Growing of *Pleurotus ostreatus* on Woods of Various Deciduous Trees

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Abstract: *Pleurotus ostreatus* (oyster mushroom) is a native, commonly widespread mushroom in Slovak deciduous forests and is used traditionally also for eating. From the viewpoint of forestry, *P. ostreatus* is a saprophytic fungus speeding up the wood decomposition. This ability could be used for biodegradation of waste wood not serviceable in forest management or wood technology. During five years, I have observed the progression in wood decomposition and fruit body production in five species of deciduous trees - beech, aspen, birch, hornbeam and alder under normal forest stand conditions. Two production strains of *P. ostreatus* were used. The external conditions for mushroom growing were identical. There was observed also the production of fruit bodies during the year, the impact of climatic conditions, the quantity and rapidity of fruit body production of different production forms, the presence of other wood destroying fungi and other factors influencing oyster mushroom growth and fruit body production.

Key words: Oyster mushroom, deciduous trees, stump, biological efficiency, fruit body production, natural conditions

1 Introduction

Wood-destroying fungi are an important physiologic-ecological group. They are essentially connected to wood and decompose it by their activity in nature. They cause great damage to living trees, processed wood and wood constructions. However, they are non-replaceable component of theforest ecosystem due to their support of the optimal nutrient cycle in nature by decomposition of wood-waste.

From the economic point of view, it is possible to consider the activity of fungi as both beneficial and injurious. The injurious activities are moderated by defensive reactions on the part of the tree, products of its metabolism, antagonistic organisms and also unsuitable physical conditions in wood of the attacked tree. The beneficial activity is grounded in decomposition of plant wastes. The gradual identification and application of relationships between wood destroying fungi and biotic influences of environment leads to extension of possibilities to realize the useful characteristics of wood destroying fungi, and to reduce their harmful activity.

Pleurotus spp. is a common genus in Slovak forests. The most well-known species is *P. ostreatus (Jacq. ex. Fr.) Kummer,* but the common ones are also *Pleurotus cornucopiae Paul ex. Fr., Pleurotus carpaticus Pilat, Pleurotus pulmonarius (Fr.)* and *Pleurotus eryngyii (D.C. ex Fr.)* in the southern part of Slovakia.

Growing of *P. ostreatus (Jacq. ex. Fr.) Kummer* does not have a long tradition in Slovakia. The great expansion of oyster mushroom growing started in the 1970's and it was done on various kinds of wood fractions and various waste biological substrates from agricultural production. The second part of the 1980's was the boom of oyster mushroom growing, but nearly all mushroom producing facilities disappeared in the 1990's. Since the beginning of the 21st Century, interest in the oyster mushroom and its cultivation has returned.

Growing of oyster mushrooms has limitations in terms of speed of production and the continual production of fruit bodies. However, it could be a perspective fungus for growing under forest management conditions. A lot of woody waste material arises at the forestry production and it is not possible to use them all effectively. Thin

branches, broken pieces of trunks and tree stumps are left in a forest stand after cutting, and they are the source of organic matter in the soil. This process of decomposition is very slow and those wooden pieces are often a barrier for other forest growth.

From the viewpoint of forestry, the oyster mushroom is a saprophytic fungus speeding up the wood decomposition. This ability could be used for biodegradation of waste wood that it is not possible to use in forest management or wood technology. The result of oyster mushroom activity could be a faster decomposed wood-waste, faster input of organic matter to the forest soil, and also the tasty fruit bodies for healthful nutriment.

2 Materials and Methods

The prime aim of our experiment was to verify the possibilities of wood decomposition of various deciduous trees by the oyster mushroom activity under the natural conditions of a forest stand. Selected tree species are commonly widespread in forest stands of central Europe. The mostly representative is beech *(Fagus sylvatica),* which is the most economically important. The stumps were prepared from recently cut logs of all selected tree species and the old logs of beech wood were used in the form with two fungal strains and the form with damaged bark and also the free standing stumps. The important part of research was to test aggression and productivity of two production fungal strains.

The occurrence of various external factors (including air temperature and air humidity, precipitation, and the occurrence of other wood destroying fungi) with potentially important influence on mushroom growing, wood decomposition and fruit body production was observed during the five years experiment. Research methodology was processed in connection with requirements of forest management and conditions in forestry practice, regarding the possibilities for practical application in natural conditions of a forest stand.

The research plot was situated in a deciduous forest stand nearby Zvolen, in central Slovakia, approximately 400 meters above sea level. Orientation of the plot is north-east, slope of terrain is moderate, average temperature during the year is 7.8°C, air humidity is about 75% and the average sum of annual precipitation is about 650-700mm.

Wood decomposition by the oyster mushroom was observed on five tree species - beech *(Fagus sylvatica),* aspen *(Populus tremula),* birch *(Betula pubescens),* hornbeam *(Carpinus betulus),* and alder *(Alnus glutinosa).* Fresh stumps, one month after cutting, were used for every tree species. Sawn-off beech stumps, more than six months old, were also used. At the end of April, stumps were inoculated with spawn of the oyster mushroom. The inoculated stumps were wrapped in plastic clingfilm in the shade. The stumps were unwrapped after the first rainy and foggy days. They were placed in the soil and covered up to the one third of the height.

The experiment consisted totally of eleven groups of stumps, and every group consisted of ten stumps. Two strains of the oyster mushroom were used for inoculation of stumps. Strain number 003 is a winter one, and for fructification needs temperatures below 16-18°C. This strain creates midsized fruit bodies clusters in white-greyish up to bluish colour, with a distinct spicy taste, suitable for cultivation on a straw or woody substratum. Strain number 139 is a hybrid year-round one with optimal fructification temperature from 15 to 25°C. This strain is not natural and was obtained by crossing of thermophilic summer and winter strains. The fruit bodies growing in higher temperatures are similar to the summer type and those growing under lower temperatures are similar to the winter type. This strain creates big, funnel-like, white-greyish up to bluish fine fruit bodies, with a distinct taste, on various types of substratum.

3 Results

Oyster mushroom growth was observed during a five-year period under conditions of a deciduous forest stand. Therefore, external growing conditions were identical for all stumps and strains at the experimental plot. The differences in mushroom growth, quantity and rate of fructification, the rate of wood decomposition, the resis tance against influences of external environment depended firstly on attributes of the tree species and on the oyster mushroom production strains.

The most important indication is the kind of wood stump on the experimental plot. The prime concern was oriented to beech wood and six sections were established from qualitatively different beech stumps. When mushroom production on beech stumps was compared, the best growth was found to on fresh beech wood infected with strain No. 003, and the poorest on old stumps with injured bark (and fully exposed above the ground; i.e. not partially buried) infected by strain No. 139.

Although fruit body production is not the most important outcome for the practical utilization of the oyster mushroom's activity in forestry, it is a very significant sign of successful mushroom growing inside the wood. However, fruit bodies are suitable for utilization in food industry, pharmacy, medicine and so on. Therefore, the evaluation of the most suitable conditions for maximal fruit body production is very useful. From this point of view, the quantitative comparison of fruit body production on wood of various trees on eleven experiment sections is interesting.

The best conditions for fruit body production were found at the section No. 2 - fresh beech infected by strain No. 003 where 18.64 kg fruit bodies grew during five years (Table 1.). Relatively high production was recorded on the fresh beech with strain No. 139, old beech with strain No. 003 and aspen infected by strain No. 003. A slightly lower production was observed on aspen, old beech, hornbeam and birch with strain No. 139. The old beech stumps with injured bark and fully exposed stumps infected by strain No. 139 produced markedly lesser amounts of fruit bodies and the production on alder wood was the lowest among all the samples tested. The highest amount of fruit bodies was recorded on a fresh beech stump No. 3 from the section No.2. During the five-year period, this 7.6 kg weight stump produced 2.63 kg of fruit bodies.

Table 1. Total survey of research material and results obtained

Section No.	Tree species	State of stump	Strain No.	Total weight of stumps (kg)	Total weight of fruitbodies (kg)	Biological efficiency-B.E. (%)
1	beech	fresh	139	144.9	15.4	15.08
2	beech	fresh	3	124	18.64	21.31
3	beech	old	139	108 .8	9.22	10.08
4	beech	old	3	112.5	14.45	14.79
5	beech	injured bark	139	117.7	4.9	5.09
6	beech	free placed	139	98	4.73	5.89
7	aspen	fresh	139	141	9.27	13.16
8	aspen	fresh	3	170.6	12.67	14.84
9	birch	fresh	139	162.5	7.1	8.74
10	hornbeam	fresh	139	135,6	8.51	8.97
11	alder	fresh	139	110.5	1.44	2.60

Mushrooms strains vary in their ability to convert substrate materials into mushrooms as measured by a simple formula known as the "Biological Efficiency (B.E.) Formula." This formula states that one pound of fresh mushrooms grown from one pound of dry substrate is 100 % biological efficiency.[1] The biological efficiency was calculated on the basis of actual weight and humidity of stumps and weight of grown fresh fruit bodies. The humidity of fresh beech and hornbeam wood was 30 %, 15 % in old beech, while fresh aspen, birch and alder wood contained 50% water.

The results of evaluation of these characteristics are very similar to results of fruit body production. The highest average value (21.47 %) was found on wood of the section No. 2 - fresh beech with strain No. 003. Relatively high values was recorded on the fresh beech with strain No. 139, old beech with strain No. 003, and aspen infected by strain No. 003. A little lower efficiency was observed with fresh aspen, old beech, fresh hornbeam

and birch with strain No. 139. The most productive fresh beech stump, No.3 from the section No.2, reached nearly 50 percent efficiency .

Production of fruit bodies started mostly in the first year except for the aspen and alder stumps with strain No. 139. Both strains only produced fruit bodies in autumn, mostly from the second part of September to the beginning of December. The best conditions for mushroom growing and fruit body development were in October. Sixty three per cent of overall fruit body production grew in October; production in September and November was approximately the same (16 and 17 % respectively), and 4 % of the total production grew in December.

The total period of fructification was 48 months and, at some of the stumps, it was 47 months. The longest period from initiation of fruit body production to termination was recorded in the case of fresh beech stumps inoculated with strain No. 003. Production on stumps on this section No. 2 was 46 month on average. A little shorter period was recorded on the old beech with strains No. 003 and 139 (43.5 and 41.5 months, respectively). There were no significant differences between fresh and old beech stumps, only beech stumps with injured bark and fully exposed produced fruit bodies during 31.7 and 36,1 months, respectively. Very interesting is difference between aspen infected by strain No. 003 (36.9 months) and with strain no. 139 (23.1 months). Fructification on alder stumps occurred only within two years with an average period of 5.9 months.

When the quantity of fruit body production within the whole period is compared (Table 2), it is evident that the main production was in the third and the fourth year (30.5 and 30.3 % of the total production, respectively). Markedly lower production occurred in the second (19.0 %) and in the fifth year (12.3%). Maximal production on stumps infected by strain No. 003 occurred in the fourth year, and maximal production on stumps with strain

Table 2. Annual production of fruit bodies and biological efficiency

Section No.	1st year	B.E. (%)	2nd year	B.E. (%)	3rd year	B.E. (%)	4th year	B.E. (%)	5th year	B.E. (%)	total (kg)	B.E. (%)
1	0.76	0.75	2.05	2.02	6.08	599	5.3	5.23	1.11	1.09	15.4	15.08
2	1.74	2.00	3.24	3.73	4.09	4.71	6.25	7.20	3.19	3.67	18.64	21.31
3	0.47	0.51	1.95	2.11	2.14	2.32	1.83	1.98	2.93	3.16	9.22	10.08
4	1.99	2.08	2.68	2.80	3.78	3.95	4.75	4.97	0.95	0.99	14.45	14.79
5	0.84	0.84	1.76	1.76	0.79	0.79	1.14	1.14	0.56	0.56	4.79	5.09
6	0.9	1.08	1.29	1.55	1.12	1.34	0.97	1.16	0.63	0.76	4.73	5.89
7	0	0	0.89	1.26	4.54	6.44	3.73	5.30	0.11	0.16	9.27	13.16
8	0.54	0.64	3.01	3.52	3.45	4.04	4.54	5.32	1.13	1.32	12.67	14.84
9	0.57	0.70	1.27	1.56	2.63	3.24	2.63	3.24	0	0	7.1	8.74
10	0.58	0 .61	1.57	1.65	2.87	3.02	11.05	1.11	2.44	2.57	8.51	8.97
11	0	0	0.49	0.88	0.95	1.72	0	0	0	0	1.44	2.,60
TOTAL	8.39	9.22	20.2	22.84	32.44	37.56	32.19	36.62	13.05	14.28	106.22	120.55
Average		0.84		2.08		3.43		3.33		1.03		10.96

No. 139 was in the third year. An extraordinary result was in section No.3 which produced the greatest amount of fruit bodies in the fifth year. The higher balanced amounts were recorded usually during three years on stumps with strain No. 003. Stumps with injured bark and fully exposed had the maximal production of fruit bodies in the second year.

Using the different production strains as a basis for comparing mushroom growth is possible only in both the fresh and old beech and aspen that were infected by the strain No. 003 and No. 139. The better quantitative values were generally recorded with strain No. 003 and the total amount of fruit bodies was 45.76 kg at a biological efficiency of 16.98%. Strain No. 139 produced under the same conditions 33.89 kg of fruit bodies and the biological efficiency was 12.77 %. The most productive stump with strain No. 003 (fresh beech) produced 2.63 kg at a biological efficiency 49.44%. The highest productivity, 2.19 kg, was attained by strain No. 139 in the fresh beech stump No.5, but the highest biological efficiency, 38.73%, was attained in the aspen stump No 1.

Table 3. Number of stumps attacked by other wood destroying fungi

Fungus	beech	aspen	birch	hornbeam	alder
Armillaria mellea	3		1		3
Bjerkandera adusta	2	1			
Diatrype distiformis.	4				
Exidia glandulosa	1	4	1	2	2
Fomes fomentarius	1				
Hypoxylon fragiforme	10	4		4	2
Ischnoderma resinosum	1				
Lycogala epidendrum	5	3	2		2
Nematoloma fasciculare	1	1			
Panellus stipticus	2			2	
Schizophyllum commune	3	3	1	2	
Spumaria sp.				2	2
Stereum hirsutum	9	5	3	2	
Trametes hirsuta	7				
Trametes unicolor			1		
Trametes versicolor	4			2	
Tremella mesenterica	1			2	
Xylaria polymorpha	2			2	

Table 4. Survey of climatic conditions

	1st year			2nd year			3rd year			4th year			5th year		
M	T	P	H	T	P	H	T	P	H	T	P	H	T	P	H
I.	-1.9	56.6	82.7	-9.4	17.8	85.3	-3.5	83.7	81.9	-7.4	63.9	78	0.6	46.7	88.1
II.	-1.1	67.6	79.4	-6.1	27.8	73.6	-4.1	28.5	75.3	-1.5	25.1	79.3	1.3	56.2	82
III.	2.4	40.9	66	3.2	75.5	81.4	2.4	24.3	77.1	-1.4	37	69.8	1.9	89.7	72.8
IV.	8.7	25	61.4	8.6	42.5	66.9	10.4	30.9	63.6	8.5	39	65.3	8.2	25.9	63.9
V.	13.6	160.1	75.3	14.2	79.1	75.3	15.7	48.2	67.9	12.5	118.1	66.9	14.6	100.3	70
VI.	14.7	79.8	68.5	14.5	115.2	72.7	16.9	85	67.6	17.2	48.5	70.7	16.3	31.4	67.6
VII.	16.6	16.7	66.3	18.5	86.3	67.7	18.3	43.4	64	20.6	21.3	60.3	20.1	27.2	63.3
VIII.	17.6	45.2	68.2	17.9	77.5	72.5	18.3	126.9	70	15.9	38	68.3	18.1	104.1	70.4
IX.	13.8	218.1	79	12.7	9.9	72.7	13	10.5	71.7	15.2	52.3	71.5	14.1	79.7	76.9
X.	10.3	43.2	78.6	7.4	19.9	75.1	7.3	65	73	9.6	36.7	74.2	7.7	21.4	75.9
XI.	3.6	54.1	83.1	1	107.3	82.6	3.1	16	81.9	3.5	65.9	82.9	-1.9	21.2	75.9
XII.	-2.8	17.8	89.8	2.3	29.2	86.5	-3.9	70.1	88.4	-0.1	32.9	81.9	0.1	62.6	82
Σ	7.958	825.1	74.86	7.067	688	76.03	7.825	632.5	73.53	7.717	578.7	72.43	8.425	666.4	74.07

M - month; T- average month temperature (°C); P - amount of precipitation (mm); H - average air humidity (%); Σ - average annual temperature, amount of annual precipitation, average air humidity.

Wood destroying fungi are a wholly common component of the forest environment and their presence was evident also on our stumps. A total of 17 other wood destroying fungi were registered during the experimental period. Some of them infected wood before infection by the oyster mushroom strains and their presence was evident mostly on old stumps. The others evinced themselves sooner or later in the majority of stumps. Most of all trees were infected beech stumps and just a few wood destroying fungi infected alder ones. The most frequent fungus was *Hypoxylon fragiforme,* the presence of which was evident especially on beech and hornbeam stumps. Among the other fungi, the more important were *Schizophyllum commune, Stereum hirsutum, Exidia glandulosa, Lycogala epidendrum ,Armillaria mellea* and *Trametes hirsuta* (Table 3) .

Climatic conditions are also a very important factor influencing mushroom growth and a survey is presented in Table 4.

Since the conditions for mushroom growth were the same, the influence of climatic changes was the same for all trees and stumps. Very important for fruit body development was a decrease in the average air temperature below 15°C, the level of air humidity above 75%, and the precipitation of about 100 mm in previous months.

4 Discussion

P. ostreatus is the most widespread mushroom throughout hardwood forests of the world, which host the most varieties from temperate climates. It is common on broadleaf hardwoods in the spring and autumn, especially cottonwoods, oaks, alders, maples, aspens, ash, beech, birch, elm, willows, and poplars.[1] A wide array of agricultural and forest products can be used to grow the mushroom, including but not limited to straw, cornstalks, sugarcane bagasse, coffee pulp, banana waste, cotton waste, hardwood sawdust, paper by-products and soybean waste. The pH at makeup can vary between 6 and 8 but should fall to an optimum of pH 5 at fruiting for maximum biomass production.[2] More than any other group of mushrooms, *Pleurotus species* can serve best to reduce hunger in developing countries, and to revitalize rural economies. Furthermore, the oyster mushroom is useful also after growth on the substratum is finished. After the crop cycle is complete, the remaining substrate is rendered into a form that can be used as feed for cattle, chickens and pigs.[1, 3-6]

The primary role of wood destroying fungi is to decompose wood, to humify it and to restore it into the organic matter cycle. Efforts to utilize those abilities rapidly increased when the techniques of artificial infection by spawn of some wood destroying fungi were developed. For forestry practice, it was a primary interest to transform waste wood in forest stands into useful organic matter in a relatively short time. It is, for instance, the biodegradation of tree stumps after windstorms or cutting of full-grown trees. Natural decomposition is relatively lengthy and takes some decades.Efforts at stump decomposition by *Kuehneromycetes mutabilis* in Germany or Slovakia were not applicable because the fungal spawn was not commonly produced.

Experiments in Slovakia were oriented to practice utilization of the oyster mushroom for decomposition of waste wood. Researchers and foresters from the Forestry Faculty of the Technical University in Zvolen observed the speed, intensity and other aspects of the mushroom's growth under common forest conditions. A very important part of this experiment was the possibility of a negative influence on surrounding growing trees by application of the oyster mushroom's spawn at stumps in a forest stand.[7] Although the oyster mushroom is commonly growing on dying trees and is thought to be primarily a saprophyte, it behaves as a facultative parasite at the earliest opportunity.[1] Those qualms were not realized during ten years of experiments that confirmed the hypothesis about the possibility of faster decomposition of artificially infected stumps. Decomposition of stumps was from three- to eight-times faster in comparison with natural conditions.

The simplest and the least dangerous is growing of the oyster mushroom in wooden stumps. It commonly grows in wood of poplar, beech, birch, willow, hornbeam, lime, alder, apple, walnut, pear, plum and other species. The next method for oyster mushroom growing in forestry practice is the decomposition of wood in soil reclamation of a deciduous forest. Thin broken branches are placed into a half-metre drain and, after infection by the oyster mushroom strain, is covered with a thin soil layer. Within a few years, the mushroom is growing and producing fruit bodies depending on external, especially climatic, conditions. Forest soil is enriched by new organic matter after the substrate is completely decomposed.

Although wood is the natural substratum for the oyster mushroom, there is not a lot of experience of intensive growing in wood with the exception of sawdust. Originally, "wooden" strains were transmuted into "agrowaste" ones due to the necessity of massive year-round production. However, the possibilities of its application in forestry are very real, although fruit body production is only seasonal and biological efficiency rarely exceeds fifty percent. The aim of my research was to evaluate one possible application, and to compare the suitability of various common deciduous trees and two production strains under the normal conditions of a forest stand. It is possible to compare the results obtained with those reported by Ginterová et al. [8] and Kodrík.[9] The methodology of their research was similar and their results also confirmed the suitability of utilizing oyster mushroom strains for faster decomposition of deciduous wood. Waste beech wood, the presence of which causes problems sometimes in forestry practice, is very successfully decomposed by application of the oyster mushroom although the biological efficiency is not very high and fruit body production is limited only to the autumn months. Aspen and poplar woods are also very well decomposed by the oyster mushroom activity with relatively high production of fruit bodies. It was confirmed by the results presented, and also by actual research, that 95% of spring infected stumps produced fruit bodies in November of the first year. Stamets.[1] reported that, on average, more than one pound of mushrooms per year was harvested from inoculated poplar stumps for more than three years. Of the 200 poplar stumps, ranging in size from 6 to 12 inches, which were inoculated in the spring, all produced by the fall of the following year. As expected, hardwoods of greater density, such as oak, took longer to produce but sustained yields for a longer period.

The results presented here confirmed a manifold increase in the rate of waste wood decomposition by oyster mushroom activity. Also confirmed was the possibility of successful application, perennial growing and fruit body production of the oyster mushroom under natural, not sterile conditions. Coherent methods for practical utilization of wood destroying fungi activity and products, especially of the oyster mushroom, have a great perspective not only in forestry and not only in Slovakia.

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References

[1] Stamets P. Growing Gourmet and Medicinal Mushrooms. Berkeley, California:Ten Speed Press, 2000, 574pp.
[2] El-Kattan MH, Gali Y, Abdel-Rahim EA, *et al.* Submerged production of *Pleurotus sajor-caju* on bagasse hydrolyzate medium. Mush. J. Tropics, 1990, 10:105-114.
[3]Zadrazil F. The ecology and industrial production of *Pleurotus ostreatus, P. florida, P. cornucopiae,* and *P. eryngii.* Mush. Sci. 1976, IX:621-652.
[4] Zadrazil F. The conversion of starch into feed by basidiomycetes. Eur. J. Appl. Microbiol. 1977, 4:273.
[5] Streeter CL, Conway KE, Horn GW. Effect of *Pleurotus ostreatus* and *Erwinia caratovora* on wheat straw digestibility. Mycologia, 1981, 73:1040-1048.
[6] Sharma AD, Jandalk CL. Studies on recycling *Pleurotus* waste. Mush. J. Tropics, 1985, 6:13-15.
[7] Ginterová A. Growing of mushrooms. Bratislava:Príroda. (in Slovak), 1985, 208pp.
[8] Ginterová A, Janotková O, Valovic K. Oyster mushroom - growing and processing. Bratislava:VU LIKO (in Slovak), 1976, 78pp.
[9] Kodrík J. Preliminary acknowledges about the oyster mushroom growing on wood stumps in forest stand. Acta Facultatis Forestalis, 1979, XXI:117-126. (in Slovak)