Fruiting Body Production of, and Suitable Environmental Ranges for, Growing the Umbrella Polypore Medicinal Mushroom, *Polyporus umbellatus* (Agaricomycetes), in Natural Conditions in Central Europe

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ABSTRACT: This article presents the ecological distribution of the edible and medicinal mushroom *Polyporus umbellatus* in Central Europe. Our main motivation is to describe the potential for commercial cultivation of this species. All data considered in this study are based on records from 70 localities in Slovakia. Fruiting bodies and sclerotia have been recorded in forests in which beech, hornbeam, and oak dominate, at altitudes ranging from 150 to 935 m (mean altitude, 403 m). In Slovakia, these areas correspond to warm, hilly, and upland beech-oak and oak-beech forests. Mean annual air temperature between 6°C and 9°C characterizes about 94% of the areas. Continuous monitoring of fruiting body production at 13 plots showed peak growth in August. In total, 192 fruiting bodies were recorded over a 5-year period. *P. umbellatus* predominantly grows in acidic soils (pH 4.5–4.99), with no individuals found in soils with pH above 7.0. Our findings can be used for growing the fungus and expanding its growth to new regions, not only in Central Europe.

KEY WORDS: altitude, edible and medicinal mushrooms, mean annual temperature, *Polyporus umbellatus*, Slovakia, soil pH

I. INTRODUCTION

The umbrella polypore mushroom, *Polyporus umbellatus* (Pers.) Fr. (Polyporaceae, Agaricomycetes), is an easily recognizable species and is considered to be an edible and tasty mushroom with medicinal properties. It has the most hygrophanous fruiting body of all species within the genus *Polyporus*.[1] A great deal of information is available on its medicinal properties[2] and on the cultivation of its sclerotium.[3] It is often referred to by the Chinese name for the herb, *Zhu ling*. All parts of the mushroom—fruiting body, sclerotium, and mycelium—contain a range of bioactive substances with differing chemical compositions and modes of action.[2] The potential of this mushroom's health benefits signifies the value of this species in the global market, especially if medicinal properties of mycelia are the same as those of the fruiting body.[4] However, the species has been overexploited in its natural habitat in some countries.[5] The species is currently investigated by predicting and modeling the suitability of its habitat, with the goal of potentially introducing it to areas where it does not currently grow.[6] The effect of environmental factors on the development and growth of mycelia is of key interest.[7] New methods for cultivating the mushroom are also being investigated.[8]

The aim of this study was to evaluate and describe habitat preferences of *P. umbellatus* in Slovakia and to contrast these with observations about its habitat in neighboring countries. Further, here we aim to analyze and summarize the production of fruiting bodies at several localities over a period of 5 years.

II. MATERIALS AND METHODS

A database of *P. umbellatus* records was compiled by processing data from personal collections of amateur field mycologists from Slovakia and by reviewing the literature and herbaria records from neighboring countries. Every record from a particular locality in Slovakia is supported by a specimen, either a fruiting body or a sclerotium. Locality is here regarded as a unique combination of summit and river phenomena and exposition, climate, and geological and soil conditions. Microlocality refers to a site of several square meters where sclerotia grow. The occurrence of emerging sclerotia at several microlocalities within one locality is characteristic of *P. umbellatus*,[9] so counts of localities, microlocalities, and study plots differ in this study. All specimens collected as part of this research are deposited in the private herbarium of V. Kunca.

The data accompanying each specimen describe the date of specimen collection, altitude, closest tree species, and soil pH. When the fungus was detected in several microlocalities, only the mean altitude of the locality was used in the statistical analysis. However, the closest tree species in every microlocality was included in the evaluation because it differed frequently. Duplicate records referring to 1 microlocality were discarded before analysis. Not all data were available for every record because the collectors did not provided some data. The following numbers of individual data records were analyzed in this study: date of collection, 105 records; altitude, 68 records; tree species, 126 records. Only 1 record from previous research[9] was used in the statistical evaluations.

Soil samples were taken at a depth of approximately 5 cm, always close to the sclerotium. Soil pH (H_2O) of 49 soil samples was measured as part of this study, though of these, 16 values had already been published.[9] Fruiting body occurrence was monitored regularly at 6 localities, which together covered 13 microlocalities in the region of central Slovakia (Table 1). The period of monitoring lasted 5 years, covering 2011–2016; however, the written records for data from 2013 were lost. Fruiting bodies were recorded and counted in the same manner, regardless of size or developmental stage. Every 2 weeks from June through September was found to be the most suitable for monitoring.[9] All abbreviations of the plots' names and their characteristics, except new localities and plot ZK 3, are identical to ones already published.[9] Plot ZK 3 is situated in the Zvolenská Kotlina Basin, near the city of Sliač, on volcanic rock deposits (tuffs) in mixed forest with *Betula pendula*, *Carpinus betulus*, and *Corylus avellana*; the plot is on a slope of 10° and at an altitude 345 m above sea level. The sclerotia were positioned more than 2 m from old birch. The results of this study are an extension of previous monitoring. We found a new locality in 2010, and unlike in the former study,[9] we subdivided some plots at the level of the individual sclerotia (microlocalities) in order to better capture the effect of small-scale environmental variation on the species. In addition, the previous locality ŠV 1 was joined with locality ŠV 2 (now ŠV 1.2 and ŠV 1.1) and included with new locality ŠV 1.3, to represent various micro-localities within the same locality. This article, however, presents only new data on fruiting body production.

We compiled a database of records from the collections of *P. umbellatus* in the Czech Republic by processing data from herbaria containing numerous mycological collections; the summary data for that country were not available before our research. Abbreviations used in the requested Czech public herbaria—BRNM, BRNU, CB, PRC, PRM—adhere to abbreviations in the Index Herbariorum,[10] which is continuously updated. We evaluated 61 records, with 44 data points describing the date of the find, 16 describing altitude, and 43 describing tree species. To depict zones with different mean annual air temperature, we used map layers of the Slovak Republic for 1960–1990.[11]

TABLE 1: Production of *Polyporus umbellatus* Fruiting Bodies over 5 Years at 13 Plots

Plots/Year	2011	2012	2014	2015	2016
J 1	3 (VIII)	1 (VI) + 4 (VII) + 1 (VIII)	4 (VI) + 1 (VII)	3 (VI)	1 (VI)
KV 1.1	1 (VIII)	3 (VII)	0	0	0
KV 1.2	1 (VI) + 3 (VIII)	1 (VII)	0	0	0
KV 2	0	1 (VI) + 2 (VII)	1 (VI) + 1 (VII)	5 (VIII)	3 (VIII)
ŠV 1.1	3 (VI) + 3 (VIII)	12 (VII) + 4 (VIII)	2 (VI) + 2 (VIII)	2 (VI)	3 (VI) + 24 (VIII) + 2 (IX)
ŠV 1.2	0	0	0	0	0
ŠV 1.3	1 (VII)	2 (VII)	1 (VIII)	2 (VIII)	5 (VI) + 4 (VIII)
ŠV 2.1	1 (VIII)	0	1 (VII) + 1 (VIII)	0	1 (VIII)
ŠV 2.2	1 (VI)	2 (VIII)	1 (VII) + 3 (VIII)	0	2 (VIII)
ŠV 2.3	1 (VI) + 2 (VIII)	5 (VII)	1 (VII) + 1 (VIII)	0	2 (VIII)
ŠV 2.4	1 (VI)	1 (VII)	0	0	0
ZK 1	4 (VII)	4 (VII)	5 (VI) + 7 (VII)	19 (VIII)	4 (VI)
ZK 3	1 (VIII)	2 (VI) + 4 (VII) + 1 (VIII)	0	2 (IX)	0
Totals by month	7 (VI) + 5 (VII) + 14 (VIII)	4 (VI) + 38 (VII) + 8 (VIII)	12 (VI) + 12 (VII) + 8 (VIII)	5 (VI) + 26 (VIII) + 2 (IX)	13 (VI) + 36 (VIII) + 2 (IX)
Total	26	50	32	33	51

VI, June; VII, July; VIII, August; IX, September.

III. RESULTS AND DISCUSSION

To date, more than 200 medicinal functions are thought to be produced by medicinal mushrooms, including antitumor, immunomodulatory, antioxidant, radical scavenging, cardiovascular, antihypercholesterolemic, antiviral, antibacterial, antiparasitic, antifungal, detoxifying, hepatoprotective, antidiabetes, and other effects.[12] *P. umbellatus* is known to have many therapeutic effects; it contains steroids and polysaccharides as its principal bioactive compounds. However, a number of other chemical constituents such as long-chain fatty acids, anthraquinones, nucleosides, cerebrosides, terpenoids, nicotinic acids, ferulic acid, D-mannitol, succinic acid, and polyporusterons have also been isolated.[2,13] Some of the positive effects on human health are linked to triterpenes, ergostherol, and D-manitol.[14–16] Mycelia of this mushroom contain large amounts of ergone, a fungal metabolite derived from ergosterol.[17] Steroids with proven cytotoxic activity against cancer cells have been isolated from fruiting bodies.[18,19] Based on this evidence, we can classify *P. umbellatus* as having antitumor, anticancer, antiviral, antibacterial, and antiprotozoal activities; enhancing the immune system; having diuretic effects; having antioxidant and free radical scavenging activity; and inducing hair growth.[2] Because of its diuretic effect on the human body, this fungus was traditionally used to treat swelling, jaundice, difficulty urinating, vaginal infections, and diarrhea.[14–17]

A number of studies using both *in vitro* and *in vivo* cultures of this species proved that a raw extract and an infusion,[20,21] as well as an ethanol extract,[20] had positive effects against Sarcoma 180 and liver cancer, among other kinds of cancer. An alcohol extract of *P. umbellatus* showed antibiotic properties against *Staphylococcus aureus* and *Escherichia coli*.[18] *In vitro* studies confirmed the increase in the survival rate of mice in addition to chemotherapy with wide effects on the immune system.[22] Research on the effects of mushroom-derived polysaccharides[23] has shown that those from *P. umbellatus* provide protection against ionizing radiation.[24] Both polysaccharide extracts of *P. umbellatus* and chemotherapy together had positive effects on treatment and quality of life of patients with cancer, including those with lung, liver, nose, and throat cancer and leukemia.[25,26] In addition, the polysaccharide extracts had great effect on toxohormone-L (a compound created by cancer cells), inhibiting its synthesis and thereby avoiding cachexia (weight loss, muscle atrophy) in rats; steroids extracted from fruiting bodies show good results against hair loss.[27] A crude drug called *Chorei*, traditionally prepared from dried fruiting bodies of *P. umbellatus*, is known in Japan and China as a remedy for kidney and other diseases.[28] An aqueous extract of the mushroom has also been shown to halt the growth of a pyrimethamine-resistant strain of malaria (*Plasmodium falciparum*).[29] The oral tradition of Chinese medicine posits that the fungus is also used to making people feel happier, younger, and stronger.

Fruiting bodies of this fungus grow mainly in broadleaf forests. They develop from blackish sclerotium on the ground near the base of trees (Fig. 1), but they can also be found within a few meters of a tree.[9] The sclerotium is dark gray to black and resembles pig excrement. It has a woody consistency and can swell and branch out when exposed to moisture. Thick, meaty stems branch out from the sclerotium, creating smaller stems with small caps on top. The entire fruiting body can reach up to 500 mm in diameter. Normally, sclerotia grow on dead roots or pieces of dead wood, 10–30 cm deep in the soil.[1,30] The distinctive feature of this mushroom species is that it is also collected at the sclerotium stage.

P. umbellatus grows in specific habitats[13]; the species is widespread but rare in the Northern Hemisphere. It can, however, be found in the deciduous forests of Asia, North America, and Europe, mostly near oak, maple, beech, birch, and hornbeam trees, and occasionally near coniferous trees, causing white rot.[1,30,31] In total, data were recorded for 150 specimens of the species collected from 70 localities (including 126

FIG. 1: Living sclerotium of *Polyporus umbellatus* at plot ZK 3 (Zvolenská Kotlina Basin, Slovakia)

microlocalities) in Slovakia. The incidence of *P. umbellatus* in surrounding countries differs from that in Slovakia. Czech herbaria contain 61 specimens and records on the species collections. In Poland, more than 20 localities are represented, and the species is considered vulnerable, with extinction possible.[32] Twelve spots are assigned on the map of Ukraine,[33] and the species is cited in 8 of 22 natural regions.[34] The species is regarded as infrequent in all places recorded in Hungary—it is very rare—but the 11 records there underrepresent its occurrence.[35] In Austria, 44 localities with 58 records are known.[36] In general, the species is consider to be rare in almost all of these countries.

In Slovakia, the species grows at altitudes ranging from 150 to 935 m, with an average altitude of 403 m (Fig. 2A). Similarly, in the Czech Republic, the average altitude calculated from the herbaria records is 428 m above sea level. In Poland, the localities where the species is found are mainly in lowlands.[32] And in Austria, the records predominantly indicate altitudes from 300 to 700 m above sea level, with most found between 600 and 700 m.[36]

In Slovakia, most of the localities studied in this research are characterized as warm, hilly, upland beech-oak and oak-beech forests. Dominant tree species in these territories are Sessile oak (*Quercus petraea*), European hornbeam (*C. betulus*), and European beech (*Fagus sylvatica*). According to our results (Fig. 2B), most specimens were collected from the vicinity of beech, hornbeam, and oak. Finds are rare in forests where other oak species, such as *Q. robur* and *Q. cerris*, occur or are dominant. In contrast

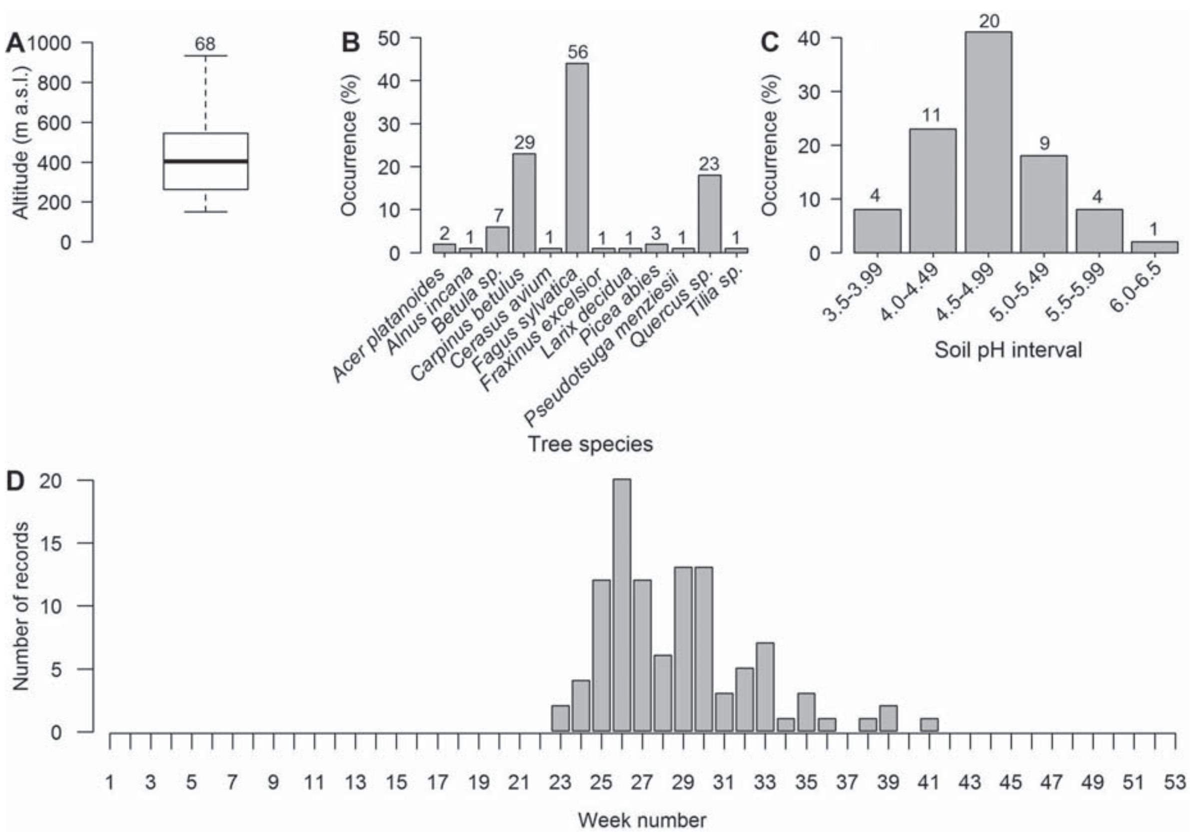

FIG. 2: Altitudinal range. Data are mean ± SD; the boxplot indicates the minimal and maximal altitudes (A). Distribution of tree species (B). Soil pH values (C). Time when *Polyporus umbellatus* fruiting bodies were reporting from localities in Slovakia (D). Week 1 represents the first week of January. Numbers above the bars in A–C represent numbers of records.

with the full list of hardwood trees near which *P. umbellatus* was recorded,[1] we found this fungus under all tree species except *Castanea sativa*, a rare and nonnative tree species in Slovakia. Finds are especially rare in the vicinity of *Acer* sp., *Alnus* sp. and *Ulmus* sp. We can, however, confirm finding *P. umbellatus* supported by *Cerasus avium*, *Fraxinus excelsior*, and *Tilia* sp.—to our knowledge for the first time. The fungus was also located close to or under conifers such as *Picea abies* and *Larix decidua*. These tree species were not native to the localities in question and were planted in the areas of natural occurrence and former broadleaf forests. It is extraordinary that we also collected this species from a plantation of *Pseudotsuga menziesii* that currently grows in territory formerly occupied by a native oak-beech forest. These very rare finds lead to possible further research to ascertain whether the fungus can really grow on the withered roots of conifers.

A similar range of tree species supporting growth of *P. umbellatus* can be found in neighboring countries. In the Czech Republic, the species grows predominantly in localities where oaks are present. Another 23% of collected specimens were recorded as taken from under spruce, but these trees almost always grow together with admixed beech. Aside from other records of specimens found under hornbeam and beech, only one was recorded close to ash. In Hungary, *P. umbellatus* can be found close to deciduous trees, most frequently *Quercus*, then *Acer*, *Carpinus*, *Fagus*, and *Populus*, and rarely near coniferous trees (*Picea*, *Pinus*).[37] In one region of Poland, the species is mainly co-located with *C. betulus*, *F. sylvatica*, and *Q. robur*.[38] In addition, it is also associated with *Tilia cordata* and *T. platyphyllos* forests there. In Ukraine, the species prefers similar broadleaf forests where oaks, beech, maple, and hornbeam are dominant.[33] Finally, in Austria, only 17 records describe the closest tree species; this is *Quercus* sp. in 13 of these records.[36]

All our records are from managed forests or forests with a detectable human influence. In Hungary, however, *P. umbellatus* is an endangered species because of the depletion of seminatural or old-growth forests and the elimination of dead wood in forests.[35]

In Slovakia, the fruiting season of *P. umbellatus* usually starts at the beginning of June and often continues until the beginning of September (Fig. 2D). The most numerous records of fruiting bodies were collected during week 26 of the year, corresponding to the end of June/beginning of July. Another peak occurs during weeks 29 and 30, in the second half of July. In the Czech Republic, fruiting bodies were most frequently found in August (50% of records), and in Hungary they were collected from June to October.[35] Records indicate that fruiting bodies of the fungus grow from July to October in Ukraine.[33] In Austria, the fruiting bodies were recorded from June to October (with only 1 record in the latter month); 62% of the records were made in July, and the highest frequency of records was in the 28th week.[36]

Environmental factors such as soil pH and temperature can greatly affect the growth of and substances within *P. umbellatus*.[7] Soil pH, together with nutrient limitations and changes in external temperature or humidity, are included among the conditions that potentially negatively affect sclerotia.[5] Soil pH is often the key factor in determining sclerotia formation; some experiments found that pH 5 constitutes the most efficient value for initial sclerotia production.[39] Soil pH values identified in this study ranged from 3.82 to 6.06 (Fig. 2C), with the mean pH of 4.75 corresponding to acidic soil.[40] To date, *P. umbellatus* has not been found in soils with a pH above 7.0. Values above pH 7.0 in laboratory cultures were detrimental to mycelial growth or to sclerotia production.[39] While developing a cultivation method, Choi et al.[8] found soil pH values between 3.98 and 4.40 to be optimal. In general, evaluating the records from Czech herbaria, we acquired very similar results for almost all evaluated parameters. With regard to soil pH, however, some of these records are from regions in which the soil is, in general, typically built of carbonates (e.g., the Moravian Karst.); this should be of interest in relation to future surveys of soil pH there.

Temperature can also play a critical role in the formation of *P. umbellatus* sclerotia.[41,42] In Slovakia, the species occurs in the warmer parts of the country. Among almost all studied localities (94%), mean annual temperature ranged from 6°C to 9°C. In general, these habitats are found in basins, hilly country, and lower uplands. Only 4 of the studied localities are outside of this type of area, and all specimens were found more than 700 m above sea level. When habitat suitability for the species was modeled and tested in China, the greatest contributor to the distribution gain was average precipitation in warm seasons, followed by mean temperature of the driest quarter and the mean annual temperature.[6] The species seems to be suboceanic in Central Europe.[35] In Austria, the species was found in a zone with a mean annual temperature ranging from 6°C to 10°C, with most records around 8°C.[36]

Five-year monitoring resulted in the collection of 192 *P. umbellatus* fruiting bodies (Table 1). Yearly production ranged from 26 to 51 fruiting bodies. The fruiting bodies were found from June to September, with the most collected in August and the fewest, in September (only 4 fruiting bodies). The maximal number of fruiting bodies in a month were found in July 2012 (n = 38), considering all plots and all years. The most fruiting bodies during 1 month from one plot (n = 24) was recorded in August 2016 in plot ŠV 1.1. This was also the highest recorded number of fruiting bodies during 1 recording session. No fruiting bodies were found in July 2015 or July 2016. At plot 2 we did not record any fruiting bodies over the 5 years; during previous observations at this location, however, we collected several fruiting bodies.[9] Over the 5 years, 57 individual fruiting bodies were found at plot ŠV 1.1. The biggest fruiting body, found at plot ZK 3, was 60 cm wide and 35 cm tall, weighing approximately 4 kg. Fruiting bodies are also found in Slovakia in May and October, albeit very infrequently (verbal personal communication from Marián Jarkovský, MSc, June 2012). We observed that production increases significantly during some seasons and probably corresponds with weather patterns.

However, some of our results could be influenced by direct or indirect effects of forestry practices and interventions at 4 plots. At plot KV 1.2,a tree close to sclerotia was cut in 2014, and at plot ŠV 2.3, some parts of the sclerotia were visibly disrupted. At plots ŠV 1.2 and J 1, some interventions were implemented in the spring of 2016 (the last year studied). Fruiting body production of the former could be influenced by a nearby 2-m-wide extraction link, where wood was being moved by an agricultural tractor; the latter, however, will probably be influenced for several years by clear-cutting across the plot.

P. umbellatus fruiting bodies grow annually and are edible.[13] Collecting the fruiting bodies is very popular among mushroom collectors in several regions of Slovakia. Collectors with a sales license can sell the fruiting bodies of this fungus at selected public places. Fruiting bodies approximately 25 cm in diameter or weighing 1 kg usually garner €3 to 5 (written personal communication from Marcel Kaščák, RNDr, March 2017). The most popular use of the fruiting bodies is in preparing soups, and less so, a risotto or sauce. The fruiting body has a very pleasant odor, to some people similar to that of dark chocolate. Sometimes the odor is so intense that some people find it to be unpleasant. Old fruiting bodies or those exposed to rain smell unpleasant, extruding a sour odor.

Some *P. umbellatus* fruiting bodies can inexplicably appear during dry periods when fruiting bodies of other species do not grow at all. Localities where the fungus occurs are kept secret by mushroom collectors, who visit them regularly, even outside the season normally associated with mushroom picking. On several occasions, the collectors we contacted would not divulge the exact location of the find, and thus we excluded it from our database. Intensive collection in Hungary and Ukraine, as well as forest management, have been shown to lead to a decline of local mushroom population density.[33,35] It is, however, apparent that fruiting bodies do not grow every year and may not grow for several years in a row (e.g., plot ŠV 1.2). This makes accurate descriptions of population trends difficult. The study of genetic diversity and tissue chemical composition of the species in Europe is a challenge for future research of medicinal mushrooms.[43] In particular, the presence of some "medicinal" substances in the fungus often depends on a number of factors, including genetic variation and mushroom origin.[2]

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