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Genus *Pleurotus* (Jacq.: Fr.) P. Kumm. (Agaricomycetideae): Diversity, Taxonomic Problems, and Cultural and Traditional Medicinal Uses

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ABSTRACT: The taxonomic difficulties in the identification of the species of *Pleurotus* are extensively discussed. The problems are attributable to the great variation and wide distribution, as well as the magnified use of genetic and biochemistry studies of strains not clearly identified. More than 1000 species of *Pleurotus* have been described throughout the world, in more than 25 related and/or confused genera. However, only approximately 50 valid species are recognized in *Pleurotus*. Modern studies based on biochemical and molecular research and interbreeding tests are useful if they are based on the macro- and microscopic morphocharacters, as well as on the color of the basidioma, the spore print, and the type of hyphal system, all of which play an important role in the taxonomic classification of the genus. Of the more than 71 names related to *Pleurotus* discussed in the present article, only approximately 24 are considered as valid species in this genus. More than 20 species of *Pleurotus* are reported from Mexico, of which only seven seem valid taxa. *P. ostreatus* is apparently the species studied the most, but at the same time numerous taxonomic problems exist in its delimitation. The wild-type is unkown in Mexico; moreover, it is the most reported and cultivated, both for commercial and research uses, together with *P. pulmonarius*, *P. columbinus*, and *P. djamor*, the latter divided into three varieties, but all of them are of interbreeding among them. The traditional uses of the species of *Pleurotus* are revised. Approximately 100 common names of these mushrooms are known in Mexico. Several species of *Pleurotus* are used in traditional medicine for approximately 35 disorders or diseases.

KEY WORDS: Genus *Pleurotus*, Pleurotaceae, taxonomy, diversity, wild species, new methods, cultural and medicinal uses.

INTRODUCTION

The species of *Pleurotus* (Jacq.: Fr.) P. Kumm. [*Pleurotus* (Fr.) Quél.] have been used as food or for medicinal purposes for a long time, and at present they have an important role as commercial edible mushrooms. In addition, *Pleurotus* has been reported as parasitic on several trees. Farr et al. (1989) reported the following 7 species on 30 different hosts: *P. albolanatus* on *Pseudotsuga*; *P. cystidiosus* on *Acer*, *Liquidambar*, *Populus*, *Quercus*, and *Salix*; *P. dryinus* on *Carya*, *Liquidambar*, *Malus*, and *Quercus*; *P. levis* on *Acer*, *Betula*, *Juglans*, *Liquidambar*, and *Salix*; *P. minutus* on *Betula*, *Carya*, and *Quercus*; *P. ostreatus* on *Abies*, *Acacia*, *Acer*, *Alnus*, *Betula*, *Carpinus*, *Carya*, *Castanea*, *Laurocerasus*, *Liquidambar*, *Liriodendron*, *Lupinus*, *Magnolia*, *Malus*, *Morus*, *Nyssa*, *Ostrya*, *Pandanus*, *Picea*, *Pistacia*, *Populus*, *Pseudotsuga*, *Quercus*, *Salix*, *Tilia*, *Ulmus*, and *Wisteria*; and *P. septicus* on *Heteromeles*. Petersen and Ridley (1996) and Petersen et al. (1999) reported *P. djamor* (or *P. opuntiae*) as the probable cause of a plant disease in New Zealand forests. Species of *Pleurotus*, such as *P. cornucopiae*, *P. cystidiosus*, *P. ostreatus*, *P. strigosus*, and *P. subareolatus*, together with species of *Hohenbuehelia*, are known to attack and consume living nematodes, through special structures named microdroplets, as studied by Barron (1977), Barron and Thorn (1987), Hibbett and Thorn (1994), and Thorn and Barron (1984).

Today high-technology commercial cultivation of several species of *Pleurotus* on different agricultural wastes and on several lignocellulosic products has great importance in many parts of the

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world. This is attributable to its broad adaptability to several substrates for the digestibility of lignocellulosic materials and its potential in mushroom cultivation as well as use in animal feedstocks (Chang and Hayes, 1978; Zadrazil and Kurtzman, 1982; Quimio, 1986; Chang and Miles, 1989; Chang, 1991; Buswell and Chang, 1993; Guzmán et al., 1993a; Lelley and Janben, 1993; Royse, 1997). The oyster mushroom, the English common name of the *Pleurotus* spp., mainly *P. ostreatus*, was first cultivated in the United States at the beginning of the last century and then was introduced to Europe and India (Chang, 1993; Gunde-Cimerman, 1999). In Mexico the commercial cultivation of *Pleurotus ostreatus* started in 1974 with mycelium from Europe (Martínez-Carrera et al., 1991a). World production of the oyster mushroom is rapidly increasing because the culture is very promising in the subtropical and tropical regions. From 1986 to 1994 it increased from 169,000 tons to 797,000 tons (372% increase); China was the main region responsible for this production (Chang, 1991, 1993; Royse, 1997). However, the typical "button mushroom" [mainly *Agaricus bisporus* (J. Lge) Imbach, also known as *A. brunnescens* Peck] (Singer, 1986, p. 486), is the most important cultivated mushroom in the world, followed by *Lentinus edodes* (Berk.) Sing. and *Volvariella volvacea* (Bull.: Fr.) Sing. (Chang, 1993). Although between 1983 and 1984 *Pleurotus* ranked sixth in world production (Chang and Miles, 1989), it is gradually displacing the others (Chang, 1991), because *Pleurotus* spp. are easier and cheaper to cultivate; at present, it is third in world production (Chang et al., 1993a; Peberdy et al., 1993). Moreover, several research studies have focused on the culture of *Pleurotus* (e.g., Eger et al., 1974; Zadrazil, 1974; Khanna and Garcha, 1981a,b; Volland-Nail, 1981; Hilber, 1982; Zadrazil and Kurtzman, 1982; Kurtzman and Zadrazil, 1982; Bresinsky et al., 1987; Laborde, 1989; Chang, 1991; Petersen and Hughes, 1993; Vilgalys et al., 1993, 1996; Petersen and Gordon, 1994; Vilgalys and Sun, 1994a,b; Labarère and Iraçabal, 1995; Petersen, 1995a; Gibriel et al., 1996; Petersen and Ridley, 1996; Müller, 1997; Scherba et al., 1999).

With regard to the edible properties of *Pleurotus*, Crisan and Sands (1978), Bano et al. (1981), Bano and Rajarathnam (1982), and El-Kattan et al. (1991) found that *P. ostreatus*, *P. florida*, *P. opuntiae*, and *P. sajor-caju* present energy values of 265–367, whereas for *Agaricus bisporus*, Buswell and Chang (1993) reported 328–381. As *P. ostreatus* is the most common species considered in the literature, and apparently the best known, this name often has been used indiscriminately and it has been confused with other species, such as *P. columbinus*, *P. pulmonarius* (frequently reported as *P. ostreatus* var. *florida*), *P. djamor* (as *P. flabellatus*), and *P. sajor-caju* (a confused name). Also, there are several misidentifications of *Pleurotus*. Käärik (1992) commented that *P. cornucopiae*, *P. pulmonarius*, and *P. salignus* have often been regarded as forms of *P. ostreatus* although they are different species. *P. cornucopiae* is erroneously named "*P. cornucopioides* Pers." (e.g., Zadrazil, 1978), while *Craterellus cornucopioides* (L.: Fr.) Pers. is a mushroom completely independent of *Pleurotus*. The erroneous name "*Pleurotus florida*" introduced by Eger and co-workers in 1979 (see later) is still used by many mycologists, such as Buswell and Chang (1993), Peberdy et al. (1993), Mittar et al. (1993), and others; the same holds for the erroneous concept of *P. sajor-caju* in commercial cultures. *P. sapidus* is an obscure synonym for *P. ostreatus* and also frequently reported as a valid species as discussed later. Anderson et al. (1973) claimed that *P. sapidus* has a lilac spore print, in contrast with *P. ostreatus*, in which it is cream colored. However, the color of the spore print in *P. ostreatus* is a confusing subject. It seems that the *P. sapidus* of Anderson et al. (1973) is *P. ostreatus*, and their *P. ostreatus* is *P. pulmonarius*, as observed by Bresinsky et al. (1987). According to Singer (personal communication, 1975), Phillips (1981), and Wakefield and Dennis (1981) the color of the spore print of *P. ostreatus* is lilac, but Bresinsky et al. (1976) consider it to be whitish to cream with slight incarnate tinges. Moreno et al. (1986) reported the spore print of *P. ostreatus* as whitish to yellowish-cream. Hilber (1982) has shown that collections with lilaceous and white spore prints are conspecific among them, a position supported by Watling and Gregory (1989). Smith (1978) determined that the spore print of *P. ostreatus* is whitish at first, then changes to lilac gray after drying. Bas (1990) considered the spore print of *P. ostreatus* as whitish, pale gray, pale lilaceous gray or pale

olive–gray–buff. Recently Petersen and Krisai-Greilhuber (1996) considered the spore print of the neotype of *P. ostreatus* grayish.

All the cultured basidiomata of *P. ostreatus* from Europe obtained by the author's co-workers (Guzmán et al., 1993a, 1994) presented a lilac to lilaceous spore print, even those identified as *P. columbinus*, whereas those of *P. pulmonarius* presented a white spore print. Several commercial cultures of *Pleurotus* reported as *P. ostreatus* actually belong to other species. *P. columbinus*, *P. pulmonarius*, "*P. sajor-caju*," "*P. ostreatus* var. *florida*," "*P. flabellatus*," *P. djamor*, and others are confused with the cultures of *P. ostreatus*. Also, the author and his co-workers found that a strain of *Pleurotus* sp. sent to Mexico from Argentina produces basidiomata belonging to *Schizophyllum commune* Fr.: Fr (!).

All the misidentifications and problems of *Pleurotus* are attributable mainly to the lack of taxonomic studies on the genus, and then to the difficulty in identifying the species and the frequent use of interbreeding tests to define species. Guzmán et al. (1994) found that the reports of *P. ostreatus* from Mexico, such as those of Guzmán (1977a), Martínez-Carrera and Morales (1988), and Martínez-Carrera et al. (1988a,b), in actuality refer to *P. djamor*. Considering the great traditional and commercial importance of the species of *Pleurotus*, the present article considers how to understand the taxonomic problems related to the genus, the definition of the genus, the best way to identify the species, and the revision of the Mexican species and their uses and culture.

MATERIALS AND METHODS

An extensive critical revision of the bibliography on *Pleurotus* (more than 230 references) is the basis of this article, as well as the experiences of the author over several years of studying their taxonomy, culture, and traditional uses of the species of *Pleurotus*.

PROBLEMS IN THE GENUS *PLEUROTUS*

Consensus regarding generic limits of *Pleurotus* has not been reached, and it is frequently related with other genera such as *Lentinus* and *Hohenbuehelia*. In modern books, for example, Hawksworth et al. (1995), *Omphalotus olearius* (DC.: Fr.) Sing., a well-known agaric belonging to Paxillaceae (Singer, 1986), is still considered *Pleurotus*, following the old concept of Gillet in 1884 (!) (Heim, 1957). The genus *Hohenbuehelia* is well separated from *Pleurotus* by its thick-walled cystidia known as metuloids. Nonetheless, Singer (1986) and Pegler (1983a) classified as *Pleurotus* species with metuloids, for example, *P. floridanus* and *P. tubarius*. As for *Lentinus*, according to Pegler (1977a, 1983a,b, 1986), it is separated from *Pleurotus* by the structure of the hyphal system, dimitic in *Lentinus* and monomitic in *Pleurotus*, resulting in a texture that is tough in *Lentinus* and fleshy in *Pleurotus*. However, there are true species of *Pleurotus* with a dimitic system as discussed later.

Genera related to *Pleurotus*, with the exception of the anamorphic states (e.g., *Antromycopsis* Pat. et Trab. and *Pachyma* Fr.) are listed in Table 1 (Konrad and Maublanc (1924–1937); Pilát, 1935; Singer, 1949, 1962, 1975, 1986; Heim, 1957). *Hohenbuehelia* is accepted by the majority of authors as an independent genus in Agaricales (e.g., Thorn, 1986). *Nothopanus* was considered an independent genus by Singer (1949, 1962, 1975), but Horak (1968) and Singer (1986) stated that this is a synonym of *Pleurotus* following Dennis (1953, 1970). Petersen and Krisai-Greilhuber (1999) and Petersen et al. (1999) designated *Nothopanus* (Singer, 1944, type *N. eugrammus*) as a synonym of *Pleurotus* but they described the genus *Neonothopanus*, with the type *N. nambi* (= *Pleurotus nambi*) to avoid confusion with the *Nothopanus* of Singer that is another mushroom for Petersen and Krisai-Greilhuber. There are two species in *Nothopanus* sensu Singer common in the neotropic: *N. eugrammus* and *N. hygrophanus*. Pegler (1983a) considered *Nothopanus* from the Caribbean region. Guzmán (1977a, 1983, 1997) discussed both as *Pleurotus* from tropical Mexico. Since the lamellae are very distant and sometimes forked or interveined, and the basidioma irregularly mottled of vinaceous red color, it is better to consider these mushrooms as independent genera of *Pleurotus*. Petersen and Gordon (1994) described *P. hygrophanus* as *Pleurotopsis guatemalensis* from Guatemala (also reported

TABLE 1
Some Genera Related to *Pleurotus* (Many of them now belong to another genera or are independent; see text. The anamorphs are not considered.)

Acanthocystis (Fay.) Kühn.
Clitocybe (Fr.) Staude
Crepidotus (Fr.) Staude
Faerberia Pouzar
Geopetalum Pat.
Hohenbuehelia Schulz.
Hypsizygus Sing.
Lampteromyces Sing.
Lentinus Fr.
Lentodiopsis Bubák
Lentodiellum Murr.
Neonothopanus Petersen et Krisai-Greilhuber
Nothopanus Sing.
Omphalotus Fay.
Omphalopsis (Noordel.) P.D. Orton
Ossicaulis Redhead et Ginns
Panellus P. Karst.
Panus Fr.
Phylloporus Quél.
Phyllotopsis J.-E. Gilbert et Donk ex Sing.
Pleurocollybia Sing.
Pleurotellus Fay.
Pleurotopsis (Henn.) Earle
Rhodotus R. Maire
Tectella Earle

later in Petersen, 1995b). However, Petersen (personal communication, 1997) maintained that *P. guatemalensis* is really *Plicatura obligua* or a similar species. The genus *Plicatura* was described by Peck (1872) based on *P. alni* Peck, a mushroom similar to *Cantharellus* on the basis of the folds in the hymenium. For Hawksworth et al. (1995) this genus belongs to the Corticiaceous mushrooms. Singer (1986) excluded this genus from Agaricales. Concerning *Lampteromyces,* it was based on *Pleurotus japonicus,* studied by Singer (1943). *P. japonicus* is a poisonous mushroom that Singer (1986) considered belonging to *Lampteromyces.*

One of the first taxonomic problems regarding *Pleurotus* is its correct delimitation and taxonomic position. There is no agreement among the specialists, because for Singer (1949, 1962, 1975, 1986) *Pleurotus* presents a broad concept, with both a monomitic and a dimitic hyphal system, in contrast to the previously discussed views of Pegler and others. Pegler and Young (1983) separate *Pleurotus* from *Lentinus* by the length of the skeletal hyphae, up to 300 µm in *Pleurotus.* Romagnesi (1969) was one of the first to observe the importance of the presence of the sclerified hyphae in *Pleurotus;* however, Bresinsky et al. (1976) and others considered such a criterion as only of limited value, because they assumed that the development of sclerified hyphae depended on the type of substrate on which the species grow. Another problem in *Pleurotus* is its taxonomic position. Konrad and Maublanc (1924–1937), Singer (1943, 1949), Heim (1957), and Dennis (1970) considered *Pleurotus* in Agaricales, Tricholomataceae. Notwithstanding, on the basis of the hyphal system, Singer (1962, 1975, 1986) and Pegler (1977a) considered *Pleurotus* belonging to the family Polyporaceae but in Agaricales. Kühner and Romagnesi (1953) considered *Pleurotus* in the Pleurotacées in the Agaricales. Jülich (1981) accepted for *Pleurotus* the family Pleurotaceae following in part Kühner and Romagnesi (1953), but in the Polyporales. Watling and Gregory (1989) considered the family Pleurotaceae in the agaric flora of Great Britain, as did Imazeki and Hongo (1983) in Japan. Pegler (1983a) placed *Pleurotus* in the Aphyllophorales, Polyporaceae, and later (Pegler, 1986) changed the family for Lentinaceae. The position most widely followed by specialists is that of Singer (1962, 1975, 1986) to place *Pleurotus* in Agaricales, Polyporaceae (e.g., Moser, 1983; Käärik, 1992) or that of Pegler (1977a) to place *Pleurotus* in Poriales, Polyporaceae.

The hyphal system, either monomitic or dimitic; cylindrical spores and hyaline, nonglobose generative hyphae; pleurotoid or flabellate habit; not well developed stipe; and white, whitish, grayish, grayish blue, lilac, or pink spore print are the main features defining *Pleurotus.* Regarding the division of the genus following Singer (1986), there is still confusion. Singer (1986) divided the genus into the sections: *Lepiotarii* (Fr.) Pil., *Calyptrati* Sing., *Pleurotus, Coremiopleurotus* (O. Hilber) Sing., *Lentodiellum* (Murr.) Sing., and *Tuberregium* Sing. It is very difficult to follow this division, however, because of inconsistent features and/or their repetition, for example, *Lepiotarii* and *Calyptrati* are distinguished by a veil, but it is also present in *P. sajor-caju,* considered in Sect. *Lentodiellum* where there are species with-

out an annulus, for example, *P. levis* and *P. hirtus*. Hilber (1982, 1989, 1997) and Zervakis (1998) considered the Sect. *Coremiopleurotus* as a subgenus of the well-developed synnematous anamorphic state, as is the case for *P. cystidiosus* and *P. smithii*, shown by Pollack and Miller (1976) and Guzmán et al. (1980, 1991), respectively. In *Pleurotus cystidiosus* the anamorph state is based on the asexual forms observed by Kaufert (1936) and Semerdzieva (1965) in *P. corticatus* s. auct, non s. Singer (1986) (see later). Zadrazil and Kurtzman (1982) observed the problem of placing *P. cystidiosus* in one of the sections of Singer's (1986) classification. Pilát (1935) divided the subgenus *Eupleurotus* Pil. into 5 sections, as *Acanthocystis*, *Omphaliopsis*, *Panellus*, *Phyllotopsis*, and *Rhodotus* now belonging to another genera. Konrad and Maublanc (1924–1937) subdivided *Pleurotus* into five subgenera. Hilber (1982, 1997) divided *Pleurotus* into three subgenera: *Pleurotus*, *Coreomiopleurotus* O. Hilber, and *Lentodiopsis* (Bubák) O. Hilber.

Regarding the anamorph state of *Pleurotus*, it is known that in *P. cystidiosus*, *P. smithii*, and others, this is assigned to the Hyphomycete genus *Antromycopsis*: *A. macrocarpa* (*A. broussonetiae*) in the first and *A. guzmanii* (*A. smithii*) in the second (Guzmán et al., 1980, 1991; Moore, 1984; Stalpers et al., 1991; Zervakis, 1998; Capelari, 1999) (see Table 2). It is interesting to observe that in some cultures of *P. ostreatus* with a high concentration of CO_2, some abnormal basidiomata with deformations similar to *Antromycopsis* sinnema are frequently obtained, such as those observed by the author in the cultures of his co-workers (Guzmán et al., 1993a) and by Zadrazil (1974, Figs. 11–1 and 12), Zadrazil (1978, Figs. 16–4 and 17), and Zadrazil and Kurtzman (1982, Fig. 5f 4). Also, Desbiens et al. (1978) observed that a *Pleurotus* sp. they cultured were sensitive to concentrations of CO_2, and developed abnormal fruiting bodies, both in macro- and microscopic features. Little is known about why or when *Pleurotus* forms its asexual state. The author had observed the *Antromycopsis* state of *P. smithii* in culture and in wild conditions. The variation in the form and color of the basidiomata under culture led to a consideration of such

TABLE 2
Species or Names of *Pleurotus* and Anamorphic States Discussed in this Article (Those in bold letters are valid or possible valid taxa.)

Antromycopsis broussonetiae Pat. et Trab. (*A. macrocarpus*)
A. guzmanii Stalpers, Seifert et Samson (*A. smithii*) (anamorph of *P. smithii*)
A. macrocarpa Stalpers, Seifert et Sampson (*A. broussonetiae*) (anamorph of *P. cystidiosus*)
A. smithii (Guzmán) Guzmán et R. Valenz. (*A. guzmanii*)
P. abieticola Petersen et Hughes
P. agaves Dennis
P. abalonus Han, Chen et Cheng (a species related to *P. cystiodiosus* and *P. smithii*) [according to Hilber, 1997, is *P. cystidiosus* subsp. *abalonus* (Han, Chen et Cheng) O. Hilber]
P. albellus (Pat.) Pegler, seems close to *P. elongatipes*
P. albolanatus (Peck) Kaufm., not well known species
P. bajocalifornicus Esteve-Rav., G. Moreno et N. Ayala
P. calyptratus (Lindbl. in Fr.) Sacc. (Sokól and Szczepka, 1995)
P. calvescens (Berk.) Sing. (*Lentinus striatulus* Lév.) (see *P. fockei*)
P. calyx (Speg.) Sing. (*Lentinus patulus* Lév.)
P. catephes (Berk.) Sacc., a poorly known species
P. columbinus Bres. (*P. ostreatus* var. *columbinus* about several authors)
P. citrinopileatus Sing. (*P. cornucopiae* var. *citrinopileatus*)
P. concavus (Berk.) Sing. [*Lentinus concavus* (Berk.) Henn.; *L. concavus* (Berk.) Corner; *Lentodiellum concavum* (Berk.) Murr.]
P. cornucopiae (Paul.: Pers.) Roll.
P. cornucopiae var. *citrinopileatus* (Sing.) Ohira (*P. citrinopileatus*)
P. corticatus (Fr.: Fr.) Quél. s. str., conspecific with *P. dryinus*
P. corticatus sensu Kaufer 1936 is *P. cystidiosus*

Continued

TABLE 2 (*continued*)

P. cystidiosus O. K. Mill. (*P. corticatus* ss. Kaufert) (anamorph: *Antromycopsis macrocarpus*)
P. cystidiosus var. ***formosensis*** Moncalvo
P. djamor (Fr.) Boedijn var. **djamor** (*P. flabellatus*; *P. mexicanus*)
P. djamor var. *roseus* Corner (*P. djamor* var. *djamor*)
P. djamor var. *salmoneostramineus* (L. Vass.) Guzmán (*P. salmoneostramineus*, *P. djamor* var. *djamor*)
P. dryinus (Pers.: Fr.) P. Kumm.
P. dubius (Lloyd) D.A. Reid (*Stereum dubium* Lloyd; *Hohenbuehelia*?), a not well known species
P. elongatipes Peck [*Hypsizygus tessullatus* (Bull.: Fr.) Sing.; see *P. albellus*]
P. eryngii (DC.: Fr.) Quél.
P. eugrammus (Mont.) Dennis [*Nothopanus eugrammus* (Mont.) Singer; *Lentinus eugrammus* Mont.]
P. ëous (Berk.) Sacc., a synonym of *P. djamor*
P. euosmus (Berk.) Sacc. (confused, related to *P. ostreatus* or *P. columbinus*)
P. ferulae Lanzi **(see Appendix)**
P. flabellatus (Berk. et Br.) Sacc. (*P. djamor* var. *djamor*)
P. flavolanatus (Berk. et M.A. Curt.) Sacc., poor known species
P. floridanus Sing. (non *florida* s. au et.)
P. florida Eger nom. nud. (*P. ostreatus* var. *florida* Eger; *P. ostreatus* or *P. pulmonarius*)
P. fockei (Miq.) Sing., a not well known species
P. fuscosqua mulosus Reid (close to *P. abalonus*, *P. cystidiosum*, and *P. smithii*)
P. hirtus (Fr.) Sing. [*Lentinus scleropus* (Pers.) Fr.]
P. hygrophanus (Mont.) Dennis [*Nothopanus hygrophanus* (Mont.) Sing.; *Pleurotopsis guatemalensis* Petersen et Gordon]
P. japonicus Kawam. [*Lampteromyces japonicum* (Kawam.) Sing.]
P. komarnitzkyi Vassilk., with an uncertain taxonomic position (Hilber, 1982; Singer, 1986), however, recognized by Hilber (1997)
P. laciniatocrenatus (Speg.) Speg.
P. levis (Berk. et M.A. Curtis) Sing.; *Lentinus levis* (Berk. et M.A. Curtis) Murr.
P. lutealbus Beeli
P. mexicanus Guzmán (*P. djamor* var. *djamor*)
P. minutus Peck [*Crepidotus minutus* (Peck) Murr.]
P. nambi (Speg.) Sacc. [*Nonothopanus nambi* (Speg.) Petersen et Krisai-Greilhuber]
P. olearius (DC.: Fr.) Gill. [*Omphalothus olearius* (DC.: Fr.) Sing.]
P. opuntiae (Dur. et Lév.) Sacc. (*P. yuccae*)
P. ostreatus (Jacq.: Fr.) P. Kumm. var. *ostreatus*
"P. ostreatus var. *appalachiensis"* Hilber, 1997
P. ostreatus var. *florida* Eger (*P. florida*; *P. ostreatus* or *P. pulmonarius*)
P. ostreatus var. *columbinus* (Quél.) Quél. (*P. columbinus*)
P. ostreatoroseus Sing. (*P. djamor* var. *djamor*; *P. roseopileatus*)
P. populinus O. Hilber et O.K. Miller (belongs to the *P. ostreatus* complex)
P. pulmonarius (Quél.) Sing. (*P. ostreatus* var. *florida*?, *P. sapidus*)
P. roseopileatus Sing. nom. nud. (*P. djamor* var. *djamor*)
P. salignus Fr., a not well known species
P. salmoneostramineus L. Vass. (*P. djamor* var. *salmoneostramineus*)
P. sajor-caju (Fr.) Sing. (*Lentinus sajor-caju*) (not *P. sajor-caju* s. auct.)
P. sajor-caju s. auct. (*P. ostreatus* and *P. pulmonarius*)
P. sapidus (Schulz. apud Kalchbr.) Sacc. (? *P. cornucopiae*; ? *P. ostreatus*; ? *P. pulmonarius*)
P. septicus Fr.: Fr. (uncertain species)
P. serotinus (Schrad.: Fr.) Pat. (*Panellus serotinus* Pers. sensu Sing., sensu Kühn.; *Crepidotus*, Murr.; *Sarcomyxa*, P. Karst.)
P. spodoleucus (Fr.) Quél., a not well known species (? *P. ostreatus*)
P. smithii Guzmán (anamorph: *Antromycopsis guzmanii*)
P. strigosus (Berk. et M.A. Curtis) Sing. (a synonymous of *P. levis*)
P. subareolatus Peck, a poorly known species (? *P. pulmonarius*)
P. tubarius (Pat.) Pegler
P. tuber-regium (Fr.) Sing. [*Lentinus tuber-regium* (Fr.) Fr.; *Panus tuber-regium* (Fr.) Corner]
P. ulmarius (Bull.: Fr.) Quél.
P. viscidus Harmaja, non *P. viscidulus* (Berk. et Br.) Clel. from Australia, that seems a *Hohenbuehelia*.
P. yuccae R. Maire (*P. opuntiae*)

changes as indicative of another or new taxa. Bresinsky et al. (1976, 1987) observed that *P. ostreatus, P. columbinus*, and *P. pulmonarius* presented large variations of the basidiomata under culture. Another anamorph genus reported in *Pleurotus* is *Pachyma*, in *Pleurotus tuber-regium* (Singer, 1986). However, *Pachyma* is also reported as the anamorph of *Poria cocos* (Schwein.) Wolf, as *Pachyma cocos* (Schwein.) Fr. (Weber, 1929), and on the other hand, the position of *Pleurotus tuber-regium* is in discussion.

Concerning the problem of the production of spores in the basidiomata of *Pleurotus* sp. in commercial culture houses, Leal-Lara (1978) described the chance discovery by Eger in 1970 (in *Arch. Mikrobiol.* **74**) of a strain with sporeless production in the basidiomata of *P. ostreatus*, which perhaps is caused by an infectious agent. In contrast, Imbernon and Labarère (1989) and Imbernon and Houdeau (1991) produced at INRA at Bordeaux, France mutant strains of *P. ostreatus* and *P. pulmonarius* without or with poorly spored production. These strains were produced by ultraviolet mutagenesis. Ohira (1979), described a sporulation-deficient mutant in *P. pulmonarius*, and Chang et al. (1985) and Change and Miles (1989) a sporeless strain in "*P. florida*."

THE KNOWN SPECIES OF *PLEUROTUS* AND PROBLEMS IN THEIR CLASSIFICATION

The few taxonomic studies on *Pleurotus* are incomplete, except that of Hilber (1982), but deal mainly with European species, of which he considered approximately 10. Singer (1986) reported approximately 40 species [but Singer (1943), considered only 12 species, then (1949) 15 species, one of them as *Pleurotus* sp., and all of them in a dichotomic key]. Pilát (1935) described more than 60 species, but many of them now belong to other genera. Konrad and Maublanc (1924–1937) considered 10 species and 64 as doubtful and/or excluded species. Kühner and Romagnesi (1953) discussed 12 European taxa, while Moser (1983) refered to only 8 and Bresinsky et al. (1976) 6. Käärik (1992) considered 7 species in the Nordic countries. Bas (1990) described 5 species from The Netherlands. Watling and Gregory (1989) considered 5 species from Great Britain; however, Rea (1922) reported 43 species, most of them now belonging to other genera (this example shows how the magnitude of the genus can change). Zervakis and Balis (1991), on the basis of morphological characteristics, including the hyphal system, recognized 4 species in Greece, but later (1996) recognized 8 species in Europe based on interbreeding, although they observed that there is controversy regarding *P. ostreatus, P. columbinus, P. pulmonarius, P. sapidus, P. cornucopiae*, and others. Hilber (1978, 1982), also based on the hyphal system and the development of asexual states, recognized *P. ostreatus, P. pulmonarius, P. columbinus, P. cornucopiae, P. opuntiae, P. komárnitzky*, and *P. eryngii*, but later (Hilber, 1997) recognized *P. cystidiosus* with two varieties, *P. ostreatus* "var. *appalachiensis*," *P. populinus, P. dryinus, P. calyptratus, P. ëous, P. cornucopiae* var. *cornucopiae*, and *P. cornucopiae* var. *citrininopileatus*. Corner (1981) from Malaysia described approximately 40 taxa in *Pleurotus* but later (Corner, 1994) excluded several "anomalous species," because of the absence of clamp connections in them. He considered these latter as belonging to *Pleurocollybia*. Pegler (1969, 1972, 1977a,b, 1983a, 1986) described 10 species of *Pleurotus* from Africa, Antilles, India, Nepal, Pakistan, and Sri Lanka. Dennis (1953, 1970) in Venezuela and adjacent countries reported 14 species of *Pleurotus*, some of them belonging to *Hohenbuehelia*. Batista-Pereira (1988) considered 8 species from Rio Grande do Sul, Brazil, of the 21 reported there. He considered *P. ostreatus*, but not *P. djamor* in any of its forms. There is probably some confusion, because he described a spore print "branco a creme até cinza," which might involve the two species. Murrill (1916) discussed 9 species for North America (Mexico was not considered) but all of them as *Crepidotus*, and among them *C. ostreatus, C. cornucopiae*, and *C. serotinus*. He also discussed 8 doubtful species, such as *Pleurotus salignus*. Imazeki and Hongo (1983) and Imazeki et al. (1988) considered only four species: *P. cornucopiae* var. *citrinopileatus, P. cystidiosus, P. ostreatus* (= *P. pulmonarius*), and *P. salmoneostramineus* from Japan. Cleland (1934–1935) reported 7 species from Australia, all of them Australian species, except his "*P. ostreatus*." Hilber, in (1989) revising the mushrooms considered as *Pleurotus*, found that 17 belong to

other genera independent of Pleurotaceae, such as *P. tuber-regium* that according to Pegler (1983b) is *Lentinus*. Recently, Petersen et al. (1999) considered 15 species of *Pleurotus*, 8 of which require further study.

According to Hawksworth et al. (1995) there are approximately 50 valid species in the genus *Pleurotus;* nevertheless, more than 1000 names have been proposed in the genus since more than two centuries ago (e.g., Saccardo, 1882–1931). However, of the 71 species discussed in the present article (Table 2), approximately 24 are valid. Then, considering that no complete modern revision of the genus *Pleurotus* exists, there is considerable confusion on the status of several species. Singer's great book (1986) on Agaricales, considered one of the most complete on the subject, did not consider *P. djamor* but *P. flabellatus*, a well-known synonym of that species, was considered in the same section as *P. ostreatus* with a monomitic system, and *P. ostreatoroseus* (another synonym of *P. djamor*) is in a section with a dimitic system. These examples show how confusing are the taxonomy and nomenclature of the genus *Pleurotus* at present.

The main species in the genus frequently discussed in the bibliography or cultured in the laboratory or in commercial factories, other than *P. ostreatus*, are *P. abalonus*, *P. citrinopileatus*, *P. columbinus*, *P. cornucopiae*, *P. cystidiosus*, *P. djamor* (as *P. flabellatus*), *P. dryinus*, *P. eryngii*, *P. levis*, *P. opuntiae*, *P. pulmonarius* (as "*P. florida*"), and "*P. sajor-caju*," among others. *P. ostreatus* seems the most studied, but at the same time the most difficult to classify because of its broad distribution and variation. As example, Singer (1956) stated that the *P. ostreatus* complex at the tropics presents a white and thin pileus and pale drab or almost white spore prints, which agree with the description of *P. djamor* (Guzmán et al., 1993b)! Even when the author showed to Singer the type of *P. smithii* in a fresh basidioma growing in its habitat at Mexico City, in 1974 (Fig. 1), Singer stated he was sure it was *P. ostreatus*, however *P. smithii* presents a scaly pileus never observed in *P. ostreatus*, in addition to other microscopic differences and the color of the spore print. Smith (1978) concluded that in *P. ostreatus* there are many variants, "or closely related taxa?" He recorded a whitish variant of *P. ostreatus* in the

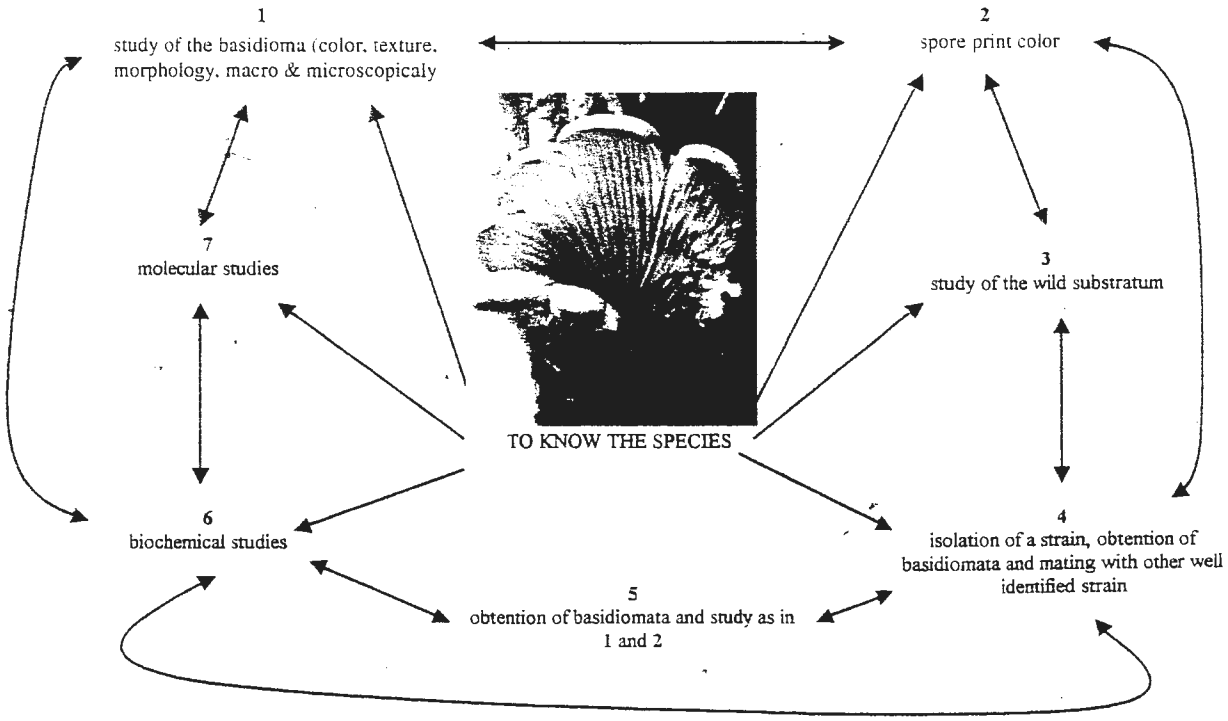

FIGURE 1. The most convenient method to fully understand the species of a *Pleurotus* (in the figure, the type of *P. smithii* in its habitat).

United States. However, the author–on a field trip in Michigan with Dr. Smith in the summer of 1965–found this white form that corresponded well with *P. pulmonarius*.

DISCUSSIONS ON SOME SPECIES

For *P. abalonus* see the later discussion of *P. cystidiosus*. *P. columbinus* is frequently considered in the literature as a variety of *P. ostreatus* (Pilát, 1935; Eger et al., 1979; Hilber, 1982, 1989, 1997; Watling and Gregory, 1989; Buchanan, 1993; Petersen et al., 1999) or a synonym of *P. ostreatus* (Bas, 1990). Kühner and Romagnesi (1953) and Moser (1983) considered it as an independent species, based on the blue pileus. For Guzmán et al. (1994) it is a valid species, based in the negative interbreeding between strains of *P. ostreatus* and *P. columbinus*, all of them from Europe (one of *P. ostreatus* from the United States); these strains were identified through the basidiomata obtained from them. *P. columbinus* is defined by its bluish deep or blue-gray tones in the pileus, colors not found in *P. ostreatus*. *P. catephes* is a poorly known species, not considered by several authors, for example, Singer (1949, 1962, 1975, 1986), Pegler (1983a,b, 1986), and Buchanan (1993). It was reported by Dennis (1953, 1970) from Trinidad (Caribbean region) and Guzmán (1983) from Mexico (Península of Yucatan). For Pegler (1977a) it is close to *P. opuntiae*, but differs in the structure of the distant lamellae.

P. citrinopileatus is known only from eastern Asia (Singer, 1943; Ohira, 1990). It is a very popular mushroom among the commercial cultures (Stamets, 1993). Petersen and Krisai-Greilhuber (1999) and Petersen et al. (1999) considered this species a variant of the European species *P. cornucopiae*, based on Ohira (1990) who showed fertility between strains of both species, in spite of the fact that the basidioma of both are different in color, yellow in *P. citrinopileatus*, whitish in the latter. Ohira (1990) named the species *P. cornucopiae* var. *citrinopileatus*. Parmasto (1987), who considered *P. citrinopileatus* an excellent edible mushroom, discussed the differentiation with *P. cornucopiae* on the basis of smell, which is like fish in the first and anise in the latter, as well as the different sizes of the spores. *P. cornucopiae* was recently discussed by Petersen and Krisai-Greilhuber (1999) in selection of the epitype from Austria. The species has a depressed to infundibuliform, cream-ocher to grayish ocher pileus, eccentric stipe, pinkish violet spore print, and a monomitic hyphal system. Blaich (1976) distinguished *P. cornucopiae* using electrophoretogram analysis of enzymes. Hilber's (1982) strains of *P. cornucopiae* sometimes produces an evanescent veil, as noted by Petersen and Krisai-Greilhuber (1999) in *P. levis* under culture. Also Sobal et al. (1997) observed a veil in the basidiomata of *Lentinus levis* developed in the laboratory. *Pleurotus cornucopiae* sensu Guzmán (Guzmán, 1977a) seems to belong to another species, as discussed in the following.

P. calyptratus is another European species, with a well developed veil and dimitic hyphal system. Recently Sokól and Szczepka (1995) described this species. Singer (1986) considered *P. calyptratus* the only representative of the subgenus *Calyptrati*. The species was considered by Singer (1943) in *Tectella*. Petersen et al. (1999) discussed that *P. calyptratus* presents nematostatic microdroplets, such as those observed in other species of *Pleurotus*.

P. cystidiosus was described from the Untied States (Miller, 1969), and then reported from Africa (Morocco) in its anamorph state (Pollack and Miller, 1976). *P. corticatus* sensu Kaufert (1936) is a synonym of Miller's species. A good photograph of *P. corticatus* sensu Kaufert by Pilát (1930) represents a probable *P. cystidiosus*, although *P. corticatus* s. str. seems conspecific with *P. dryinus* according to Singer (1986). At present, *P. cystidiosus* is known in the southeastern United States, Europe, Africa, India, Taiwan, Indonesia, Java, and Brazil (Han et al., 1974; Jong and Peng, 1975; Moore, 1985; Stalpers et al., 1991; Zervakis et al., 1992; Moncalvo, 1995; Capelari, 1999). Capelari (1999) reported *P. cystidiosus* from Brazil in both its anamorphic state, *Antromycopsis macrocarpa*, and the basidioma, which was not preserved. Moncalvo (1995) described a new variety of the teleomorph: *P. cystidiosus* var. *formosensis*, close to *P. smithii* according to him, based on differences found in the basidioma, color of the spore print, and in DNA studies. It is interesting to observe that this Asiatic mushroom is closer to the Mexican and South American species than

to the North American and pantropical species *P. cystidiosus*. *P. smithii*, which differs from *P. cystidiosus* in the pleurocystidia, is known from Mexico and Peru (Guzmán, 1975; Guzmán et al., 1980), Cuba (Rodríguez and Camino, 1990) and Argentina (Spinedi, 1995), in both perfect and anamorph states in all the reports. *P. smithii* was not considered by Petersen et al. (1999). Hilber (1997) considered *P. smithii* (with its anamorph state) as a synonym of *P. cystidiosus* subsp. *cystidiosus*, but he did not consider Mexico or South America in the distribution of this mushroom where *P. smithii* is common. *P. abalonus* is a mushroom from Japan and Taiwan, closely related to *P. cystidiosus* and *P. smithii*. It differs in the size of spores, up to 14 µm, long vs. up to 18–20 or 17–18 µm in *P. cystidiosus* and *P. smithii*, respectively, and in addition it does not have pleurocystidia (Han et al., 1974; Neda and Forukawa, 1987). However, Singer and Hilber (1977) considered *P. abalonus* related to *P. cystidiosus*. For Imazeki and Hongo (1983), *P. abalonus* is a synonym of *P. cystidiosus*, but Imazeki et al. (1988) did not consider both species. Zervakis (1998) and Zervakis et al. (1994) found that *P. abalonus* and *P. cystidiosus* are not compatible. Recently, Reid et al. (1998) described *P. fuscosquamulosus* from South Africa, which it is very close to *P. cystidiosum*, *P. smithii*, and *P. abalonus*. Reid and co-workers discussed that the South African species differs from those species mainly in the cheilocystidia and also in the color of the basidioma in *P. abalonus*, but they presented an interesting interbreeding test among these species. *P. fuscosquamulosus* is not compatible with *P. cystidiosus* and *P. smithii*, using strains from the Miller collection and the American Type Culture Collection (ATCC), respectively. However, it presented 100% of compatibility with a strain of *P. cystidiosus* from the ATCC (!). The Miller strains of *P. cystidiosus* and *P. smithii* were 17.5% compatible, and a strain of *P. cystidiosus* from Taiwan was 5% compatible with *P. fuscosquamulosus*. These observations of Reid and co-workers show how important it is to take care in conclusions based only on interbreeding tests. Petersen et al. (1999) did not consider *P. fuscosquamulosus*.

P. djamor is the most important species in the tropics and subtropics, and as discussed by Guzmán et al. (1993b), was known as *P. flabellatus*. Hilber (1997) named this mushroom *P. ëous* with *P. flabellatus*, *P. salmoneostramineus*, and *P. ostreatoroseus* as synonyms, but he did not consider the name *P. djamor* (!). Pegler (1976) considered *P. ëous* from India, with pink basidioma. *P. eusmus* is another species, of doubtful taxonomic position, related to *P. ostreatus* (Singer, 1962) or to *P. columbinus* (Hilber, 1989). *P. djamor* is the valid name for *P. ëous*, although often confused with *P. ostreatus*, as the "tropical form of *P. ostreatus*" of Singer (1956). All the native strains reported by Martínez-Carrera (e.g., Martínez-Carrera and Morales, 1988) as *P. ostreatus* are *P. djamor*. Even the pink form considered by Corner (1981) as *P. djamor* var. *roseus* is *P. djamor* var. *djamor* because of the interbreeding among them (Guzmán et al., 1993b). Also, *P. ostreatoroseus* considered by Bononi et al. (1991) and Cedano et al. (1993) from Brazil and Mexico, respectively, is *P. djamor* var. *djamor* (Guzmán et al., 1993b). *P. djamor* is a pantropical mushroom (Pegler, 1977a,b, 1983a, 1986; Nicholl, 1996), but it also reaches New Zealand (Petersen and Hughes, 1999), where Petersen (1995a,b) and Petersen and Ridley (1996) reported it as *P. opuntiae*. However, Nicholl (1996) found that the New Zealand strains are compatible with those Mexican strains identified as *P. djamor*. The reports of *P. flabellatus* by Pegler (1977a,b, 1983a) from India, Africa, and Antilles, respectively, belong to *P. djamor*, according to Pegler (1986). Nicholl (1996) and Petersen (1995a) divided *P. djamor* into three variants according to the color of the pileus: (1) whitish, tan to pale, (2) grayish, and (3) pink, but all intercompatible among themselves. Indeed, *P. djamor* presents a great variation in the color of the basidioma, as observed by Guzmán et al. (1993b), depending on the light of the habitat; the pink forms are from the forests and the whitish forms are from open areas, contrary to the opinion of Petersen and Hughes (1999) and Nicholl (1996), who stated that substrates or edaphic factors may maintain the natural variation. Concerning the distribution of *P. djamor*, Vilgalys and Sun (1994b) found spores of this tropical mushroom in Switzerland, China, Hawaii, and Canada by a spore trapping method in selected strains of *Pleurotus*. To find spores of *P. djamor* in Hawaii or China seems no surprise, because the first place is tropical and the second has a broad tropical and sub-

tropical zone in the south. But to find spores of *P. djamor* in Switzerland and Canada is surprising, and perhaps an error. Probably the finding in Switzerland is due to spores of *P. opuntiae* from the Mediterrean region, where it is common, and on the other hand, *P. djamor* and *P. opuntiae* are two closely related species, as will be discussed. Other questions will focus on the authenticity of the identification of the strains. *P. lutealbus* from Africa (Pegler, 1972, 1977a) is closely related to *P. djamor*; it presents yellowish to whitish pileus and pleurocystidia. It is interesting to observe that *P. djamor* from Cuba is unknown although it is surely a common mushroom there. Kreisel (1971) reported only from Cuba *P. hirtus* and *P. concavus* (see later), and Pegler (1988) reported only *P. flavolanatus*; however, Pegler (1983a) did not consider *P. flavolanatus* from the Antilles. Even Singer (1986) did not consider it.

P. dryinus is a good temperate species, distinguished by its veil. *P. corticatus* s. str. is considered by Singer (1986) and Käärik (1992), among others, as a synonym of *P. dryinus*, although *P. dryinus* in Mexico seems a complex as will be discussed. *P. elongatipes* described by Peck from the eastern United States is not a well-known species. According to Redhead (1986) the correct name is *Hypsizygus tessullatus*. Singer (1986) recorded this taxon as *H. tessullatus* based on Singer and Kuthan (1980). *Pleurotus albellus* from the Antilles (Pegler, 1983a) seems a closely related species to *P. elongatipes*, for the well-developed stipe and white basidioma. Indeed a careful study is necessary in these mushrooms.

P. hirtus is a neotropical complex. It is known from South America (Singer, 1956), Cuba (Kreisel, 1971), and Mexico (Guzmán, 1975). For Singer (1956) *P. hirtus* is composed of four species: *P. hirtus* s. str., *P. calvescens*, *P. concavus*, and *P. calyx*. All of them present white basidiomata. For Pegler (1983a) *P. hirtus* s. str. is a synonym of *Lentinus scleropus*; *P. calvescens* is a synonym of *L. striatulus*, and *P. concavus* is *L. concavus* (also for Corner, 1981), and *P. calyx* is a synonym of *L. patulus* (Pegler, 1983a). Of these names, *L. striatulus*, besides its synonym *P. calvescens*, also has the synonym *P. fockei* (Pegler, 1983a), but Pegler (1983b) considered this latter as a valid species, common in the Caribbean region and Brazil, and closely related to *P. concavus*, from which it differs in the large pileus and short stipe. Patouillard, according to Pegler (1983b), reported *P. fockei* as *Lentinus calvescens* from Martinique (see Table 2). Singer (1986) considered *P. fockei* as a valid species in the subgenus *Lentodiellum* together with *P. hirtus*, *P. concavus*, and *P. calyx*, among others. Recently, Dickson (personal communication) showed the author that Hedger is studying some specimens of *P. fockei* gathered in Cuyabeno, Ecuador in the postprogram of an expedition to Ecuador (Hedger et al., 1995).

P. levis seems a valid species, as discussed by Guzmán (1975), based on Singer (1962) and Farlow (1929). Singer (1986) also recognized this species. However, Pegler (1983b) stated that this mushroom is *Lentinus* following the position of Murrill (1915). *P. laciniato-crenatus* is known only from Argentina (Singer, 1950), where it seems common (Guzmán, 1977b). It is a not a well-known species as its hyphal system is unknown (Singer, 1986). It is an edible mushroom, cultured in that country, although Blumenfeld (1994) did not consider this species. *P. opuntiae* is another species with whitish basidioma and whitish spore print, and sometimes an indeterminate species (Hilber, 1982, 1997). It was described from Algeria on *Opuntia* (Cactaceae) and it has a broad distribution in the Mediterrean region on this plant, and on *Agave* and *Yucca* (Amarilidaceae) and on *Phytolacca* (Phytolaccaceae) (Pilát, 1935; Kühner and Romagnesi, 1953). Dennis (1970) recorded the species from Venezuela. Pegler (1977a) reported *P. opuntiae* from Kenya and Naivasha (both in eastern Africa) with the same lecythiform cheilocystidia as those observed in the Venezuelan material by Dennis (1970) and in *P. catephes* (Pegler, 1977a). García-Rollán (1998) in Spain considered this species good for commercial culture. *P. yuccae* described on a stem of *Yucca* is a synonym (Pilát, 1935). The reports of *P. opuntiae* from Mexico (Tlaxcala) and New Zealand (Petersen, 1995a,b; Petersen and Krisai-Greilhuber, 1999) are confused. These authors considered a fungus identified first as *P. agaves*, and then as *P. opuntiae*. However, Nicholl (1996), as discussed, observed that the New Zealand strains are compatible with *P. djamor*, but not with those from Mexico as *P. agaves* (*P. agaves* "is much smaller"; Petersen, personal communication) or *P. opuntiae*. *P. agaves* described on leaves of *Agave* by

Dennis (1970) from Venezuela is a related and poorly known species in this interesting complex. The Mexican mushroom of Petersen seems to be *P. cornucopiae* s. Guzmán (1977a), also reported on *Agave* leaves, as Petersen found those materials from Mexico. Even Petersen (personal communication, 1997) considered first his Mexican material as *P. cornucopiae*, but after a mating test it checked with *P. pulmonarius*. He observed also that this Mexican material was selling in a popular market at Tlaxcala city, as Guzmán (1977a, 1997) observed with *P. cornucopiae* in several popular markets of Mexico. As the plants *Opuntia* and *Agave* are of Mexican origin, the distribution of *P. opuntiae* is obviously in Mexico. Nevertheless the species has not been well defined because the reports from Mexico (e.g., Estrada-Torres and Aroche, 1987; Petersen and Krisai-Greilhuber, 1999) need to be confirmed. Petersen and Krisai-Greilhuber (1999) stated that an epitype is needed. Guzmán (1977a) did not consider *P. opuntiae* in spite of the seven widely distributed species of *Pleurotus* reported from Mexico, but *P. cornucopiae* considered by him is strongly related. *P. opuntiae* is close to *P. djamor*, even Corner (1981) assumed close relationships between them. Indeed, a careful morphological, genetic, and biochemical study on this complex and even on *P. levis* observed also in Mexico on *Agave* leaves is necessary to define these species.

Regarding *P. pulmonarius*, it had been confused with *P. ostreatus* several times; as Eger et al. (1979) stated that *P. pulmonarius* is a temperate tolerant of *P. ostreatus*. However, Hilber (1982), Bresinsky et al. (1987), Cailleux and Joly (1993a, b); Petersen and Hughes (1993), Vilgalys et al. (1993), Zervakis et al. (1994), and Petersen and Ridley (1996) separated *P. ostreatus* from *P. pulmonarius* based on their incompatibility and morphological characteristics. Petersen et al. (1999) separated in their key these two species by the different colors of the pileus and by the season when they develop their basiomata, winter for *P. ostreatus* and spring and summer for the latter, in spite of the fact that Petersen claimed several times that the mating tests are the most important means of identification in *Pleurotus*, as discussed later. Bunyard et al. (1996) separated both species on the basis of DNA studies. Bresinsky et al. (1976) interbred strains of *P. pulmonarius* with *P. columbinus*, *P. ostreatus*, and *P. cornucopiae*, and described negative results. They distinguished *P. pulmonarius* for its whitish to brownish pale basidioma, *P. ostreatus* for its brown dark to pale pileus, and *P. columbinus* in its grayish blue pileus. Romagnesi (1969) separated *P. ostreatus* from *P. pulmonarius* and *P. cornucopiae* in the color of the spore print and the size of the spores, besides the hyphal system. *P. ostreatus* var. *florida* nomen nudum, also known as "*P. florida*," was proposed by Li and Eger (1979) from a strain isolated in Florida (United States). This name was never published following nomenclature and taxonomic rules, but unfortunately it created great confusion, because several commercial strains were used in cultures in tropical countries, such as those reported by Go et al. (1981), Khanna and Garcha (1981a,b), Rajarathnam and Bano (1991), Buswell and Chang (1993), Mittar et al. (1993), and Peberdy et al. (1993). Eger's fungus is a synonym of *P. pulmonarius* (Bresinsky et al., 1976; Hilber, 1982; Singer, 1986; Singer and Harris, 1987; Watling and Gregory, 1989; Guzmán et al., 1994). Guzmán et al. (1994) obtained basidiomata of *P. pulmonarius* from a strain of Eger deposited in Mexico by Zadrazil through Martínez-Carrera (Martínez-Carrera et al., 1988a,b). Moreover, the confusion on Eger's mushroom was more complicated, because Stamets and Chilton (1983) erroneously reported this mushroom as *P. floridanus*, which is an absolutely independent species described by Singer (1986). *Pleurotus pulmonarius* presents white to whitish or gray pileus, white spore print, and a monomitic hyphal system. Moreover, *P. pulmonarius* is common in summer and *P. ostreatus* in winter, as observed Cailleux and Joly (1993b) and Petersen et al. (1999). Guzmán et al. (1994) found that a Cuban strain identified as *P. columbinus* (IE-136), obtained from a Czechoslovakian institution, that produces blue basidiomata, is compatible with the Zadrazil strain. This shows how problematic it is to base the taxonomic decisions only on the interbreeding. *P. pulmonarius* is common in the Mediterranean region and in the eastern United States as stated previously and observed by Singer and Harris (1987) and Guzmán (1996).

P. sapidus seems conspecific with *P. ostreatus* (Hilber, 1982; Zervakis et al., 1994) or with *P. pulmonarius* (Zervakis and Balis, 1995). However, for some authors (e.g., Peberdy et al., 1993) it is a valid species. Buchanan (1993) considered *P. sapidus* conspecific with *P. cornucopiae*. *Pleurotus sajor-caju* is a southern Asiatic and African species, with a well-developed annulus at the apex of the stipe, and considered by Pegler (1969, 1977a, 1983b, 1986) in *Lentinus*. However, the cultivated commercial strains of *P. sajor-caju* in Europe, Asia, and the United States belong to *P. ostreatus* or *P. pulmonarius*, based on the basidiomata obtained (Guzmán et al., 1994; Pegler et al., 1999). *P. sajor-caju* is known among the commercial edible mushroom products as "gray oyster mushroom" or "phoenix-tail mushroom." Those strains of Chang and Hayes (1978), Nair and Kaul (1980), Hilber (1982, 1989), Mueller and Gawley (1983), Quimio (1986), Martínez-Carrera et al. (1988a,b), Chang and Miles (1989), Okwujiako (1990), Aslan-Azizi et al. (1990), Zervakis and Labarère (1992), Yoo and Cha (1993), Chang (1993), Chang et al. (1993a,b) and Gibriel et al. (1996) surely belong to *P. ostreatus* or *P. pulmonarius* for the flaveliform, not infundibuliform basidiommata developed and without annulus. The strains of "*P. sajor-caju*" in Mexico (IE-44 or INIREB-49) used by Martínez-Carrera et al. (1988a,b) developed *P. ostreatus* basidiomata (Guzmán et al., 1994). The basidiomata obtained by Mueller and Gawley (1983) agree with *P. ostreatus* or *P. pulmonarius*. Kurtzman and Zadrazil (1982) stated that the strains ITCCF 1725 and ATTC 32978 identified as *P. sajor-caju* and cultured in Asia produce excellent mushrooms both in flavor and in texture, unlike *P. sajor-caju*. Smith (1993) reported strains of *P. sajor-caju* in the International Mycological Institute at Kew without any information. A good color figure of the basidiomatae of *P. sajor-caju* is found in Pegler (1972). Hilber (1989) assumed that those reports of *P. sajor-caju* with synnema stage (Nair and Kaul, 1980) belonged to *P. cystidiosus*. From another point of view, Zadrazil and Kurtzman (1982) and Roxon and Jong (1977) considered *P. sajor-caju* as a valid species of *Pleurotus*, but Zervakis et al. (1994) found that the strains of *P. sajor-caju* form with *P. pulmonarius* a tight cluster indicative of a genetic affinity. For Chang (1991) the commercial cultures of *P. sajor-caju* belong to the complex *P. ostreatus*. Petersen et al. (1999) observed that *P. sajor-caju* is a misidentification of *P. pulmonarius*.

P. tuber-regium considered by Singer (1949, 1962, 1975, 1986) belongs to *Lentinus* according to Pegler (1972, 1977a, 1983b, 1986) and Watling (1991, 1998), or to a *Panus* according to Corner (1981). This mushroom, in fact, presents a cinnamon brown pileus and stipe (Pegler, 1972; Watling, 1998) not common in *Pleurotus*, and its anamorph state is known as *Pachyma* (Singer, 1986). It is known from Africa and Asia, and distinguished by its large buried sclerotium up to 20–30 cm long. Recently, in a molecular study Neda and Nakai (1995) found that *P. tuber-regium* is distantly related to *Lentinus* and *Panus*, and they concluded that this mushroom belongs to *Pleurotus*. However, Petersen et al. (1999) pointed out that microdroplets were found in cultures of this fungus (Hibbett and Thorn, 1994), which are typical for *Pleurotus*.

P. serotinus is *Panellus serotinus* according to Singer (1949, 1962, 1975, 1986) or *Sarcomyxa serotina* according to Horak (1968), although it was considered in the bibliography as *Pleurotus* (e.g., Rea, 1922) or as *Crepidotus* (e.g., by Murrill, 1916). Another indeterminate confused species reported in the bibliography is *P. komarnitzkyi*, considered by Hilber (1982) as having uncertain taxonomic position, but for Singer (1986) it is probably a *Clitocybe*. Hilber (1997) considered this a valid species from Asia. *P. spodoleucus* is another not well known species, sometimes considered as a synonym of *P. ostreatus* (Imazeki and Hongo, 1983). Singer (1943) considered it a valid species, but Singer (1986) did not consider this species. A genetic study on this mushroom was made by Yoo and Cha (1993). May and Royse (1988) and Magae and co-workers in 1990 (in Buchanan, 1993, who considered this name as *P. ostreatus*) studied the enzymes of this mushroom. Benjamin (1995) reported some medicinal properties of this species. *P. dubius* is a not well known species. It was considered by Reid (1962) from New Zealand based on *Stereum dubium* described by Lloyd in 1925. But this mushroom probably belongs to another genus (*Hohenbuehelia*?), because it presents cystidia with

thick walls and subglobose spores. *P. subareolatus* is another poorly known species, described from the eastern United States. According to Anderson et al. (1973) and Groves (1962) it is close to *P. ostreatus*, but the spore print is white. Probably it is *P. pulmonarius*.

NEW METHODS AND PROBLEMS IN THE IDENTIFICATION OF THE SPECIES OF *PLEUROTUS*

Modern methods based on genetic and biochemical studies seem to be overemphasized. Moreover, the authors who follow them claimed that the morphological taxonomic features have been found insufficient in *Pleurotus*. Buchanan (1993) stated that macroscopic features in isolation are not very useful to support taxonomic conclusions and the commercial strains may carry ambiguous or incorrect names. Petersen (1995b) claimed that some taxonomic conclusions based on enzyme studies on *Pleurotus* are inexact, because they did not include interbreeding experiments, such as those of May and Royse (1988) and Zervakis et al. (1994), in which even *P. sajor-caju* is considered a valid species, even though this is an erroneous name for some strains of *P. ostreatus* or *P. pulmonarius*. Many modern authors (e.g., Vilgalys et al., 1993; Eger et al., 1979) claimed that the macroscopic and microscopic characteristics are unreliable for classification in *Pleurotus* (e.g., in the *P. ostreatus* complex). However, Vilgalys et al. (1993) distinguished three groups of *P. ostreatus* in the United States: (1) *P. ostreatus* s. str. with lilac-gray to purplish vinaceous spore print in the east, even in Florida [where Li and Eger (1979) described their "*Pleurotus florida*," actually contaxic with *P. pulmonarius* or *P. ostreatus*, according to the strains], and also from California and Arizona; (2) *P. pulmonarius* from the northern states and also from California and Arizona, with a white, yellowish, buff to lavender gray spore print and with a distinctive coloration in the basidioma, contrary to the European interpretations, which reported this species as whitish, lacking darker pigments; and (3) a new species, named *P. populinus* from the northern states with whitish, not lilac spore print. They did not submit information on other features and also the hyphal system in any of the three species. Concerning use of only interbreeding as a method, Petersen and Ridley (1996) showed that a strain from New Zealand named *P. pulmonarius*, is compatible with *P. ostreatus*, *P. eryngii*, *P. populnus*, *P. pulmonarius*, and *P. abieticola*, but not with *P. djamor* from Mexico. More recently, Petersen and Hughes (1997) stated that *P. abieticola*, described from Russia, has negative interbreeding with all the species cited above. The observations of Reid et al. (1998) on *P. fuscosquamulosus*, that this species is compatible or not (0% or 100%) with *P. cystidiosus* according to the origin of the strain, showed also, together with the Vilgalys and Petersen observations discussed above, how confusing the taxonomy of *Pleurotus* is when based only in interbreeding tests!

The modern concept of the species of the genus *Pleurotus* needs to deal with morphological features, such as form of basidioma, type of surface of the pileus and stipe, and color of all the parts, including the spore print and the type of hyphal system, besides biochemical and molecular data, and interbreeding. It is necessary to revise the status of several species, and then the number of species of *Pleurotus*. Petersen (1995b) and Petersen et al. (1999) claimed that it is necessary to make a contraction, but if we base the contraction of the species only on mating tests (as several authors claimed in other mushrooms, e.g., Boidin, 1986) or on biochemical or molecular studies, we can make taxonomic mistakes. Certainly, the interbreeding and biochemical studies play an important role, but not the only one. Indeed the problem is complex, because first we need to have an exact concept of the species, as Petersen and Krisai-Greilhuber (1996) presented for *P. ostreatus*.

The almost "common" taxonomic confusions on *Pleurotus* have opened the door to genetic (interbreeding), biochemical, and molecular studies (e.g., Eugenio and Anderson, 1968; Blaich, 1976; Eger, 1978; Raper, 1978; Volland-Nail et al., 1981; Hilber, 1982; Bresinsky et al., 1987; May and Royse, 1988; Royse and May, 1993; Vilgalys et al., 1993, 1996; Ogawa, 1993; Peberdy et al., 1993; Buchanan, 1993; Vilgalys and Sun, 1994a,b; Labarère and Iraçabal, 1995; Zervakis and Balis, 1995; Bunyard et al., 1996; Müller, 1997). The variation in the form and color of the

basidioma of *Pleurotus* in culture is so large that it often leads to wrong identifications or to inappropiate conclusions. It is known that *P. ostreatus, P. djamor, P. pulmonarius,* and others present in culture some features not typical in the wild basidioma, for example, the presence of long stipe, deformation in the basidioma similar to synnema, change in the color, etc., such as those observed by Zadrazil (1974, 1978), Desbiens et al. (1978), Zadrazil and Kurtzman (1982), and Guzmán et al. (1993a, 1994). The cultivated strains and interbreeding among them, and the biochemical and molecular studies in *Pleurotus,* without a careful taxonomic analysis, are creating an atmosphere of confusion on the taxonomy of the genus. Neda and Nakai (1995) and Petersen et al. (1999), for example, determined that *Pleurotus tuber-regium,* discussed previously as *Lentinus* or *Panus,* presents more affinities with *Pleurotus* than with those genera. Also Neda and Nakai (1995) showed that *P. ostreatus* and *P. pulmonarius,* two different species, are very close and they did the same with *P. abalonus* and *P. cystidiosus.* Zervakis and Balis (1995) discussed that *P. sajor-caju* is an Asiatic variety of *P. pulmonarius.* Bresinsky et al. (1987) determined that mating and fruiting are two important steps to be followed in the identification of *Pleurotus* and they claimed *P. ostreatus* plays an important role in the specialization of several species. However, with *P. cystidiosus* and others, Bresinsky et al. (1987) said that the "compatibility is reduced" (*P. ostreatus* and *P. cystidiosus* are two different species!). These authors stated that between *P. ostreatus* and *P. pulmonarius* genetic barriers were erected early in the separation of these fungi.

Regarding the species concept, it is generally accepted that species are not capable of interbreeding, or the hybrids between them are sterile or rarely formed in nature, as stated by Boidin (1986) and Raven in 1994 (in *Nature Conservation* **44**, taken from Petersen, 1995b) in several fungi. Bresinsky et al. (1976) claimed that the species concept should be based primarily on macro- and microscopical features, on macro- and microchemical characters, and on ecological observations. However, they observed that physiological and biochemical information would also be useful to understand the variation of the species. For Hilber (1982) and Boidin (1986) interbreeding tests are necessary to elucidate the species. Eger (1978) and Eger et al. (1979) established that the definitions of species, especially in the genus *Pleurotus,* are controversial. They based their concept only on interbreeding experiments and found that several different species are conspecific, but they used strains not so well identified, as stated by May and Royse (1988). Eger "described" *P. florida* or *P. ostreatus* var. *florida,* a very questionable name, as it was discussed. Vilgalys et al. (1996) wrote: "Mating compatibility studies and molecular phylogenetic analysis provide a useful framework for understanding species concepts and taxonomy of . . . *Pleurotus.*" They studied 15 groups associated with one or more morphological species, among them *P. agaves* from Mexico (a confused complex related to *P. cornucopiae* sensu Guzmán, as previously discussed) and others from New Zealand, Australasia, Brazil, and *P. levis,* this latter previously considered as *P. dryinus* in Vilgalys and Sun (1994a,b). After interbreeding and biochemistry studies in a strain from Quebec (Canada), Volland-Nail et al. (1981) could not define the species.

Petersen (1995b) rejected taxonomic analyses based only on morphological features. He stated: "Morphological characters of basidiomata are like the tip of an iceberg." However, later, in Petersen et al. (1999), he distinguished in a key 15 species of *Pleurotus,* based only on morphological and color features, even on the seasonal fruiting. It is necessary to be cautious also in those cases of hybridization by protoplast fusion. For example, Ogawa (1993) hybridized *P. cornucopiae* with *Lentinula edodes* and *Lyophyllum decastes* (Fr.) Sing.

It is certainly necessary to revise several described species and also to describe new species, on the basis of modern methodology. However, in this case a careful concept of a species has to be followed. Hawksworth (2000) commented on the concept of species according to Petersen and Hughes (1999), who stated that the species concept will be based on evolutionary and reproductive information, but they concluded that a species is what a good taxonomist recognizes; in other words, *a species depends on the investigator criteria.* Hawskworth observed well that these Petersen and Hughes ideas reflect the apocryphal concept of the species. This is absolutely true.

DESCRIPTION OF THE GENUS *PLEUROTUS* AND ITS TAXONOMIC POSITION

To define the limits of *Pleurotus*, the concept of the genus accepted in the present article is shown in Table 3. This concept is an adaptation of that of Fries (1821, 1838), Pegler (1977a, 1983a, 1986), Singer (1986), Batista-Pereira (1988), Hilber (1989, 1997), Bas (1990), and Kääarik (1992), among others. Both monomitic and dimitic hyphal systems are considered in the genus, and the context is fleshy or soft. No metuloids are present in the genus but pleurocystidia are common in some species (e.g., *P. cystidiosus*). The surface of the pileus is generally smooth, although scaly in some species (e.g., in *P. cystidiosus* and *P. smithii*), rarely viscid (e.g., in *P. viscidus*), or most frequently dry. The color of the spore print presents a wide variation from white, yellowish, gray, lilaceous to pink. The flavor is usually fungoid and pleasant, sometimes like fish or anise. *P. djamor* presents both odor and flavor that are farinaceous. Jong and Birmingham (1993) reported fragrant, sweet, and floral aromas for *P. euosmus;* slightly fragrant, mushroom, fruity, bitter cocoa, anise, almond, and yeast for *P. ostreatus;* and fragrant for *P. sapidus*.

However, for a correct identification of the species of *Pleurotus*, it is recommended to obtain a strain of the material and to obtain basidiomata and try interbreeding the strain with others from a well identified species to obtain fertile basidiomata and to study the development of these latter. Biochemical and molecular studies will be useful in this taxonomic study. But as shown in Table 4 and Fig. 1, it is very important to follow morphological and color features, genetic studies, and biochemical and molecular research. Furthermore, point 8 in Table 4 and Fig. 1 will be the most important in the taxonomic study of *Pleurotus*, but the identification should never be based exclusively on genetic, biochemical, or molecular studies, without the information of points 1 and 2.

Concerning the taxonomic position of *Pleurotus*, it is considered here as a member of the Family *Pleurotaceae*, together with *Lentinus* Fr., *Neolentinus* Redhead et Ginns, and *Lentinula* Earle in Order Poriales (or Polyporales). This position follows in part Singer (1986) and takes into consideration those observations by the author (in Guzmán et al., 1997) on *Lentinula*. This latter genus is considered by Pegler (1983c) as a member of the Tricholomataceae family in Tribe Collybieae in Agaricales, on the basis of the inflated hyphae of the context. However, as observed by Corner (1981) and Guzmán et al. (1997), those inflated

TABLE 3
Description of the Genus *Pleurotus*

Basidioma flabelliform or sometimes infundibuliform. **Pileus** white, whitish, yellow, brownish pale or dark, grayish brown, blue, grayish blue, pink or orange pink, dry or sometimes viscid or hygrophanous, smooth or scaly, or tomentose at the center. **Lamellae** decurrent, uniformly white, whitish, pink or orange-pink, with concolorous edge. **Stipe** absent or as lateral or eccentric, short or long, smooth, tomentose, or hirsute mainly at the base, solid. **Velum** and **ring** present in some species. **Context** fleshy or soft, white or whitish. **Odor** and **flavor** pleasant, fungoid, or farinaceous. **Spore print** white, yellowish, pink, grayish, lilaceous, lilac-gray, or pale vinaceous. **Spores** hyaline, cylindrical, thin walled. **Pleurocystidia** absent or present, never as metuloid. **Cheilocystidia** usually present, but not as metuloid. **Hyphal system** monomitic or dimitic, with inflated hyphae up to 25 µm wide. **Hymenophoral trama** subregular or irregular. **Pileal surface** undifferentiated. **Clamp connections** present. **Mycelia** white, with nematode-trapping structures. **Anamorph state** as synnemae with black globose heads and black spores. **Habitat** on living or dead deciduous plants (mainly trees), rarely on coniferous trees, growing also on several lignocelulolitic substrates.

TABLE 4
A Methodology to Identify the Species of *Pleurotus* (The numbers are in order of importance.)

1. A careful study of the basidioma (color of all the parts, texture, type of surface of the pileus, position and surface of stipe, presence of veil)
2. Color of the spore print in fresh
3. Wild substrate
4. Isolation of strains and their interbreeding with other strains
5. Obtaining fructifications (basidiomata) of the cultured mycelium
6. Biochemical studies
7. Molecular studies
8. A careful correlation of the above points

hyphae of *Lentinula* are like those observed in *Pleurotus*, but at the same time completely different of those of the Tribe Collybieae in the Tricholomataceous fungi, for example, *Collybia* (Fr.) Staude. *Collybia* presents the inflated hyphae with thin walls, 0.5–1 µm thick, while in *Pleurotus* and *Lentinula* the walls are 1–2 µm thick. In conclusion, there are not substantial differences between *Pleurotus* and *Lentinus* vs. *Lentinula* to consider these genera in different orders.

THE KNOWN SPECIES OF *PLEUROTUS* IN MEXICO AND THEIR CULTIVATION

There are 23 species and varieties of *Pleurotus* reported from Mexico (Table 5), of which only 7 seem to be valid taxa. Of these, Pegler (1983b) considered *P. hirtus* and *L. levis* as belonging to *Lentinus* (*L. scleropus* and *P. levis*, respectively). *P. hirtus* is common in the tropics, while *P. levis* is found in the subtropical humid forests and also in temperate forests (Guzmán, 1975). Recently, Sobal et al. (1997) developed in the laboratory basidiomata of this species with a veil only in the early stages. The report of Gándara (1930) for *P. eryngii*, without any information, seems to be a mistake, because this species is unknown in America. *P. bajocalifornicus* is known only in a desert from Baja California Peninsula (Moreno et al., 1993). The spore print was not recorded; it presents a monomitic system, collybioid habit, and no veil. For *P. catephes* see earlier. Concerning *P. elongatipes*, it was reported without any description from a tropical area of Mexico (Welden and Guzmán, 1978). A careful study of those materials of this mushroom is necessary at ENCB. This species seems related to *P. albellus* (Pegler, 1983a) from the Antilles. *P. cornucopiae* was reported by Guzmán (1977a) growing on the base of leaves of *Agave* (mainly *A. atrovirens* Karw.) in the central plateau of Mexico. This species seems to be the *P. opuntiae* sensu Petersen (Petersen and Krisai-Greilhuber, 1999) or *P. levis* according to Guzmán (1977a) as discussed. *P. floridanus* was reported by Herrera

TABLE 5
The Known Species of *Pleurotus* in Mexico (Only the first bibliographic reference of the taxon is presented in each case. Names in boldface are recognized species.)

P. agaves (Petersen and Ridley, 1996) (?*P. opuntiae*)
P. bajocalifornicus (Moreno et al., 1993) (only known from Baja California Peninsula)
P. catephes (Guzmán, 1983)
P. cornucopiae (Guzmán, 1977a) (confused with *P. opuntiae* and *P. levis*)
P. djamor var. ***djamor*** (Guzmán et al., 1993a)
P. djamor sensu Petersen and Hughes (1993) and Petersen and Ridley (1996): ?*P. opuntiae*
P. djamor var. *roseus* (Guzmán et al., 1993b) (*P. djamor* var. *djamor*)
P. djamor var. *salmoneostramineus* (Guzmán et al., 1993b) (*P. djamor* var. *djamor*)
P. dryinus (Guzmán, 1975; Valenzuela et al., 1981) (a complex species in Mexico)
P. elongatipes (Welden and Guzmán, 1978)
P. eryngii (Gándara, 1930) (an erroneous report?)
P. eugrammus (Welden and Guzmán, 1978) (*Nothopanus eugrammus*)
P. flabellatus (Welden and Guzmán, 1978) (conspecific with *P. djamor*)
P. floridanus (non *P. florida* s. auct.); ?*Hohenbuehelia* (Herrera, 1960 from Isla Socorro)
P. hirtus (Guzmán, 1975); *Lentinus scleropus*
P. hygrophanus (Guzmán, 1983) (*Nothopanus hygrophnus*)
P. levis (Guzmán, 1975); *Lentinus levis*
P. mexicanus (Guzmán and Johnston, 1974) (conspecific with *P. djamor* var. *djamor*)
P. opuntiae (Estrada-Torres and Aroche, 1987); still poorly known species related with *P. agaves, P. cornucopiae, P. djamor* and *P. levis*
P. ostreatoroseus (Welden and Guzmán, 1978) (*P. djamor* var. *djamor*)
P. ostreatus (Guzmán, 1977a) (unknown in the wild)
P. roseopileatus (Guzmán, 1977a) (*P. djamor* var. *djamor*)
P. smithii (Guzmán, 1975); anamorph: *Antromycopsis guzmanii* (*A. smithii*) (Guzmán et al., 1980; Stalpers et al., 1991)

(1960) from Isla Socorro (in the Pacific Ocean), with two good pictures, but without any description. It is necessary to check the herbarium material at MEXU of Herrera's specimens; but as discussed this Singer's mushroom may belong to *Hohenbuehelia*. This report is independent of those cultures referred to as *P. florida* s. auct. or erroneously named *P. floridanus* (see earlier). *P. smithii* (Guzmán, 1975; Guzmán et al., 1980, 1991; Mora et al., 1984) is fairly common in the temperate regions (e.g., Valley of Mexico City) and subtropical regions (e.g., Xalapa and Morelos). It has been observed as parasitic on trees: *Schinus molle* L., *Populus* spp., *Quercus* spp., and *Psidium guajava* L., although in Cuba (Rodríguez and Camino, 1990) it was reported from a *Ficus retusa* L. As discussed, *P. smithii* is close to *P. cystidiosus*, but different because of the pleurocystidia present in the latter, although no interbreeding between both species has been done. It is interesting to observe that *P. smithii* in culture frequently produces the synnematous phase (Guzmán et al., 1980; Spinedi, 1995). Mora et al. (1984) described the wild synnematous phase growing on the stipe of a wild basidioma, and Martínez-Carrera et al. (1991b) obtained basidiomata from a differentiation of small synnemata.

There is confusion regarding the presence of *P. ostreatus* in Mexico. It seems that all the reports of this species in Mexico (e.g., Guzmán, 1977a, 1983; Martínez-Carrera, 1984; Martínez-Carrera and Morales, 1988; Acosta-Urdapilleta et al., 1988, 1995; Bernabe-González and Garzón-Mayo, 1995; Herrera and Ulloa, 1998) belong to *P. djamor*, as observed by Guzmán et al. (1993b). Navarro et al. (1996) found that Mexican strains of *P. ostreatus* from Morelos were incompatible with strains from the United States and Germany. *P. djamor* is the "tropical form" or the "white form" of *P. ostreatus*, as discussed by Kaul and Kachroo (1970) in India, and considered by Singer (1956). *P. djamor* is the most important species in Mexico for its wide tropical and subtropical distribution (Guzmán et al., 1993b). *P. mexicanus* (Guzmán and Johnston, 1974) is conspecific with it; however, Guzmán et al. (1993b) reported a confused monomitic hyphal system in the not so well preserve type at ENCB. It is probably that this hyphal system is really dimitic. Herrera and Ulloa (1998) recorded *P. mexicanus*. These authors also recorded *P. cornucopiae*. *P. opuntiae* is a species not well known in Mexico. The record of Estrada-Torres and Aroche (1987) in Mexico needs revising, even that by Petersen and Krisai-Greilhuber (1999) gathered in Tlaxcala on *Agave* leaves. *P. opuntiae* sensu Petersen seems close to *P. cornucopiae* or *P. levis* (both sensu Guzmán, 1977a). *P. ostreatus* s. str., following Petersen and Krisai-Greilhuber (1996), is either unknown in Mexico or perhaps grows in coniferous and temperate forests in the north of the country. *P. dryinus* is known only in the northern and central states of Mexico (Guzmán, 1975; Valenzuela et al., 1981). It was recently reported by Nava and Valenzuela (1997) from the State of Mexico. The well-developed veil, as well as the size of spores, are the important features of this species. However, *P. dryinus* seems a complex, according to the size of spores, at least in Mexico, that is now in study by the author in collaboration with Valenzuela.

TABLE 6
Commercial Cultivated Species of *Pleurotus* in Mexico

P. citrinopileatus
P. columbinus
P. djamor var. *djamor*
P. djamor var. *salmoneostramineus* (*P. djamor* var. *djamor*)
P. djamor var. *roseus* (*P. djamor* var. *djamor*)
P. ostreatus
P. pulmonarius (*P. florida*)
P. sajor-caju s. auct. (*P. ostreatus*) (not *Lentinus sajor-caju*)

Concerning the commercial and/or experimental cultures on *Pleurotus* in Mexico, 8 taxa (Table 6) are the most commonly considered. Of these, *P. ostreatus*, *P. columbinus*, "*P. sajor-caju*," "*P. florida*," *P. pulmonarius*, and *P. djamor* (this latter with its typical and pink forms) are the most important, all of them are foreign strains (from the United States or European) (except for those of *P. djamor*). Nonetheless, only *P. ostreatus* is commercially cultivated using high technology by two or three important factories (Martínez-Carrera et al., 1991a). But many small companies cultivate *Pleurotus* in small mushroom farms. These cultures began in the region of Xalapa in the 1980s and now are spreading in many cities of

Mexico (Mata, 2000). They use mainly straw, but sometimes coffee pulp, sugar cane bagaze, tequila bagaze (from *Agave tequilana* L.), and other agriculture wastes (Martínez-Carrera, 1984; Martínez-Carrera et al., 1984, 1988b; Guzmán-Dávalos et al., 1987; Acosta-Urdapilleta et al., 1988; Guzmán-Dávalos and Soto-Velazco, 1989; Soto-Velazco et al., 1991a,b; Cedano et al., 1993; Guzmán et al., 1993a; Bernabe-González, and Garzón-Mayo, 1995; Mata and Gaitán-Hernández, 1995; Nieto-López and Sánchez, 1997). Aguilar et al. (1993) presented an interesting rural experiment, where a commercial farm for cultivating *P. ostreatus* was set up in an Indian region of Mexico (Cuetzalan and Puebla). Sobal et al. (1997) discussed the Mexican production of *Pleurotus* in Mexico, 356 tons in 1990 and 1825 tons in 1997, versus the world production of 909.000 tons in 1990 (Chang and Miles, 1991). The center of Xalapa (first as INIREB, and actually as Instituto de Ecología) was the first institution in Mexico to develop experimental cultures in a special mushroom house in 1983 (Martínez-Carrera, 1984; Martínez-Carrera et al., 1984, 1988a,b; Guzmán et al., 1993a; Lara-Herrera et al., 1998). The commercial strains of *P. sajor-caju* used frequently, as discussed, are *P. ostreatus* or *P. pulmonarius* according to the strains. *P. djamor* with its varieties (ecological forms, Guzmán et al., 1995) are from native Mexican strains, except the strains of *P. djamor* var. *salmoneostramineus*, which it seems is from Asia, also that of *P. citrinopileatus*. The commercial cultivation of *Pleurotus* in Mexico started in the 1970s (Martínez-Carrera et al., 1991a) with European strains of *P. ostreatus*. The commercial product was called "seta" (plural "setas," a Spanish name that means mushroom), and now this common name is the most used in the country for species of *Pleurotus*.

At present, the following Mexican institutions have research programs on the culture of *Pleurotus*: (1) Colegio de Posgraduados at Puebla, with Martínez-Carrera as head; (2) ECOSUR in Tapachula, Chiapas, with Sánchez as head; (3) Instituto de Botánica in the University of Guadalajara, with Soto-Velazco and Guzmán-Dávalos as the principals; (4) Instituto de Ecología in Xalapa, with Mata as head; (5) Instituto de Química in the University of Mexico with Leal-Lara as head; (6) University of Guerrero, in Chilpancingo, with Bernabe-González as head; and (7) University of Morelos in Cuernavaca, with Acosta-Urdapilleta as head (e.g., Guzmán-Dávalos et al., 1987, 1989; Acosta-Urdapilleta et al., 1988, 1995; Soto-Velazco et al., 1991a,b; Martínez-Carrera et al., 1991a,b; Ramírez-Carillo et al., 1991; Guzmán et al., 1993a; Mata and Gaitán-Hernández, 1995; Bernabe-González and Garzón-Mayo, 1995; Hernández-Ibarra et al., 1995; Leal-Lara in Paredes et al., 1996; Sánchez in López-Arevalo et al., 1996; Nieto-López and Sánchez, 1997). Some of the few chemical studies on *Pleurotus* developed in Mexico are those of Trigos and Martínez-Carrera (1992) and Trigos et al. (1994) and are based on the content of ergosterol.

TRADITIONAL MEDICINAL USES OF THE SPECIES OF *PLEUROTUS* AND TREATMENT OF ALLERGIES

Although they are very common in Mexico compared to other edible mushrooms (Guzmán, 1977a), all the species of *Pleurotus* have traditional edible and medicinal uses (Guzmán, 1994a,b, 1997). However, these mushrooms are so important in the country that there are almost 100 common names for these species (Guzmán, 1997), as shown in Table 7. Many of these names are related to the habitat, such as those of "hongo" (= mushroom) or "oreja" (= ear) "de cazahuate," ". . . de encino," ". . . de izote," ". . . de maguey," ". . . del café," ". . . del bagazo de la caña," which mean fungus of the tree *Ipomea* spp., of *Quercus* spp., of *Yucca* spp., of *Agave* spp., of the coffee pulp, and of sugar cane bagaze, respectively. Those common names together with the word "nanácatl," meaning mushroom, are indigenous from the Nahuatl language. The commercial name for the cultivated *Pleurotus* is seta, as previously discussed.

As for medicine, the species of *Pleurotus* are recommended in Mexico to reduce cholesterol levels; to fight diabetes, high blood presure, nervous disorders; to promote good memory; as an antiparasitic; for sexual dysfunction; for rejuvenation; as a laxative; to darken hair; and as an intestinal antiinflammatory and for intestinal ulcer. Small fragments of dry specimens and powder obtained from dry specimens are used. Capsules are even made with the powder (Guzmán, 1994a,b).

TABLE 7
Common Names of *Pleurotus* spp. in Mexico

Ahuananácatl
Cazahuananácatl
Cazahuate
Cazahuatem
Cuahuiztacnanácatl
Cuauhiztac
Cuauhzahuátic
Cuazahuananácatl
Cui moni
Chhó xuni
Chiltizcatl
Chilla nalhat
Hongo blanco
Hongo blanco de mayo
Hongo de cazahuate
Hongo de chonotl
Hongo de cocohuite
Hongo de encino
Hongo de izote
Hongo de jonote
Hongo de la paja
Hongo de la pulpa del café
Hongo de madroño
Hongo de maguey
Hongo de palo
Hongo de palo blanco
Hongo de palo mulato
Hongo de tejomite
Hongo de xonote
Hongo del bagazo
Hongo del bagazo de la caña de azúcar
Hongo del café
Hongo del madrecacao
Hongo del maguey
Hongo del naranjillo
Iawakamazlat
Iczonanágatl
Iztacnanácatl
Jetch
Jonacate
Kewaru kowaru
Kikíncne
Kju wada
Lawakamazlat
Magueyero
Malhat kiwi
Matomananácatl
Mazajielle de agua
Menanácatl
Mezonanácatl
Mezorras
Oreja
Oreja blanca
Oreja colorada
Oreja de burro
Oreja de cazahuate
Oreja de cazahuate rosa
Oreja de izote
Oreja de jonote
Oreja de maguey
Oreja de palo
Oreja de patancan
Oreja rosada
Orejas
Pechuga
Pechuga de maguey
Pleuroto
Pleurotus
Pobnec
Repollo
Riruchi
Sacita
Sacocox
Sakitah
Seta
Seta de cultivo
Sinche
Tasnara
Techalonanácatl
Tepetomananácatl
Tepetomananágatl
Tetecuin
Trompa de palo
Trompetitas de los palos
Tua tasnara
Utuxa yekua
Xinche
Xonanácatl
Xonocote
Xonocuahnanácatl
Xononanácatl
Xonotnanácatl
Xumpililomazlat
Yehyecañanágame
Yehyegannágame

Note: Nanácatl means mushroom in Indian; hongo (in Spanish) means mushroom; cazahuate is the common name of a tree; maguey is *Agave*; maguellero means that which grows on the leaves of *Agave;* oreja means ear; pechuga means breast; repollo means cabbage; seta means mushroom; xonote is a wild tree.

TABLE 8
Medicinal Properties of and Medical Conditions Treatable with *Pleurotus* spp. According to Diverse Bibliographic Sources (*See text.*)

Anticarcinogenic
Activator of cellular immune system
Antibacterial
Antibiotic
Antiinflammatory
Antitumoral
Antibacterial
Antiparasitic
Antifungal
Aphrodisiac (sexual power)
Arteriosclerosis (prevention)
Assist in recovering from fatigue
Asthma
Cardiovascular effects
Constipation
Cholesterol (reduce)
Cold
Darken hair
Diabetes
Diuretic
Fever
Gastrointestinal disorders
Good memory
Headache
Hematological effects
High blood pressure
Hyperlipidemia
Hypocholesterolemic activity
Hypotensive renal effects
Intestinal ulcer
Intestinal antiinflammatory
Nervous disorders
Rejuvenation
Renal effects
Sexual decadence
Stomach ache
Vigor (produce)

In other countries, several species of *Pleurotus* have been reported in traditional medicine or they are being explored extensively for their pharmaceutical utility (e.g., Buswell and Chang, 1993; Sani and Atri, 1999; Gunde-Cimerman, 1999; Wasser and Weis, 1999). In traditional medicine they are being used to prevent or assist in more than 30 diseases or disorders (Table 8). Regarding the medicinal properties reported in the bibliography, care is necessary when referring to the old books, because the identifications of the mushrooms can be erroneous. For example, the "phansomba" mushroom from India, which belongs to a *Phellinus*, was erroneously identified as *P. ostreatus* (unpublished notes of Vaidya in India). Stamets (1993) mentioned *P. citrinopileatus* that "potentially cures pulmonary emphysema" according to Chinese sources. Oso (1977), Singer (1986), Watling (1991, 1998), and Benjamin (1995) discussed the sclerotia of *P. tuber-regium* that are used by the native peoples in Africa as food and for diverse medicinal purposes, such as healing stomach ache, constipation, fever, and high blood pressure. It is interesting that Watling (1991) reported a sclerotia gathered in Cameroon (Africa) and sowed in the tropical greenhouse of the Botanic Garden at Edinburgh. Seven years later, Watling (1998) found basidiomata in the same sclerotia. Gunde-Cimerman (1999) and Wasser and Weis (1999) discussed the importance of *Pleurotus* spp. in medicine, their nutritional value, and their importance as a source of several substances of medical interest.

In reference to the anticancerous activity reported for *Pleurotus* by the above authors, Benjamin (1995) discussed, based on the bibliography, that *P. spodoleucus* possesses this activity. In *P. sajor-caju*, Tam and co-workers in 1986 (Saini and Atri, 1999) commented that an aqueous extract has been reported to reduce the rates of nephron deterioration in persons suffering from renal failure. Buswell and Chang (1993) recorded, based on Vogel and co-workers, Ikekawa and co-workers, Bobek and co-wokers, and Tam and co-wokers, antitumoral effects, hypocholesterol effects, and hypotensive activity of extracts of *P. ostreatus*. Chang and Miles (1989) pointed out the hematological effects and cardiovascular or hypotensive and renal effects of *P. ostreatus* and *P. sajor-caju*. Antibiotic effects and antitumoral effects were discussed by Cochran (1978).

The species of *Pleurotus* in farming incite an allergic reaction or picker's lung in some mush-

room house workers (Eger, 1978; Zadrazil, 1978; Zadrazil and Kurtzman, 1982; Chang and Miles, 1989; Mittar et al., 1993), as observed by the author in Mexico (Guzmán et al., 1993a). This allergy is produced by the large number of spores from the basidiomata, that sometimes form a mist of spores in the mushroom houses. Nevertheless, this adverse allergic reaction is not dangerous if persons who are working inside the houses change their activity for an external operation, for example, preparation of the substrate outside. The author himself observed that when a person is inside a mushroom house with plenty of basidiomata in production for a long period of time, headaches and other symptoms such as cold or respiratory disorders are present. The symptoms change, however, according to the individuals' sensitivities. Fatigue, mild headache, sinus pressure, coughing, mild difficulty in breathing, pain in the limbs and joints, and generalized malaise or ill feeling (influenzalike symptoms), even fever of 39–40°C, which disappeared without treatment, are common signs of the allergy produced by the spores of *Pleurotus* cultivated in commercial houses.[1]

Recently, the author came across the book by Ying et al. (1987) where important information on the medicinal properties of *P. ferulae, P. ostreatus, P. cornucopiae, P. spodoleucus, P. citrinopileatus,* and *P. ulmarius* is discussed. *P. ferulae* cures gastropathy and kills insects and worms. *P. ostreatus* cures lumbago and painful legs, numbed limbs, and discomfort in tendons and blood vessels. The water extract is used against sarcoma and Ehrlich carcinoma. *P. cornucopiae* is used also against sarcoma and Ehrlich carcinoma. Aqueous extract of *P. spodoleucus* was tested against the growth of sarcoma. *P. citrinopileatus* and *P. ulmarius* may cure pulmonary emphysema and *P. ulmarius* is also used against sarcoma and Ehrlich carcinoma.

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