 \pm 1.19b	7.13 \pm 0.18b	0.820 \pm 0.01f	78.19 \pm 0.80h
Week-2	4.32 \pm 0.05f	13.49 \pm 1.02c	8.25 \pm 0.35c	0.594 \pm 0.01e	71.01 \pm 0.74g
Week-3	4.20 \pm 0.04ef	19.11 \pm 0.38d	8.43 \pm 0.04c	0.470 \pm 0.01d	65.46 \pm 0.14f
Week-4	4.05 \pm 0.07de	22.08 \pm 1.48e	8.65 \pm 0.06c	0.427 \pm 0.02cd	62.54 \pm 0.24e
Week-5	3.84 \pm 0.08cd	26.84 \pm 0.55f	9.30 \pm 0.02d	0.396 \pm 0.01cd	57.27 \pm 0.23d
Week-6	3.66 \pm 0.06c	30.17 \pm 0.40g	10.33 \pm 0.47e	0.367 \pm 0.01bc	52.95 \pm 0.67c
Week-7	3.36 \pm 0.08b	35.54 \pm 0.68h	11.60 \pm 0.28f	0.361 \pm 0.01ab	46.55 \pm 1.32b
Week-8	3.03 \pm 0.03a	41.19 \pm 3.08i	12.84 \pm 0.23g	0.277 \pm 0.01a	41.88 \pm 0.43a

Table 2. Lignin, cellulose, hemicelluloses, C/L and reducing sugar contents (% of dry substrate) of tea leaf waste at different periods of SSF by *L. sajor-caju*. (Results are expressed as mean \pm SD (standard deviation) of three independent experiments. Values in the same column with different alphabets are significantly different at $p < 0.05$).

Cultivation time	Lignin	Hemicelluloses	Celluloses	Cellulose to Lignin ratio (C/L)	Reducing sugars
Week-0	27.9 \pm 0.42e	10.78 \pm 0.78e	38.0 \pm 0.56d	1.37 \pm 0.007a	0.89 \pm 0.03a
Week-1	22.08 \pm 0.68d	9.75 \pm 0.78e	34.80 \pm 0.56c	1.58 \pm 0.021b	1.16 \pm 0.02ab
Week-2	20.95 \pm 0.21cd	7.80 \pm 0.85d	34.05 \pm 0.35bc	1.63 \pm 0.007bc	1.28 \pm 0.02ab
Week-3	20.87 \pm 0.37cd	7.65 \pm 0.92d	34.10 \pm 0.42bc	1.64 \pm 0.007c	1.42 \pm 0.04ab
Week-4	20.75 \pm 0.78cd	7.0 \pm 0.28cd	34.20 \pm 0.84bc	1.65 \pm 0.021cd	1.60 \pm 0.02b
Week-5	19.67 \pm 0.93cd	6.85 \pm 0.35bcd	33.15 \pm 0.49abc	1.69 \pm 0.057de	1.74 \pm 0.06b
Week-6	18.90 \pm 0.42ab	5.75 \pm 0.21abc	33.15 \pm 0.15abc	1.76 \pm 0.007fg	4.99 \pm 0.68c
Week-7	18.81 \pm 0.57ab	5.3 \pm 0.42ab	32.65 \pm 0.91ab	1.72 \pm 0.014ef	7.21 \pm 0.47e
Week-8	17.96 \pm 0.50a	4.2 \pm 0.57a	32.20 \pm 0.85a	1.80 \pm 0.007g	6.40 \pm 0.15d

Table 3. Amounts of total dry weight, ascorbic acid and total carotinoids of fresh and fermented tea leaf waste before and after SSF. (Results are expressed as mean \pm SD (standard deviation) of three independent experiments. Values in the same column with different alphabets are significantly different at $p < 0.05$).

Type of sample	Total dry weight (g)	Ascorbic acid (mg/g)	Total Carotinoids (mg/g)	In-vitro digestibility (% of dry substrate)
Control	30.00 \pm 0.97a	0.077 \pm 0.02a	0.166 \pm 0.014a	34.77 \pm 0.47 a
Fermented substrates	32.43 \pm 0.86b	0.176 \pm 0.035b	0.828 \pm 0.046b	52.28 \pm 0.36b

found to reach 32.20% of the total dry weight at the end of fermentation (Table 2) after a reduction of 15.26% from the initial cellulose content referring increased production of cellulases. Cellulose degradation is a usual phenomenon during SSF of lignocelluloses as reported by Bisaria et al. (1997), Vega et al. (2005), Sherief et al. (2010) and Jahromi et al. (2011). Hemicellulose degradation was found higher than that of cellulose and at the end the reduction was 61.04% compared to non-fermented one. The higher hemicelluloses degradation could be the indicative of the higher degradation of the cell wall component of the substrates produced by the extracellular enzymes (xylanase, xylosidase, arabinase and pectinase) of the fungi used.

Cellulolytic enzyme activities

Because of secretion of extracellular enzymes, edible mushrooms i.e., *L. sajor-caju* and *P. pulmonarium* are able to convert a wide variety of lignocellulose materials (Rajaratnam, 1981; Buswell et al., 1993). The increase of

free sugar (Table 2) and decrease of cellulose and hemicellulose (Table 2) during SSF indicated the presence of degradation cellulolytic enzyme activities of *L. sajor-caju* while growing on tea leaf waste. Therefore, crude enzymatic activities of *P. sajor-caju* were measured at the period of 7 weeks SSF since the highest concentration of reducing sugars was found at this point. CMCase, avicelase and cellobiase activities were 2.38, 2.02 and 1.55 IU/g respectively. These activities directly correlate with the degradation of cellulose. The fungus also showed high α -amylase activity and low xylanase and moderate pectinase activity. Very low xylanase activity was also reported by Kumaran et al. (1997) during SSF of Sago hampus, a starchy lignocellulosic by-product prepared from sago palm.

Improvement of antioxidative nature and in-vitro digestibility

Total dry matter, anti-oxidative properties and in-vitro dry matter digestibility of tea leaf waste were also changed after

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SSF (Table 3). Increase of dry matter by 8.1% was because of increased biomass of the fungal mycelial growth. Ascorbic acid production was improved by 129.16%. The growth of *L. sajor-caju* also contributed to improving significantly the levels of total carotenoid by 398.79%. Possession of high antioxidant activity of some common edible mushrooms has already been reported earlier (Cheung *et al.* 2003; Cheung & Cheung 2005). Most importantly, a very high increase of IVDMD (50.35%) was also observed. Delignification of tea leaf waste before fermentation through chemical pretreatment led this improved IVDMD. This result was supported by the findings that digestibility is usually inversely related to the lignin concentration (Kamra & Zadrazil 1985). Karunanandaa *et al.* (1995) and Garcha *et al.* (1995) also reported higher digestibility of paddy straw because of faster delignification than other lignocellulosic wastes by mutant strains of *P. forida* in SSF. As ruminal microbes do not secrete any ligninolytic enzyme (Zadrazil, 1995) the reduced lignin of the fermented material facilitated more efficient degradation of structural carbohydrates of hyacinth, thus, increased the digestibility. Therefore, the SSF used in this study helped to accumulate a higher amount of soluble sugars through bioconversion which will be easily digestible by ruminants.

CONCLUSION

Solid state fermentation of pre-treated tea leaf waste not only improved nutritive values such as protein and available polysaccharide fractions as an energy source for ruminants but also made it more digestible due to higher delignification. Furthermore, the fermented product was also rich in some anti-oxidative agents such as ascorbic acid and total carotenoids. However, the bioconverted product should be checked by in-vivo feeding trial and toxicity tests before using as nutritionally improved animal feed.

References

- Adsul MG, Ghule JE, Shaikh H, Singh R, Bastawde KB, Gokhale DV, Varma AJ. 2005. Enzymatic hydrolysis of delignified bagasse polysaccharides. *Carbohydrate Polymer*, 62: 6–10.
- Akinyele BJ, Olaniyi OO, Arotupin DJ. 2011. Bioconversion of selected agricultural wastes and associated enzymes by *Volvariella volvariella*: An edible mushroom. *Res. J. Microbiol.* 6(1): 63–70.
- AOAC (Association of Official Analytical Chemists). 1980. Official methods of analysis. 13th edn. Washington, D.C., USA. pp. 1081.
- Baldrian P, Valaskova V, Merhautova V, Gabriel J. 2005. Degradation of lignocelluloses by *Pleurotus ostreatus* in the presence of copper, manganese, lead and zinc. *Res. Microbiol.*, 156:670–676.
- Bender PF. 1970. Under-utilized resources as animal feedstuffs. National Academic Press, Washington, DC, pp. 100.
- Bisaria R, Madan M, Vasudevan P. 1997. Utilization of agro-residues as animal feed through bioconversion. *Bioresour. Technol.*, 59: 5–8.
- Bressani R. 1993. Grain quality of beans. *Fd. Rev. Int.* 9: 287–297.
- Buswell JA, Cai YJ, Chang ST. 1993. Fungi and substrate associated factors affecting the ability of individual mushroom species to utilize different lignocellulosic growth substrates. In: Chang ST, Buswell JA, Chiu SW (eds) *Mushroom Biology and Mushroom Products*, Chinese University Press, Hong Kong, pp. 141-150.
- Cheung LM, Cheung PCK. 2005. Mushroom extracts with antioxidant activity against lipid peroxidation. *Food Chemistry*, 89:403–409.
- Cheung LM, Cheung PCK, Ooi VEC. 2003. Antioxidant activity and total phenolics of edible mushroom extracts. *Food Chemistry*, 81:249–255.
- Das DVM, Weeks G. 1979. Effects of polyunsaturated fatty acids on the growth and differentiation of the cellular slime mold *Dictyostelium discoideum*. *Exp. Cell Res.*, 118:237–243.
- Das N, Mukherjee M. 2007. Cultivation of *Pleurotus ostreatus* on weed plants. *Bioresour. Technol.*, 98: 2723–2726.
- Dubois M, Gilles KA, Hamilton T R, Rebers PA, Smith F. 1956. Determination of sugars and related substances. *Anal. Chem.*, 28: 350–356.
- Ejiofor MAN, Oti E, Okafor JC. 1987. Study on the fermentation of seeds of African oil bean tree (*Pentachetra Macrophylla*). *The Int. Tree Crop. J.*, 4: 135–144.
- Fadahunsi IF, Sanni AI. 2010. Chemical and biochemical changes in bambara nut (*voandzeia subterranea* (L) Thours) during fermentation To 'tempeh'. *Electro. J. Environ. Agric. Food Chem.*, 9(2): 275-283.
- Foyle T, Jennings L, Mulcahy P. 2007. Compositional analysis of lignocellulosic materials: Evaluation of methods used for sugar from cotton seed. *Food Microbiol.*, 9:177–183.
- Garcha HS, Khanna PK, Dhanda S. 1995. Improvements in delignification and digestibility of Paddy straw by SSF using hyperlaccase mutants of *Pleurotus florida*. *Mushroom Research*, 4: 59–64.
- Hammond JWB, Wood DA. 1985. *Metabolism, Microbiology*. 2nd edn. In: Flagg PB, Spencer DM, Wood DA (eds) *The Biology and Technology of the cultivated Mushrooms*, John Wiley and Sons, Chichester, pp. 63-80.
- Hendriks ATWM, Zeeman G. 2009. Pretreatments to enhance the digestibility of lignocelluloses biomass. *Bioresour. Technol.*, 100:10–18.
- Hiscox JD, Isrealstam GF. 1979 A method for the extraction of chlorophyll from leaf issue without maceration. *Canadian J. Botany*, 57: 1332–1334.
- Hoegger PJ, Majcherczyk A, Dwivedi RC, Svobodova K, Kilaru S, Kues U. 2007. Enzymes in wood degradation. In: Kues U (ed) *Wood production, wood technology and biotechnological impacts*, Universitatsverlag Gottingn. Germany, pp. 389-438.
- Howard RL, Abotsi E, van Rensburg ELIJ, Howard S. 2003. Lignocellulose biotechnology issues of bioconversion and enzyme production. *Rev. Afri. J. Biotechnol.*, 2: 602–619.
- Ilyumi FB, Hanafi MM, Radziah O, Kamarudin MS. 2006. Fungal solid state culture of palm kernel cake. *Bioresour. Technol.*, 97: 477–482.
- ISO 20483. 2006. Determination of the nitrogen content and calculation of the crude protein content – Kjeldahl method. The International Organization for Standardization, Geneva, Switzerland.
- Iyayi EA, Aderolu ZA. 2004. Enhancement of the feeding value of some agro-industrial by-products for laying hens after their solid state fermentation with *Trichoderma viride*. *Afr. J. Biotechnol.* 3: 182–185.

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- Jahromi MF, Liang JB, Rosfarizan M, Goh YM, Shokryazdan P, Ho YW. (2011) Efficiency of rice straw lignocelluloses degradability by *Aspergillus terreus* ATCC 74135 in solid state fermentation. *Afri. J. Biotechnol.* 10(21): 4428-4435.
- Kadiri M. 1999. Physiological studies of some Nigerian mushrooms. Ph.D. Thesis, University of Ibadan, Ibadan, Nigeria.
- Kamra DN, Zadrazil F. 1985. Influence of oxygen and carbon dioxide on lignin degradation in solid state fermentation of wheat straw with *Stropharia rugosoannulata*. *Biotechnol. Letters*, 7:335-340.
- Karunanandaa K, Varga GA, Akin DE, Rigsby LL, Royse DL. 1995. Botanical fractions of rice straw colonized by white rot fungi: changes in chemical composition and structure. *Animal Feed Science Technol.*, 55: 179-199.
- Kumaran S, Sastry CA, Vikineswary S. 1997. Laccase, cellulose and xylanase activities during growth of *Pleurotus sajor-caju* on sago hampas. *World J. Microbiol. Biotechnol.* 13: 43-49.
- Lateef A, Oloke JK, Gueguim Kana EB, Oyeniyi SO, Onifade OR, Oyeleye AO, Oladosu OC, Oyelami AO. 2008. Improving the quality of agro-wastes by solid-state fermentation: Enhanced antioxidant activities and nutritional qualities. *World J. Microbiol. Biotechnol.* 24:2369-2374.
- Lechner BE, Papinutti VL. 2006. Production of lignocellulosic enzymes during growth and fruiting of the edible fungus *Lentinus tigrinus* on wheat straw. *Process. Biochem.*, 41: 594-598.
- Leifa F, Pandey A, Soccol CR. 2001. Production of flammulina velutipes on coffee husk and coffee spent ground. *Braz. Arch. Biol. Biotechnol.*, 44: 205-212.
- Leonowicz A, Matuszewska A, Luterek J, Ziegenhagen D, Wojtas-Wasilewska M, et al. 1999. Biodegradation of lignin by white rot fungi. *Fungal Genet. Biol.*, 27: 175-185.
- Lowe SE, Theodorou MK, Trinci AP. 1987. Cellulases and xylanase of an anaerobic rumen fungus grown on wheat straw, wheat straw holocellulose, cellulose, and xylan. *Appl. Environ. Microbiol.* 53: 1216-1223.
- Matsuo M. 1997. Preparation and components of okara-ontjom, a traditional Indonesian fermented food. *Nippon Shokuhin Kagaku Kogaku Kaishi.* 44: 632-639.
- Methods of vitamin assay. 1966. The association of vitamin chemists, 3rd edn. Interscience publishers, New York, pp. 287.
- Miller GL. 1959. Use of dinitrosalicylic acid for determination of reducing sugar. *Annual Biochem.* 31: 426-428.
- Minson DJ, McLeod MN. 1972. The in vitro technique: its modification for estimating degradability of large number of tropical pasture samples. Division of Tropical Pastures Technique, Paper No. 8, CSIRO, Australia.
- Moore J, Cheng Z, Hao J, Guo G, Guo-Liu J, Lin C, Yu L. 2007. Effects of solid-state yeast treatment on the antioxidant properties and protein and fiber compositions of common hard wheat bran. *J. Agric. Food Chem.*, 55: 10173-10182.
- Mtui G, Nakamura Y. 2005. Bioconversion of lignocellulosic waste from selected dumping sites in Dares Salaam, Tanzania. *Biodegradation*, 16:493-499. doi: 10.1007/s10532-004-5826-3
- Mosier N, Wyman C, Dale B, Elander R., Lee YY, Holtzapple M, Ladisch M. 2005. Features of promising technologies for pretreatment of lignocellulosic biomass. *Bioresour. Technol.*, 96:673-686.
- Mukherjee R, Ghosh M, Nandi B. 2004. Improvement of dry matter digestibility of water-hyacinth by solid state fermentation using white rot fungi. *Indian J. Experimental Biol.*, 42:837-843.
- Murata K, Miyamoto T. 1967. Studies on the nutritional value of tempeh. *J. Vit.*, 14: 191-197.
- Odufa AS. 1983. Biological changes during production of ogiri, a fermented melon (*Citrullis vulgaris* schar) product. *Qualities planetarum: Plt. Fd. Hum. Nut.*, 32: 11-18.
- O'Toole DK. 1999. Characteristics and use of okara, the soybean residue from soy milk production: A review. *J. Agric. Food Chem.*, 47: 363-371.
- Pandey A, Nigam P, Soccol VT, Singh D, Mohan R. 2000. Advances in microbial amylases. *Biotechnol. Appl. Biochem.*, 31:135-152. doi: 10.1042/BA19990073
- Rajarathnam S. 1981. Studies on the pathological and biochemical aspects during cultivation and storage of the mushroom *Pleurotus flabellatus*. Ph.D. Thesis, University of Mysore, Mysore.
- Rubin EM. 2008. Genomics of cellulosic biofuels. *Nature*, 454:841-845.
- Saddler JN, Chan MKH, Mes-Hartee B. 1987. Cellulase production and hydrolysis of pretreated lignocellulosic substrates. In: Moo-Young M (ed) *Bioconversion technology principles and practice*. Pergamon Press, Max Well House, Elmsford, New York, pp. 149.
- Sanni AI, Ogbonna DN. 1991. Biochemical studies on owoh — a Nigerian fermented soup condiment from cotton seed. *Food Microbiol.*, 8:223-229.
- Sherief AA, El-Tanash AB, Temraz AM. 2010. Lignocellulolytic enzymes and substrate utilization during growth and fruiting of *Pleurotus ostreatus* on some solid wastes. *J. Environ. Sci. Technol.* 3: 18-34.
- Shimizu M, Kunoh H. 2000. Isolation of thatch-degrading bacteria and their physiological characters. *J. Jap. Soc. Turfgrass Sci.*, 29: 22-31.
- Shrivastava B, Thakur S, Khasa YP, Gupte A, Puniya AK, Kuhad RC. 2011. White-rot fungal conversion of wheat straw to energy rich cattle feed. *Biodegradation*, 22: 823-831.
- Sun R, Lawther J, Banks W (1996) Fractional and structural characterization of wheat straw hemicelluloses. *Carbohydrate Polymer*, 29: 325-331.
- Tilley JMA, Terry RA. 1963. A two stage technique for in vitro digestion of forage crops. *J British Grassland Soc.*, 18: 104-111.
- Vega A, Caballero RE, Garcia JR, Mori N. 2005. Bioconversion of agroindustrial residues by *Pleurotus ostreatus* cultivation. *Revista Mexicana De Micologia*, 20: 33-38.
- Xiao C, Bolton R, Pan WL. 2007. Lignin from rice straw kraft pulping: Effects on soil aggregation and chemical properties. *Bioresource Technol.*, 98:1482-1488.
- Yan L, Shuya T. 2006. Ethanol fermentation from biomass resources: Current state and prospects. *Appl. Microbiol. Biotechnol.*, 69:627-642.
- Zadrazil F, Puniya AK, Singh K. 1995. Biological upgrading of feed and feed components. In: Wallace RJ, Chesson A (eds) *Biotechnology in animal feeds and animal feeding*, VCH Verlagsgesellschaft mbH, Weinheim, Germany, pp. 55-70.