Armillaria mellea (Vahl. : Fr.) P. Kumm. a non-timber forest resource in the Ñhöñho culture: promoting sustainable development and ethnomycotourism

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Research

Abstract

Background. The indigenous and mestizo communities in Mexico have used *Armillaria mellea* as a non-timber forest resource, mainly as food; ecologically it is an abundant species in forests. For this reason, we establish *A. mellea* as a species with cultural importance and a high potential for the development of sustainable regional and ethnomycotourism projects.

Methods. The field work was carried out in the *Ñhöñho* communities of Texquedó and Xahai, Querétaro; Mexico. Semi-structured surveys were applied to local specialists in collecting mushrooms. Species were identified at the taxonomic level. Participation-action workshops were held for the organization and development of ethnomycotourism events.

Results. A total biomass of 107.11 kg of *A. mellea* was collected with the support of the "*hongueros*" (local mushroom collectors) during the rainy seasons of 2017, 2018 and 2019. A greenhouse-type solar dehydrator was designed to process the mushrooms with a minimum dehydration capacity of 30 and a maximum of 100 kg of fresh mushrooms; and value-added products were designed with edible wild mushrooms. On the other hand, tours and mushroom collections (edible and inedible) were designed with local specialists, academics and visitors; promoting and laying the foundations for the development of ethnomycotourism with an approximate economic income per year in each community of 700 to 1200 dollars. Finally, as a result of this project, the non-profit civil organization; Ethnomycology, Research and Community Development A.C.

Conclusion. Mushrooms constitute the basis for the planning of regional sustainable projects, as means of revaluing traditional systems, and strengthening the local economy, as well as conservation and management under a biocultural approach.

Keywords. Mycotourism, Ethnomycotourism, Value-added products, Edible wild mushrooms, Otomí, Mexico

Background

In México, wild mushrooms constitute an important natural resource for indigenous and mestizo rural communities in different regions (Moreno-Fuentes 2014). This relevance has been documented in different parts of the world (Yamin-Pasternak, 2011); where the cultural importance assigned to this particular biological group is based mainly on the anthropocentric categories of food and medicine (Lampman, 2007; Guzmán, 2008), in addition, in some cases, commerce (Boa, 2005; Moreno-Fuentes 2014). It is estimated that more than 300 species of wild mushrooms are used in the country (Garibay-Orijel *et al*., 2006); more recent approximations report the use of 371 species of edible wild mushrooms and 170 as medicinal ones; the high ethnomycological diversity is directly associated with the high biological diversity of the group; as well as the number of studies carried, placing Mexico as the main country in which ethnomycological research is carried out, after India and Nigeria (Moreno-Fuentes & Garibay-Orijel, 2014).

Fungi as well as other natural resources, such as plants and animals; they constitute complex socioecological relationships, constituting traditional ecological knowledge (TEK). The TEK is a complex of knowledge and practices above all of use and exploitation; traditionally it was considered exclusive of indigenous groups and regions (Whyte 2013), however, current research with rural and semi-urban mestizo peoples highlights their complex socioecological relationships (Estrada *et al*., 2021; 2022). TEK manifests itself in aspects such as; knowledge and use of species, food systems, traditional medicine, classification systems, domestication and cultural selections processes; among other aspects (Whyte, 2013). One of the premises of TEK is the traditional classification that is based on the recognition of the species, based on morphological, ecological or cultural characteristics; the traditional classification constitutes the basis of cognitive development and practices associated with consumption and exploitation (Brown, 2019). In turn, TEK is an integral part of biocultural diversity, a concept that has become highly relevant and is recognized as a complex of socioecological relationships, of biological and cultural components at different space-temporal scales (Gutiérrez-Santillán *et al*. 2019a).

Fungi, in addition to being important in food and medicine (Lampman, 2007; Guzmán, 2008), have great economic potential, however, as a non-timber forest product, have received little attention in forest management schemes (Garibay-Orijel *et al*., 2010). The collection of wild mushrooms is an activity carried out by the "*hongueros*/*hongueras*" (local mushroom collectors) within the territory of rural communities; this collection is based on the correct traditional identification of the species, that is, on the ethnomycological TEK. Fresh become a precious resource; furthermore, dehydrated is a form of local processing; where both forms of exploitation generate resources for the communities (Yamin-Pasternak, 2011; Fusté-Forné, 2019; Dincã & Timiş-Gânsac, 2020).

Guided mushroom collections, systematized and organized by experts and managers of this resource, in which people outside the communities participate; they have been the basis for the development of mycotourism or ethnomycotourism (Thome-Ortiz, 2015; Jiménez-Ruiz *et al*., 2017). Generally, under action-participation schemes between the academic and community and general society; programs and strategies focused on sustainable local development have been established, the main protagonists being fungi. Therefore, mycotourism (understanding as the only collection of mushrooms) constitutes a source of economic income for many communities but specially ethnomycoturism inside indigenous and mestizo rural communities adding the cultural component not always observed in traditional mycotourism (Frutos-Madrazo *et al*., 2011; 2012; Jiménez-Ruiz *et al*., 2016). Besides having the main function of the ethnomycological biocultural heritage, promotes the revaluation of traditional food systems based on the consumption of edible wild mushroom species, strengthens the ethnomycological TEK among "*hongueros*/*hongueras*" and new generations in local communities, contributes to the dissemination and knowing about fungi to the rest of society, promotes good management of non-timber forest resources; and they may even favor the conservation of biodiversity (Halme *et al*., 2016).

On the other hand, the commercialization of edible mushrooms has focused on easily cultivated species; restricting the cultivation and commercialization of wild species (Royse, 2014) to local and seasonal markets. Wild species are rarely cultivated outside the traditional system, due to their specific ecological requirements associated with their developmental and reproduction, their mycorrhizal relationships, and environment conditions such as temperature

and humidity; as well as seasonality (Boa, 2005; Savoie & Largeteau, 2010). Large-scale commercialization has focused on the production of cultivable saprobic species such as mushrooms (*Agaricus campestris*), oyster mushrooms (*Pleurotus* spp.) and shitake (*Lentinula edodes*). However, there is a growing list of possible species that have few requirements for fruiting, through the establishment of protocols for their cultivation, even generating a process of semi-domestication or domestication; or for the development of mycosilviculture (Savoie & Largeteau, 2010). Some candidate genera are *Agaricus*, *Pleurotus*, *Neolentinus* and *Clitocybe* (Sánchez & Mata, 2012). But no attention has been paid to the genus *Armillaria*, which may have a high potential. *Armillaria* belongs to the Physalacriaceae family with 35 species distributed throughout the world. Most of these species are saprobic and some even parasites of plants, as in the case of *Armillaria mellea*. This mushroom is facultative saprobe, which means that when the plant dies, it can continue to bear fruit; which can be considered a potential for intense cultivation. Culturally, in Mexico this fungus is common in ethnomycological research, but at the same time, with little value; for example, in communities in the southwest of Querétaro, it occupies the tenth place of cultural importance, where it is ecologically abundant (Robles-García *et al.*, 2018).

Despite its abundance compared to other edible wild mushrooms, *A. mellea* has not been considered in the design or development of exploitation strategies, community economic strengthening, management or commercial cultivation. Therefore, we suggest its high potential as an important cultural species, constituting relevant roles at cultural level (Platten & Henfrey, 2009), being part of the ethnomycological TEK, with frequent presence in ethnomycotourism routes due to its abundance in its habitat; easy to handle in its collection, processing and marketing. Therefore, the present research proposes *Armillaria mellea* as the basis for the constitution and execution of a sustainable regional development model and its systematized exploitation; which includes the collection, dehydration, processing and development of value-added products; for local and regional marketing. Additionally, this research seeks to establish the bases of ethnomycotourism, as a sustainable alternative activity that promotes the revaluation of traditional knowledge, the adequate dissemination of mycoculture and ethnomycotourism, economic strengthening; as well as their participation in the management of the conservation and reforestation of forests.

Materials and Methods

Study area

San Ildefonso Tultepec is located in the municipality of Amealco de Bonfil, southwest of the state of Querétaro, Mexico, the local population belongs to the indigenous group *Ñhöñho* (otomí). It is a community located at 2390 meters above sea level, with an average annual temperature of 15°C, its climate is temperate humid with abundant rains in summer. The vegetal structure is constituted by different species like *Quercus* genus (oak), and some of *Pinus* (pine). The communities of Texquedó and Xahai have a broad cultural history regarding the collection of edible wild mushrooms, 33 ethnomycological species have been reported (Robles-García *et al.*, 2018). In addition to this, there has been contact with the community (Robles *pers. comm.*, 2015); both aspects were important to establish these localities as the study areas (Figure 1).

Fieldwork and processing of ethnomycological data

The ethnomycological fieldwork was carried out during the rainy season, between the months of July to October, 46 visits were made during three consecutive years (2017, 2018 and 2019). The guided tours were carried out within the perimeter of the forests bordering the communities on trails known and frequented by "*hongueros/ hongueras*"; local mushroom collectors; collecting all the varieties of fungi that were recognized as edible. During the collection of the ethnomycological material, data were obtained on the number of sporomes and their fresh biomass. The collected fungi were weighed in a conventional mechanical scale and subsequently cleaned and cut into small pieces for dehydration. Once dehydrated, they were stored in sealed bags or properly labeled glass jars. In addition to the processing of the fungi, specimens were collected for their correct taxonomic identification in the laboratory, for this, their morphological characteristics were described fresh, dehydrated, stored in boxes and labeled (Robles-García et al. 2018). All the mushrooms recognized as edible were collected, once collected, they were grouped under the traditional classification criteria (Dayarathne *et al.*, 2016), weighed and cleaned with brushes and knives, removing dirt and litter; to start the solar dehydration process (Mendieta-Toboada & Medina-Vivanco, 1995). The identified specimens were donated directly by local people, deposited in the ethnomycological collection, Dr. Teófilo Herrera Suárez of the Universidad Autónoma del Estado de Hidalgo with the collection number Robles 698.

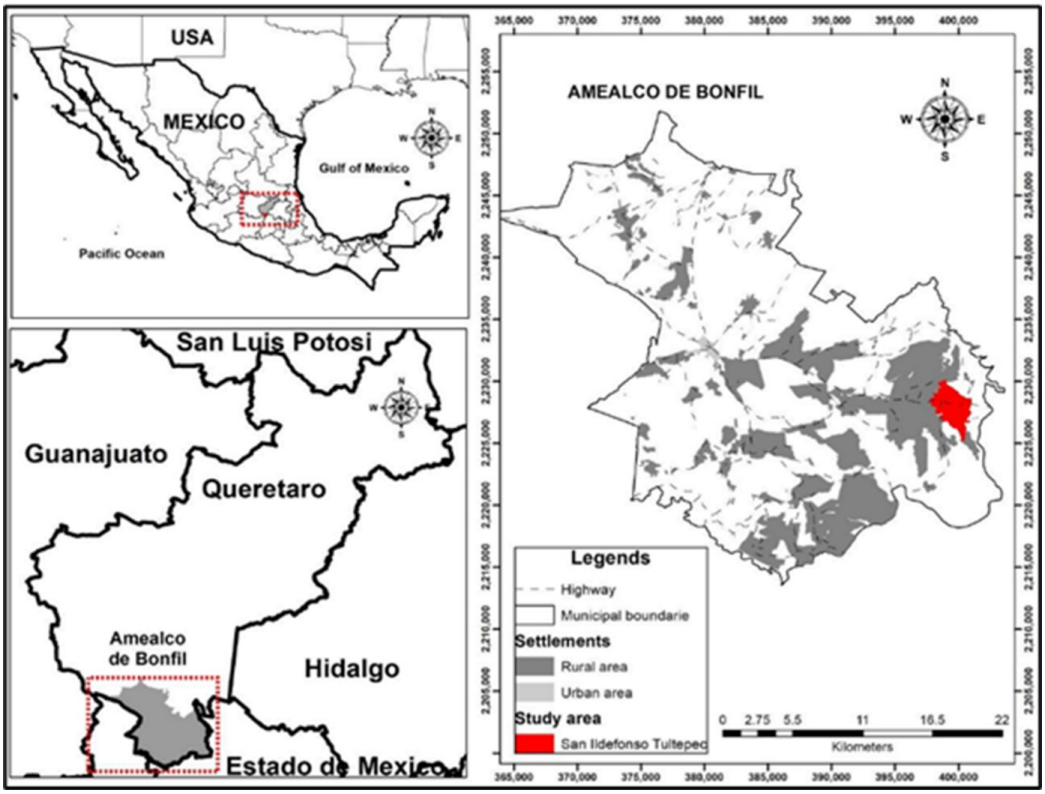

Figure 1. Spatial location of the municipality of San Ildefonso Tultepec, Amealco, Querétaro, Mexico. The oak forest (*Quercus*) with some pine (*Pinus*) sites predominates in the area. Socioculturally, the indigenous group that occupies this territory is the otomí, who call themselves *ñhöhño* (indigenous group).

Participative and collaborative work was regulated based on article 2 of the Constitución Política de los Estados Unidos Mexicanos in section A, section VI (DOF, 2020). The work was sustained under the free, inclusive and open incorporation of people (informants) during all facets of research, such as the collection of mushrooms, their processing into value-added products, and ethnomycotourism development. The methodological principles followed in this research are supported by participatory revaluation for the co-creative research process (Albuquerque *et al.* 2014; Delgado & Rits, 2016). Based on the continuous dialogue of knowledge, in which the academic sector provides technical-scientific information, to optimize the use of mushrooms, using accessible and environmentally friendly technologies (Melgarejo-Estrada *et al.*, 2018) and participating fungi gatherersprovide traditional knowledge on the management of wild mushrooms *in situ*.

In a complementary way to promote *Armillea mellea* as a non-timber forest resource with high potential in sustainable regional development, a qualitative systematized review was carried out, from which the status of its knowledge in Mexico was documented. The review was based on a search for information available on the internet, for which a set of keywords were used to define the object of study (*A. mellea*), the research area (ethnomycology, edible wild mushrooms, indigenous groups, traditional knowledge) and regionalization (Mexico; Gutiérrez-Santillán *et al.*, 2019b). From the information obtained (scientific articles, popular articles, graduate and postgraduate thesis, books and book chapters), information was extracted about its biological-ecological and socio-ecological aspects, in this second field the traditional nomenclature with which it is recognized stands out, to the species in a cultural way and the indigenous groups that use it.

Data analysis

In order to determine if *A. mellea* is the species with the highest abundance and biomass and if it is optimal for sustainable use, a simple linear correlation was performed between the number of sporomes and the biomass obtained for each of the species. The same function is given from the design of the range-abundance curve with the total frequency data to conclude whether *A. mellea* is a species with potential for exploitation with respect to the total of fungal species collected. Finally, to know if there are significant differences between the biomass production of *A. mellea* between the years studied, a Kruskal-Wallis test was applied with the Mann-Whitney comparison between pairs and the Bonferroni correction. All statistical analyses as well as the range-abundance curve were performed with the Past statistical program (Hammer *et al.*, 2001).

Technological contributions

A polycarbonate mushroom dehydration module was designed, the same model was built in each of the communities. The modules are basically similar to a greenhouse (Vox *et al*., 2010), where the structure is made of wood and the walls and ceilings of polycarbonate. The dimension of the dehydrators is 3.5 m long, 3 m wide with a height of 1.8 m. Inside there are two structures similar to shelves made of wood (0.5 m wide x 2.5 m long x 1.5 m high), on the shelves are the plastic rails, where the properly cleaned and cut mushrooms are placed to start your dehydration process. The dehydrators work with solar energy concentrated indoors, similar to conventional greenhouses (Gorjian *et al*., 2011). Also, as part of the technological contributions, the dehydrated mushrooms were packaged and labeled for commercialization, establishing some distribution routes at the local level and in nearby cities. In addition, they were processed into value-added gastronomic products (Fusté-Forné, 2019; Dincã & Timiş-Gânsac, 2020).

Ethnomycotourism

As part of the complementary activities to the collection, processing and transformation of local edible wild mushrooms. Mycotourism or ethnomycotourism routes were designed inside the otomí community and developed, through methods of action-participation and dialogue of knowledge (Albuquerque *et al*., 2014; Delgado & Rits, 2016) between the academic sector and the participating local inhabitants. First, through a communal assembly, prior and informed consent was obtained for the acceptance of the entry of external visitors to the communities (International Society of Ethnobiology 2006; http://ethnobiology.net/codeofethics/). The routes were designed based on the information obtained in the tours during the field work, supplemented with contributions from the "*hongueros/hongueras*" on the sites where the different species of mushrooms (edible or inedible) are more frequent. An organizing committee was assigned, who determined the collaborative work of each of the people who participated in the development of the event. The invitation was made to external visitors (mainly from nearby cities). In general, the experience consisted of welcoming them by the local authorities; later, guided tours were conducted by an academic (main author) and by the "*hongueros/hongueras*", also known as "*recolectores de hongos*" (mushroom pickers). The tours are intended to promote traditional ecological knowledge regarding mushrooms, as well as their revaluation within traditional food systems. During the tours, the visitors were explained socio-ecological aspects; for example, common name, scientific name, type of fungus, type of substrate, mycorrhizal association, morphological characteristics, cultural characterization, edibility or toxicity; and also, the concerns expressed by the visitors themselves were answered.

The event ended with gastronomic activities, where the protagonists are edible wild mushrooms cooked in a traditional way (Fusté-Forné, 2019); these activities were complemented by the sale of local handicrafts and value-added products made with mushrooms.

Results and Discussion

The ethnomycological diversity recognized for both communities corresponds to 12 genera with 15 fungal species; a medium diversity compared to that previously reported, some socio-ecological aspects that remain is the nomenclatural assignment, recognizing in otomí the name "*hyethe*" for the definition of fungus, as well as the specific traditional names for each of the species (Robles-García *et al*., 2018). During the sampling period, a total of 3,730 sporomes was collected, equivalent to a biomass of 339.362 kg; same that were collected in an area of 1.5 km^2. *Armillaria mellea* has the highest number of fruiting bodies with 35% (n= 1,303 sporomes), consequently the highest percentage in biomass (32%) with 107.11 kg (Table 1). In addition, a highly significant correlation (r= 0.92, p= 0.00, $p<0.05$) is observed between the number of collected sporomes and its biomass, that is, the greater the number of fungi, the greater biomass.

Therefore, of the total of fungi species in for the two communities, it was observed that *A. mellea* has the highest collection frequency, followed by *Ramaria* spp. (n= 573; 75.665 kg), *Agaricus campestris* (n= 414; 6.89 kg) and *Butyriboletus frostii* (n= 330; 40.493 kg). These different collection frequencies between *A. mellea* with respect to the other species can be observed graphically in the range-abundance curve. Therefore, from the perspective of edible use, this species constitutes an important non-timber resource with high potential for in situ production and management. *A. mellea* was determined as a highly profitable species when evaluating biomass (harvest in the forest) during the three years of the research. This was also observed in the design of the range-abundance curve, where the total frequencies of the different species of wild edible fungi, in both communities in the three years of fungi collected; show *A. mellea* as the most abundant species, followed by the species seen in Table 1.

Finding that there is no significant difference in the harvest of this species (H= 5.186, p= 0.07, p< 0.05). However, this may vary slightly depending on the environmental conditions or the intensity of the collection, as demonstrated by the pair test, which does present a significant difference between the years 2017 and 2019 (p= 0.03, p< 0.05).

Table 1. Diversity of edible mushrooms in the *Ñhöñho* community of San Ildefonso, Amealco, Mexico. Regarding the number of sporomes and biomass collected between the years 2017-2019. Traditional names in spanish and in the *Ñhöñho* language to recognize these species of edible mushrooms. NOTE: The nomenclature was written directly by collaborators who can read and write in their mother tongue.

Species	Spanish name / Ñhöñho name	Number of sporomes	Biomass (kg)
Armillaria mellea (Vahl.:Fr.) P. Kumm.	Hongo de tronco / "*Hyethe nduza*"	1303	107.11
Ramaria sp.	Hongo patitas de pájaro / "*Hyethe tsi´ntsu*"	573	75.665
Agaricus campestris (L.)	Hongo blanco / "*Hyethe nt´axi*"	414	6.89
Butyriboletus frostii (J.L. Russell)	Hongo de buey rojo / "*Hyethe joboy n´teni*"	330	40.493
Boletus variipes Peck	Hongo blanco / "*Hyethe nt´axi*"	234	24.708
Fistulinella wolfeana Singer & J. García	Hongo salado / "*Hyethe uxki*"	231	33.56
Xerocomus illudens (Peck) Singer	Hongo de azufre – Hongo agrio / "*Hyethe ixka*"	175	10.7
Amanita basii (Guzmán & Ram.-Guill.	Cashimón / "*Kaxamón*"	130	16.435
Lactarius indigo (Schwein.) Fr.	Hongo azul / "*Hyethe ñoi*"	106	4.796
Butyriboletus speciosus (Peck) D. Arora & J.L. Frank	No name in spanish / "*Hyethe joboy*"	101	8.31
Boletus auripes Peck	Hongo de Manteca / "*Hyethe dega ndega*"	39	4.24
Calvatia cyathiformis (Bosc) Morgan	Hongo bola / "*Hyethe bola*"	36	2
Hypomyces lactifluorum (Schwein) Tul. & C. Tul.	Trompa de puerco / "*Hyethe xiñu dega ts´udi*"	30	1.9
Retiboletus griseus (Frost) Manfr. Binder & Bresinsky	Hongo de pasto / "Hyethe ngut´ei" / "*Hyethe dega ñonxu*"	20	1.505
Butyriboletus cf. *appendiculatus* (Schaeff.) D. Arora & J.L. Frank	No name in spanish / "*Hyethe joboy*"	8	1.05
Total		**3730**	**339.362**

Use of *Armillaria mellea* and technological contributions

For the assessment of the *in situ*, production of *A. mellea* in an area of 1.5 km^2 of oak forest, some members of the community participated in the collection process. Groups of four to six people were organized, including local specialists in the mushroom identification ("*hongueros/ hongueras*"), accompanied by academics, which allows directing the research under the knowledge dialogue scheme (Albuquerque *et al.*, 2014: Delgado & Rits, 2016). For efficient dehydration, especially of *A. mellea* and other larger fungi, the fungi were cut into small pieces and spread on the grids of the dehydration modules (Figure 2). A couple of times during the dehydration process they were moved to obtain a homogeneous dehydration process, once dehydrated, they were packed in portions of 40 gr. Inside the dehydration modules, the temperature varies depending on the climatic conditions, with a temperature ranging from 18°C to 62°C. The modules work in a similar way to a greenhouse in which the heat source is the sun (Gorjian *et al.*, 2010), they have a dehydration capacity of up to 100 kg (with a minimum of 30 kg) and the dehydration process takes on average 1.5 days; a high percentage in contrast to controlled trials (Mendieta-Taboada & Medina-Vivanco, 1995).

During the development of the project some technical problems arose. For example, in 2017 (initial year of the project) the dehydration processing of fungi was affected by the presence of excess of moisture and insects, affecting the final production by up to 50%. In 2018, a standardized protocol for processing harvested mushrooms was followed, cleaning and cutting the mushrooms into smaller pieces resulting in a faster and more efficient dehydration process, preventing its decomposition by moisture and verifying that the mushrooms did not have any insects upon entry to the dehydration modules. The standardization conserved more than 90% of the collected biomass. In 2019 between 70-80% of the production obtained was destined to edible products, while the rest of

the production (about 20%) was destined for self-consumption. By 2019, the procedure was fully standardized and is now carried out with an efficiency of almost 100%.
On the other hand, the modules were used as greenhouses for the reproduction of native oaks using a substrate enriched with fungal processing material (*in vivo* inoculation of mycorrhizal species) to promote reforestation and increase the biomass production of wild edible fungi, especially *A. mellea*, as non-timber forest resources (Tapia-Tapia & Reyes-Chilpa, 2008); It should be mentioned that from this perspective it is necessary to do more research, since the studies are incipient (Melgarejo-Estrada, 2014).

Since the project began in 2017, the local population gradually became interested in the activities of this project, a) Firstly, in the collection and sale of edible wild mushrooms, b) later, through the ethnomicotourism tours. It is worth mentioning that the process to integrate new participants into the project has been gradual. However, the local inhabitants began with the organization of groups, with the purpose of providing maintenance to the forest, with activities such as making gaps for firebreaks, pruning tree branches, as well as reforestation with local trees every year.

An activist group specialized in promoting forest reforestation called "Corazón de árbol Querétaro" (Heart of tree Queretaro) led by a woman and her family, and academic guidance. It began in 2018 with its own resources, the application of management plans for timber resources, which directly use wood from the forest, calling mainly charcoal makers, potters and people who use lumber as firewood. It is worth mentioning that between 2018 and 2020 more than 35,000 trees of native oak and pine species have been planted, which have been inoculated with species of edible fungi such as *Laccaria* spp. This process helps establish tree seedlings (Rodríguez- Gutierrez et al., 2019).

It is important to mention that local conflicts have arisen in the area due to clandestine logging, carried out by external groups from other places, therefore, a joint effort between the community and local authorities is sought to curb environmental deterioration. In order to propose management plans, in which these illegal activities are stopped, there is an integral management of the forest, and it is possible to continue with ethnomycological activities, as a means of sustainability. Since the collection of mushrooms, consolidate an emerging activity, which is becoming increasingly important, constituting a non-forest timber resource, which can be exploited with high profitability. For this, feedback is essential between the different sectors, local, academic, civil and local authorities, to raise awareness about the importance of the forest, fungi and water.

In this case, *A. mellea* and many other edible wild mushrooms need a proper monitoring plan as climate change plays an important role because every year was different, and the rainy season could be shorter compared to the last ten years and due to the decrease in vegetation cover (*Quercus* spp. and *Pinus* spp.; that people use without an adequate management plan). It is important to mention that this species is the most abundant in terms of frequency and biomass (data observed in the range-abundance curve), although it is only collected by local people for self-consumption and sometimes for local sale (Robles-García *et al*., 2018).

For this reason, we proposed to the community that *A. mellea* is a highly usable species as a non-timber forest resource, an important source of economic income and the basis for the establishment of this sustainable regional development project (Halme *et al*., 2016). Also, as a cultural contribution, at the consideration of the local participants, a name in the *ñhöhño* language was assigned to each dehydration module. For example, in Xahai the module was called "*hyethe*" which means "fungus" or "in summer", in Texquedó the module was called "*no'öar zaa jo xí majwänl*" which means "nature is true". Carrying out this real estate award procedure reinforces community ties and highlights the importance of the project, as a source of alternatives for sustainable development (Whyte, 2013).

As part of the project, the innovation of developing gastronomic products, made from *A. mellea*, was proposed, adding value to this species and managing it as a sustainable and economically effective non-timber resource (Fusté-Forné, 2019). Non-timber products are important for many cultures around the world, with which traditional mushroom based foods are made, such as *Boletus edulis*, *Pleurotus ostreatus* and *Inonotus obliquus* in Romania (Dincă & Timiş-Gânsac, 2020). *A. mellea* dehydrated was packaged in hermetically sealed bags or glass jars, in a 40 g presentation for sale (Figure 3a) and a local liquor (alcoholic drink) with the peculiar earthy flavor of *A. mellea* was made (Figure 3b). These two commercialization products promise a potential market within gourmet cuisine (Boa, 2005). On the other hand, the revaluation of traditional gastronomy was promoted with edible wild mushrooms (Dincă & Timiş-Gânsac, 2020), especially with *A. mellea*. This was tasted by the visitors during the

mycotourism or ethnomycotouristic tours; providing visitors with new culinary experiences (Jiménez-Ruiz *et al*., 2016; 2017; Figure 3c).

Figure 2. Collection and processing of *Armillaria mellea* in the community of Xahai. a) Mushrooms at one of the collection sites. b) New generations identifying and collecting the "hongo de tronco" ("trunk fungus", *A. mellea*). c) Dehydration module "*hyethe*" with other species such as *Amanita basii*, *Ramaria* spp., *Boletus variipes*, *Butyriboletus frostii* and *Fistulinella wolfeana*. d) Mrs. Martha Pascual with buckets of mushrooms collected during the rainy season.

Due to the relation between local work groups and the academic support is based on the reciprocity, the communication, the process of accompaniment is permanent so that makes the dialogue and the conflict resolution accessible and easier. Fortunately, the training that the participants have received has been maintained and each year is strengthened with the activities carried out, in this sense, people have a certain degree of autonomy, so it is important to mention that the effect that the project has had, at least on the participating people, has had great repercussions on their daily activities during the rainy season, so it will undoubtedly be a work that will last over time.

However, there are two important aspects to consider, for example, first, with the advent of technology (such as smartphones and computers), it has been easy for the participants to be able to make their own publicity and promote their products and merchandise locally on different social networks and media, so the dependency of the academic part is less than when the project starts. And second, since one part is operational (people from the community) and the other part is administrative (part of the academic contribution), if one is lost or stops participating, the project runs the risk of being lost over time if the people are not able to maintain it on their own and they would have to look for an alternative to replace the activities that were carried out and take into account those factors of success or failure, depending on the local context and the reasons for leaving the project as an antecedent to consider it as a variant of the process (Palomino-Villavicencio *et al*., 2016).

Figure 3. Products made with dehydrated *A. mellea*. a) Packaged dried mushrooms for sale or self-consumption. b) Trunk mushroom liquor. c) "Tamales" made with *A. mellea* served during ethnomycological tours.

Socioecological aspects of *Armillaria mellea*

The socioecological characterization of *A. mellea* can mainly be observed in the traditional names with which it is known in different regions of Mexico; as well as the recognition of its ethnotaxonomic characteristics, that distinguish it from other fungi species (Estrada-Torres & Aroche, 1987; Robles-García *et al.*, 2018; Ruan-Soto, 2018a).

Armillaria mellea is a fungus used by maya, zapotec, nahua, totonac and otomí communities in Mexico, where in each of the regions it receives a traditional name. In the surrounding otomí region, Estada-Torres and Aroche (1987) record the name "*kjo ndinza*" ("*kjo*" = spongy and "*ndinza*" = trunk or trees). In Acambay, State of Mexico it is known as "*yakjolencho*/*kjolencho*" ("*ya*" = the, "*kjo*" = fungus, "*lencho*" = a tree called Lorenzo) or San Lorenzo. In the Nahua locality of San Isidro Buensuceso in Tlaxcala, *A. mellea* is known by the traditional name "*tetecuitl*" ("*tecuitlat*" = slime or "*cuitla*", excrement; probably means stone excrement), the taxa were highly appreciated as food, however,

the same local people recognize a decrease in the species, as a response to the clearing of the oak forest, where it grew (Montoya *et al*., 2003).

In Querétaro, it is recognized with the name "*hyethe*" that means in summer or in the rainy season, "*dega*" (loan from the spanish "de") and "*ndunza*" which means tree (Robles-García *et al*., 2018). This species is distinguished from similar ones such as *Hypholoma fasciculare*, *Omphalotus illudens*, *Galerina marginata* (toxic specie) and species of the genera *Gymnopilus* and *Pholiota*, due to the bright yellow color of the pileus, its striation along the stipe and by the white color of the gills (Lampman, 2007), same characteristics pointed out by the local inhabitants.

For this particular *ñhöhño* region, *A. mellea* is a specie that mentioned with a low frequency of mention and when it is recognized it is in the last places, which is an indication of its low cultural appreciations, compared to others of greater cultural appreciation such as *Amanita basii*, *Lactarius indigo*, *Fistulinella wolfeana*, *Ramaria* spp., or *Boletus variipes*; which are species that are more popular due to the cultural appreciation (Robles-García *et al*., 2018).

However, its presence within the socioecological collective is abundant in the central-southern region Mexico (Estrada-Torres & Aroche, 1987; Montoya *et al*., 2003; Garibay-Orijel *et al*., 2009), this species has been reported in 17 of 32 states of the country, mainly in ethnomycological research (Lampman, 2007; Ruan-Soto & Ordaz-Velázquez, 2015; Ruan-Soto, 2018b), lists of species (García *et al*., 1998; Rodríguez *et al*., 2010; 2018) and works of plant phytopathology with commercial interest (Marmolejo & Cortes, 2007; Rivas-Valencia *et al*., 2017).

These aspects constitute it as a real and tangible unit in the cultural collective and at the ethnobiological level; as part of the biocultural diversity (Gutiérrez-Santillán *et al*., 2019a) of edible wild mushrooms. Their socioecological relationships are related to the rainy season, their growth habit, as well as the various forms of local consumption. These socioecological characteristics constitute it as a species of cultural importance, due to its presence in cultural roles, such as nomenclature, cognitive systems, in traditional food and in the economy (Platten & Henfrey, 2009); with potential for exploitation due to its abundance and biomass, as a non-timber forest resource for sustainable use.

The case of *A. mellea* is similar to other species of fungi collected by indigenous communities, representing an economic benefit, for example; to *Tricholoma magnivelare* in Oaxaca (Martínez-Carrera *et al*., 2002). In Mexico, the large-scale commercial dimension needs to be explored as in Bolivia and Peru, countries that have a strong social organization and have government support as well as international cooperation for their productive programs. In these populations, because of the reforestation programs with pine, they take advantage of the "*k´allampas*" (*Suillus luteus*), producing up to two tons per year (Soriano-Bellota *et al*., 2016).

In Bolivia, the Agricultural and Mushroom Association of Yana Rumi (AACYR in spanish), in the Punata municipality, department of Cochabamba and the Association of Agricultural Producers of the Acacio Basin (ASPACA) in the Potosí department, are examples of community associations focused on the use of dehydrated mushrooms. They sell the dehydrated mushrooms at 10-15 bs (1.4-2.1 USD) per bag (with 100 gr approximately). They are also participating in the elaboration of innovative mushroom based (as they call it) culinary products from edible wild mushrooms such as chicharrón, piqué, lapping, soft drinks, preserves and mates. Another example of this development project is the community company; La Campera SAC Marayhuaca, Lambayeque, in Peru where mushrooms are used for commercial culinary purposes through the collaboration between the La Campera SAC and restaurants that offer mushrooms as part of their menu.

As in the previous examples, in the communities in the state of Querétaro, Mexico; the development of value-added culinary alternatives, based on *A. mellea*, has been promoted. With the aim of promoting community development as a co-creative research tool (Melgarejo-Estrada *et al*., 2018), through the use of ethnomycological knowledge dialogue and *in situ* production in forests (Savoie & Largeteau, 2010); as well as in its abundance. In addition to the research project, the civil association called Ethnomycology, Research and Community Development A.C. (EtIDeC A.C.; website: https://es-la.facebook.com/EtIDeC/) which addresses: the taxonomic identification of wild edible mushroom species, the evaluation of biomass production, the development of technologies (design, construction and operation of dehydration modules), systematization of the process of drying fungi, elaboration of food products, ethnomycological tours and the reproduction of native oaks for reforestation. In this association the participation of members of the *ñhöhño* community is important and the main objectives is to jointly promote

the establishment of work, exploitation, management and conservation of natural resources schemes, with special focus on wild edible mushrooms.

The management and consolidation of a formal civil association ensures that the projects continue and belong to the communities themselves, since the social actors are the owners of this project, which guarantees that, once the technical monitoring time and academic research continue. Therefore, this model can be extrapolated to other communities by the local inhabitants themselves, in such a way that natural resource management networks are generated, in this case edible wild mushrooms, under any regulatory, protection and management framework by the local people (Gasca-Zamora, 2014; Palomino-Villavicencio *et al.*, 2016). It is desirable that a high percentage of the community works together in this process but is complex because of lack of local organization, the low interest by local government in supporting these activities and the little participation of schools or research centers in carrying out a large-scale intervention. In this case, the increase in tourist activities related to nature has had a positive effect on the population, which leads to care for its biocultural heritage (fungi in this case), however, it is important to mention that even today the people make use of the forest since they are still communities with a degree of marginalization, so in the future it is expected that the organization will continue to increase, and the local authorities generate adequate use and management programs.

Wild mushrooms should be part of forest management plans as integral elements of community development through their use and transformation into value-added products (Garibay-Orijel *et al.*, 2010; Dincă & Timiş-Gânsac, 2020). In this research process, it was found that participatory revaluation research and knowledge dialogue (Delgado & Rits, 2016) are applicable methods of active and proactive research in ethnomycological works (Melgarejo-Estrada *et al.*, 2018). Community participation is fundamental and essential for decision-making and project orientation in order to ensure that the benefits are collective through the co-creation of the different actors. As well as ethnomycological studies in the forest regions of the country and other areas of the world, in order to identify species with potential for the establishment of similar projects. It is important to consider that the availability of edible wild mushroom species is regulated by their natural distribution and environmental conditions, where the species with the largest size and biomass are restricted to temperate forests, while in tropical areas the species are smaller size, and easy to decompose (Moreno-Fuentes & Garibay-Orijel 2014).

Ethnomycotourism

The ethnomycological routes were previously designed within the areas belonging to the community's oak forests. These basically consist of a tour guided by local experts ("*hongueros/hongueras*") and academics. During these tours, visitors have the opportunity to interact with nature and collect mushrooms, both edible and inedible. Local expert and academic staff provide information on the biological cultural knowledge of fungi, abundant in aspects of their identification, both at a taxonomic and cultural level (Jiménez-Ruiz et al. 2017).

The cultural aspect makes the difference between ethnomycotourism and mycotourism, in addition, ethnomycotourism is carried out in indigenous communities or with some degree of cultural roots (mestizo rural communities). In both types of populations, there is extensive knowledge and management of the species of edible and non-edible fungi.

The ethnomycotourism carried out in the communities began in 2017, being continuous for 2018 and 2019; on average, four tours have been made per year, two in each of the communities of Xahai and Texquedó, each with an average duration of 4-6 hours. The tours had the participation of ten to thirty people (considering a load capacity of 25-30 people per day), generating income of fifteen to twenty-five thousand MXN (750-1250 USD). The visit ended with a tasting of edible wild mushrooms cooked in a traditional way; as is done in many parts of Mexico and in other regions of the world (Fusté-Forné, 2019; Dincă & Timiş-Gânsac, 2020). As a complementary activity, the sale of value-added products (dehydrated mushrooms and mushroom liquor) and other local products such as medicinal plants and typical embroidery were carried out. It is worth mentioning that in September 2018, within the framework of the IV Festival for the Culture of Wild Mushrooms, the First Mushroom Fair was held in San Ildefonso Tultepec, Amealco, Querétaro, adding the municipal seat to the development of these events. The visitors interacted with members of communities in Oaxaca, State of Mexico and Tlaxcala (Mexico).

Ecuador was the invited country, whose representatives shared their experiences in the ethnomycological field; generating a space for growth and consolidation of these activities, as a means of sustainable regional development and biological conservation.

Fairs and festivals with edible wild mushrooms are also promoted in countries such as Bolivia and Peru; something very similar to gastronomic tourism, an important activity with cultural and economic relevance, developed in the northeast of Spain, in the Alta Ribagorca region. This activity shows the deep role that forest foods (mushrooms) have within the culture as part of their identity, economy, forest planning and sustainable management in rural territories (Fusté-Forné, 2019).

In Mexico there is a growing promotion of mycotourism and ethomycotourism activities, whose objective is to contribute to the local economy, revalue traditional food systems and the valuation of these knowledge and practices by people who are interested in the community; this reinforcing the knowledge and importance of edible wild mushrooms. (Frutos-Madrazo *et al.*, 2011; 2012; Jiménez-Ruiz *et al.*, 2016; 2017). Ethnomycotourism is constituted by a series of recreational activities, each day with greater realization and demand in Mexico.

However, there is no formal information on its performance, so it is necessary to establish a regulatory framework, ethnomycological research and the development of protocols for the correct execution of activities; as well as for the protection of traditional mycological knowledge.

During 2019 it was proposed by the Transdisciplinary Group of Biocultural Mexican Defense a guide with some important considerations to take in order to make cultural events safer to the visitors as well as the community, because it establishes a protocol where some points apply not only for mushroom fairs but many cultural biological resources. For example, it considers that it is prohibited the extraction of any organisms (animal, plant or fungi) without the community informed consent, and it could be possible only with a document where the extractors (academic or not academic) agree to back with the results of the use of extracted material. Another important point is the prohibition of any kind of damage to the ecosystem because of the aim of this events is to promote the respect of biocultural diversity. And finally, for mushroom fair, create a group of specialists (academics and local people) to differentiate the edible and poisonous species to avoid any kind of accident.

The demand for ethomycotourism in Mexico is so relevant that it should be mentioned that during 2020 it was derived from the policies established by the federal government in the face of the global pandemic caused by the SARS-COV-2 virus (COVID-19; DOF 2020). Whereby federal decree the gathering of people in public and private spaces is prohibited; the mushroom fairs and festivals were promoted and carried out through digital presentations on the internet, where local specialists and academics continue to promote Mexican, ethnomycology, as well as the appreciation and taste for mycotourism or ethnomycotourism. For this reason, Ethnomycology, Research and Community Development A.C. as a working group, it carried out a similar dynamic with a high digital audience during the month of September; showing that digital media are excellent for communication and dissemination of ethnomycological knowledge.

During the rainy season were developed three mushroom fairs, this data comes from 2018 and 2019 were the first and second fair was presented with normal activities, and 2020, were, the third edition presentation was different because of the global situation of pandemic contingence, the event was reduced compared with the past years adding virtual activities and with a limited availability for a maximum concurrence of 35-40 people with all the prevention measures.

Nowadays the virtual conferences can be consulted directly in the website: https://es-la.facebook.com/EtIDeC, and a video that can be watched in the following link: http//youtu.be/7vKJOSTCF3o.

In general, ethnomycological tourist routes are proposed as an alternative to ecotourism; where the base is biocultural tourism (Cervantes & Serrano, 2017). It promotes endogenous traditional knowledge, the consumption of edible species, the traditional nomenclature and culinary, strengthens community economies, reaffirms environmental education and revalues natural resources (Garibay-Orijel *et al.*, 2010; Jiménez-Ruíz, *et al.*, 2016).

Derived from our experience and proposals for cultural meetings, whose main objective is the strengthening, integration, configuration and development of a common cultural space, through actions of education, culture and science (IPANC 2022). A quick guide is proposed with basic descriptors for the development of ethnomycotourism or cultural fairs where the protagonists are wild edible mushrooms. We mentioned that these steps can also enhance the sustainable use of other types of natural resources

General considerations

A) Periodicity: it refers to the frequency of the events, the availability of the resource must be considered. It is important to mention that the abundance of wild edible mushrooms is related to the rainy season (july, august and september mainly).
B) Organizers: the general activity must be organized and directed by a group of people representing the community, like a civil association, ejido representatives, or community assembly. In addition, people with knowledge about the local fungal diversity ("*hongueros*/ *hongueras*") should be included.
C) Place: physical area where the event will take place must have the basic services for its execution and the attention of visitors (tourists).
D) Exhibitors: they are all those people who support with their knowledge and skills in the central theme of the event, for example, technicians, professionals, academics or researchers, as well as local experts of the diversity of edible wild mushrooms and local guides. Local or regional artisans can also be included.
E) Support: these can be infrastructure, as well as economic resources granted through government management, donations from non-profit civil associations, as well as fundraising by members of the organizing community.
F) Visitors: they are all those participants that include academic-researchers, community representatives, of organization representatives, legal representatives and participants (tourists); also people who know about fungi, who take the role of field guides.
G) Ethnomycotourism routes: these are understood as the transects within the forest through which visitors in the company of guides recognize the environment in which fungi develop and grow. It is designed with the intention that visitors acquire traditional biological-ecological and ecological knowledge of fungal diversity.
H) Value-added products: refers to any perishable or non-perishable product that is designed from wild mushrooms.

General Develompent

A) Program: schedule of activities, must include the date of completion, place, representatives and sponsors.
B) Promotion of the event: refers to advertising in different media, printing on paper or vinyl, impact on social networks and local media such as radio.
C) Arrival of visitors to the community: this should preferably be at a good time in the morning, visitors arrive in the community by means of local or private transportation.
D) Words of welcome: addressed to visitors (tourists) by the organizing committee.
E) Field tours: these last between 3 and 4 hours, they are carried out by local guides in the company of tourists.
F) Educational talks: aimed at the general public in which ethnomycological knowledge and practices are exposed.
G) Gastronomic tasting: consumption of local foods prepared from wild edible mushrooms.
H) Cultural event: it is the accompaniment of the gastronomic tasting, generally it refers to traditional or local music and dance.
I) Sale of handicrafts: stands with items for local sale available to the public.
J) Farewell: words by the organizing committee to close the event addressed to visitors (tourists).

Limitations

A) Lack of inputs: these may be necessary products, for example, a low abundance of fungi, or even the necessary infrastructure.
B) Lack of economic funds: these can be for the installation of infrastructure, the acquisition of artisan products or the development of other activities.
C) Conditions of the forest: high degrees of disturbance or droughts.
D) Lack of community organization: internal disagreements about holding the event.
E) Lack of visitors: refers to the low presence of tourists.
F)

The tours also serve as applicable proposals for other communities with similar goals. Taken the experience from previous years and 2020, it is proposed that mycotourism or ethnomycotourism be carried out through face to face and digital activities; providing greater diffusion. In addition, the local economy can be strengthened by entering new market systems through digital platforms. Continuing with the economic support to local communities, the conservation of traditional knowledge and the execution of sustainable development projects, where fungi are the protagonists. These processes indirectly strengthen the traditional language, derived from the interest of tourists

and visitors who wants to learn about the local names in *Ñhöñho* that are given to mushrooms, where the locals are proud to teach those names in their language, revaluing their traditional knowledge, as part of their cultural identity.

Conclusion

Armillaria mellea is a species with a high cultural relevance, as well as a high potential for utilization, compared to other species of edible wild mushrooms; that are culturally appreciated.

Despite showing the profitability so *A. mellea*, it is necessary to study edible wild mushrooms in many other regions of Mexico, and the rest of the world, in order to identify other species that may have similar roles with sustainability in the medium and long term.

A. mellea due to its ability to cultivate *in situ* biomass in the forest in a natural way, it is considered a non-timber forest species for the implementation of sustainable regional development projects. Culturally, despite not being one of the most popular top species in Mexican ethnomycology, it has extensive traditional ethnomycological knowledge; reflected in the nomenclature in different indigenous languages, their variety of uses, and the complex socioecological knowledge. For the *Ñhöñho* communities of Texquedó and Xahai, the integral use of *A. mellea*, together with other species of fungi; provide an alternative form of sustainable community development, economic strengthening as a source of temporary employment, strongly supporting the revaluation of traditional food systems, where wild edible mushrooms are the main protagonists, and revaluing their traditional nomenclature system associated with these taxa; as well as knowledge systems.

On the other hand, the implementation of sustainable technology and the development of value-added products constitute elements for economic strengthening, and indirectly promote strategies of local reforestation with native species, in order to obtain greater resources and profits. In addition, they motivate the formation of community civil organizations to manage and protect their resources; where the main actors are the local inhabitants and the academic media, an accompaniment in its consolidation. All these aspects together provide the bases for the development and consolidation of mycotourism or ethnomycotourism, as recreational activities culminating in a good management and use of non-timber forest resources. Both activities are seen as an economic source, in which visitors learn about the perception, knowledge and use of the different species of edible and inedible wild mushrooms; local communities strengthen their traditional ethnomycological knowledge systems and *in situ* biological conservation is favored. By designing this work and assessing the importance of wild edible mushroom species as means of local sustainability and cultural strengthening, we propose the importance of generating similar local protocols that promote the conservation and management of species from a biocultural approach, generating an investigation action participation of incidence in indigenous and rural localities.

Declarations

List of abbreviations: No abbreviations.
Ethics approval and consent to participate: The ethical approval for the development of this research was granted by the *Ñhöñho* communal council of each of the localities (Texquedó and Xahai, Querétaro, México), who in an assembly prior to the development of the work, were informed about the objectives and scope of the study. proposal. For the participation of each of the informants, prior and informed consent was obtained for the application of interviews, their participation in the collections, as well as during the ethno-tourism events.
Consent for publication: Not applicable.
Competing interests: There are no competing interests.
Authors contributions: DRG, AME, ASG= Research proposal, TVGS, AME= literature search, DRG, TVGS= Interview application, DRG, TVGS= Field collection, DRG= Community event organization, DRG, AME= Species identification, TVGS= Analysis of data, TVGS= Drafting of the manuscript, AME, ASG= Revision and correction of the draft of the manuscript, TVGS= Sending and editorial follow-up.
Data availability: All data are available in the manuscript.
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