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Antagonistic effectiveness of Macromycetes against *Candida albicans* strains and *Issatchenkia orientalis*

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Abstract

The trend to search novel natural antifungal compounds has recently been increasing. Interspecific interactions between 30 Macromycetes species and fungal pathogens (*Issatchenkia orientalis, Candida albicans* strains) have been evaluated using dual culture plate assay. Interaction reactions between studied fungi were different: deadlock after mycelia contact or at a distance, overgrowth without initial deadlock, partial or complete replacement after initial deadlock with contact. Domination of replacement (78.7 %) of pathogenic fungi by Macromycetes was established. Complete replacement was almost twice more frequent (30.7 %) than partial replacement (19.3 %). These results clearly indicate effectiveness of Macromycetes against pathogenic fungi via contact antagonism. Strong antagonistic activity with high antagonistic index (AI) was established by xylotrophic species *Ganoderma applanatum* (AI = 22.5), *Lentinula edodes* (AI = 21.0), *Flammulina velutipes*, *Irpiciporus litschaueri* and *Pleurotus ostreatus* (AI = 20.5), leaf litter decay fungus *Crinipellis schevczenkoi* (AI = 21), and soil saprotroph *Lyophyllum shimeji* (AI = 21).

Introduction

One of the major and global health care threat in dermatology, gynecology, and pediatrics continue to represent fungal infections. The most common fungal pathogen is *Candida albicans* that is the predominant cause of candidiasis. Such fungal infections can be subdivided into major groups: cutaneous (skin and its appendages), mucosal (oropharyngeal, esophageal, and vulvovaginal) and systemic (bloodstream infections, i.e., candidemia and other forms of invasive candidiasis) (Papon *et al*. 2013). AIDS and cancer patients as well as in transplant individuals are at high risk of candidiasis due to the immunosuppression.

In addition, frequently isolated non-albicans *Candida* species like *Issatchenkia orientalis* (formerly *Candida krusei*) have shown gradual emergence as a cause of invasive candidiasis (Samaranayake and Samaranayake 1994; Samaranayake *et al*. 2014) and also onychomycosis in patients with chronic mucocutaneous infections (Hossain and Ghannoum 2001).

Also of concern is the continued emergence of new facts of resistance to the existing commercial drugs.

At the same time, poor effect of some drugs and high possibility of candidiasis recurrence, as well as the toxicity of drugs of modern drug therapy, based on ketoconazole, emphasize the search for new effective antifungal agents with low bayside effect.

It is worth considering that interspecific fungal antagonism can be a powerful emerging tool in the development of mycoproducts (or biotech-products) against pathogenic fungi. The encouraging results of studies of the antifungal activity of Macromycetes against most pathogenic fungi have contributed to the growing interest in this problem. Numerous experiments have shown inhibition of the growth of *Candida* sp. under the influence of various species of Basidiomycetes: *Lentinula edodes* (Hirasawa *et al*. 1999; Hearst *et al*. 2009), *Agrocybe perfecta*, *Climacodon pulcherrimus*, *Oudemansiella canarii*, *Pycnoporus sanguineus* (Rosa *et al*. 2003), *Oudemansiella* spp. (Vahidi and Namjoyan 2004), *Laetiporus sulphureus* (Turkoglu *et al*. 2007; Petrović *et al*. 2014), *Coprinus cinereus* (Ndyetabura *et al*. 2010), *Agaricus brunnescens*, *Lactarius vellereus* (current name: *Lactifluus vellereus*), *Terfezia boudieri* (Dogăn *et al*. 2013), *Amanita muscaria*, *A. phalloides*, *Lactarius* spp., *L. densifolius*, *L. gymnocarpoides* (current name: *Lactifluus gymnocarpoides*), *Russula kivuensis* (Chelela *et al*. 2014), *Cantharellus cibarius* (Popova 2015), *Agaricus bisporus*, *Trametes gibbosa* (Waithaka *et al*. 2017), *Morchella esculenta*, *Verpa bohemica* (Shameem *et al*. 2017), *Entoloma speculum* (Kodiyalmath and Krishnappa 2018), *Pleurotus ostreatus* (Gutef *et al*. 2020). These examples show clearly the significant antifungal potential of fungi and testify the relevance and prospects of such investigations. Altogether, the knowledge and understanding of different mechanisms of biological, chemical, physical action, directly caused by the species interaction of fungi, reveals alternative ways of their use as natural biotechnological tools for ecological bioremediation, biologically control the pathogens of agricultural crops or forests and as biological helpers in healing serious diseases (Petre 2015).

The aim of our study was to investigate the interspecific interactions between Macromycetes species and *Saccharomycetaceae* fungi in dual-culture.

Experimental

Fungal species

Thirty macrofungi from different ecophysiological (wood decaying, saprotrophic, entomophilic, and leaf litter decaying) and taxonomic groups were screened (Table 1). All the mushroom species used in this study were kindly supplied by the Mushroom Culture Collection (IBK) of the M.G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine (Bisko *et al*. 2016). Stock cultures were maintained on beer-wort agar-agar slants at 4 ºC.

The *Issatchenkia orientalis* Kudryavtsev 301, *Candida albicans* (C.P. Robin) Berkhout 17/138 and clinical strains of *C. albicans* 311, 315, 319 were from the Culture Collection of Microorganisms of the Institute of Epidemiology and Infectious Diseases of the National Academy of Medical Sciences of Ukraine. Strains *C. albicans* 311, 315, 319 were isolated from people with different infections with undergone long-term antibiotics therapy and show resistance to antibiotic drugs (mainly to streptomycin, penicillin, oxacillin, ampicillin, some of them to amoxicillin and others). Stock cultures were maintained on potato-dextrose-agar (PDA) slants at 4 ºC.

All fungi were transferred from stored cultures to PDA Petri dishes and cultured at 26 ± 1 ºC to obtain mycelial colonies. Mycelial plugs 8-mm were cut from at the mycelial active growth stage using a sterile borer and used as inoculum in dual culture.

Dual-culture experiments

Macromycetes were screened for their ability to suppress the mycelial growth of *Saccharomyceta-ceae* fungi in vitro dual-culture plate assays on PDA by the method described by Badalyan *et al*. (2002; 2004). The antagonistic ability of each fungal organism was determined using a rating scale for the 3 main types of reactions (A, B, C) and 4 sub-types (C_{A1}, C_{B1}, C_{A2}, and C_{B2}). Types A and B were deadlock (mutual inhibition, in which

neither organism was able to overgrow the other) at mycelial contact (A), or at distance (B); type C replacement, overgrowth without initial deadlock. The intermediate sub-types scored were: C_{A1} partial and C_{A2} complete replacement after initial deadlock with mycelial contact; C_{B1} partial, and C_{B2} complete replacement after initial deadlock at a distance.

The following score was assigned to each type or sub-type of reaction: A = 1; B = 2; C = 3; C_{A1} = 3.5; C_{B1} = 4; C_{A2} = 4.5; C_{B2} = 5. The antagonism index (AI) was then calculated for each fungal species using the following formula (Eq. 1):

$$AI=A(nx1)+B(nx2)+C(nx3)+C_{A1}(nx3.5)+C_{B1}(nx4)+C_{A2}(nx4.5)+C_{B2}(nx5) \quad (1)$$

where n = frequency of each type or sub-type of reaction (Badalyan *et al.* 2002; 2004).

Saccharomycetaceae together with the macromycetes were incubated in the thermostat at 26 ºC. The growth of fungi was monitored daily for a month. The morphological changes (coloration of mycelia and agar, visualization of the demarcation line, producing of exudate drops, formation of dense zones of mycelium, fruiting body primordia etc.) in interacted colonies were noted. The type of interaction was recorded on the 30th day of the experiment.

All experiments were independently conducted in three replicates.

Results and Discussion

The interaction between fungi is quite broadly, engaging and important field of study. Of particular interest is the cause-effect relationship of biological and biochemical bases for immune and defense reactions of competing species. Different concepts have been used to characterize the Macromycetes interaction with other fungi in co-culture (Bruce and Highley 1991; Badalyan *et al*. 2002; 2004; Barinova *et al*. 2008; Owaid 2017; Pasaylyuk 2017). To our opinion, the determination of antagonistic ability according to the method of Badalyan *et al*. (2002; 2004) using a rating scale and calculation of an antagonistic index is more appropriated for the screening and evaluation of the antifungal potential of Macromycetes in solid medium. The interactions between all tested fungi were established. The results obtained at the process of growth in dual cultures are shown in Table 1 and some examples are illustrated in Fig. 1. Performed screening allowed easy to determine the most active fungus species with high antagonistic index (AI) from different ecological groups: xylotrophic species *G. applanatum* (AI = 22.5), *L. edodes* (AI = 21.0), *F. velutipes*, *I. litschaueri* and *P. ostreatus* (AI = 20.5), leaf litter decay fungus *C. schevczenkoi* (AI = 21), and soil saprotroph *L. shimeji* (AI = 21). Previous experiments also showed that xylotrophic fungi *P. ostreatus*, *F. velutipes*, *Ganoderma* sp. had the strongest competitive effect against mycoparasitic fungi (*Clonostachys rosea*, *Trichoderma harzianum*, *T. pseudokoningii*, and *T. viride*) (Badalyan *et al*. 2004). Moreover, it was found that *P. ostreatus* possessed strongest antagonistic activity against cereal pathogenic fungi (*Gaeumannomyces graminis* var. *tritici* (current name: *Gaeumannomyces tritici*), *Bipolaris sorokiniana*, *Fusarium culmorum*, *Rhizoctonia cerealis* (current name: *Ceratobasidium cereale*) (Badalyan *et al*. 2002).

Studied by us fungi produced a different variety of interaction reactions: deadlock after mycelial contact or at a distance, overgrowth without initial deadlock, partial or complete replacement after initial deadlock with contact (Fig. 2). However, domination of replacement (78.7 %) of pathogenic fungi by Macromycetes was established.

Furthermore, complete replacement was almost twice more frequent (30.7 %) than partial replacement (19.3 %). These results clearly indicate effectiveness of Macromycetes against pathogenic fungi via contact antagonism. This tendency is in line with observation of antagonistic activity of 17 species xylotrophic Basidiomycotina against pathogenic fungi (*Bipolaris sorokiniana*, *Fusarium culmorum*, *Gaeumannomyces graminis* var tritici, *Rhizoctonia cerealis*) (Badalyan *et al*. 2002). Probably different mechanisms affect species interactions. Generally, any type of antagonism (at mycelial or hyphal level) or parasitism is caused by production of different compounds such as ferments, toxins, antimycotic substances that are capable of volatility as well as able to the diffusion (Woodward and Boddy 2008). It is important to

remark that response of species interaction in certain model experimental conditions can change

Table 1. The interactions of studied fungi and their antagonism index (AI).

Fungi species	Strain	***I. orientalis***	***C. albicans strains***				**AI**
		301	17/ 138	311	315	319	
Auriporia aurea (Peck) Ryvarden	5048	C	C	C_{A1}	C	A	13.5
Coprinus comatus (O.F. Müll.) Pers.	137	C_{A2}	C_{A2}	C_{A1}*	C_{A1}	C_{A1}*	19.5
Cordyceps militaris (L.) Fr.	1862	C_{A1}	C_{A2}	C_{A1}*	C_{A1}	C_{A1}*	18.5
Crinipellis schevczenkoi Bukhalo	31	C	C_{A2}	C_{A2}	C_{A2}	C_{A2}	21.0
Cyclocybe aegerita (V. Brig.) Vizzini	1853	C	C	C_{A1}	C	C	15.5
Flammulina velutipes (Curtis) Singer	1878	C_{A2}	C_{A2}	C_{A2}*	C_{A1}	C_{A1}*	20.5
Fomes fomentarius (L.) Fr.	355	C_{A2}	C_{A2}	C_{A2}	C_{A2}	A*	19.0
Fomitopsis betulina (Bull.) B.K. Cui, M.L. Han &Y.C. Dai	327	C_{A2}	C	C_{A2}	C_{A2}	A*	1 7.5
Fomitopsis pinicola (Sw.) P. Karst.	1523	C	C	C*	C	C	15.0
Ganoderma applanatum (Pers.) Pat.	1701	C_{A2}	C_{A2}	C_{A2}*	C_{A2}	C_{A2}	22.5
Ganoderma lucidum (Curtis) P. Karst.	1900	C	C	C*	C	C	15.0
Grifola frondosa (Dicks.) Gray	976	A	B	C_{A2}*	A	C_{A2}	13.0
Hericium erinaceus (Bull.) Pers.	970	A	A	B*	A	C_{A1}	8.5
Hypsizygus marmoreus (Peck) H.E. Bigelow	2006	C_{A1}	A	A*	C_{A1}	C_{A1}*	12.5
Inonotus obliquus (Fr.) Pilát.	1877	C	C	C_{A1}	C	A	13.5
Irpiciporus litschaueri (Lohwag) Zmitr.	5312	C_{A2}	C_{A2}	C_{A1}	C_{A1}	C_{A2}	20.5
Laetiporus sulphureus (Bull.) Murrill	352	C	C	C*	C	C*	15.0
Lentinula edodes (Berk.) Pegler	502	C	C_{A2}	C_{A2}*	C_{A2}	C_{A2}*	21.0
Lepista luscina (Fr.) Singer	64	A	A	A*	A	A*	5.0
Lyophyllum shimeji (Kawam.) Hongo	1662	C_{A2}	C_{A2}	C*	C_{A2}	C_{A2}	21.0
Morchella esculenta (L.) Pers.	1953	A	B	A	A*	A	6.0
Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora	1928	C_{A1}	C_{A1}	C_{A2}	C_{A1}	C_{A1}	18.5
Oxyporus obducens (Pers.) Donk	5085	C	C	C	C	C	15.0
Phellinus igniarius (L.) Quél.	1578	A	C_{A2}	C_{A1}	C_{A1}	A	13.5
Pleurotus djamor (Rumph. ex Fr.) Boedijn	1526	B	C_{A2}	C_{A1}*	C_{A2}	C_{A2}	19.0
Pleurotus eryngii (DC.) Quél.	2015	C_{A2}	C_{A2}	C_{A1}*	C	C_{A1}	19.0
Pleurotus ostreatus (Jacq.) P. Kumm.	551	C_{A2}	C_{A2}	C_{A1}*	C_{A2}	C_{A1}*	20.5
Schizophyllum commune Fr.	1768	C	C_{A2}	C	A	C*	14.5
Trametes versicolor (L.) Lloyd	353	C	C	C	C	C	15.0
Xanthoporia radiata (Sowerby) Ţura, Zmitr., Wasser, Raats & Nevo	2454	A	A	A*	A*	A*	5.0

Legend: A – deadlock after mycelial contact, B – deadlock at a distance, C – overgrowth without initial deadlock, C_{A1} – partial replacement after initial deadlock with contact, C_{A2} – complete replacement after initial deadlock with contact, * – the presence of polymorphism of *C. albicans*.

in natural habitat due to the effecting any antagonistic or parasitism mechanisms that provide full functioning of ecosystem (Bruce and Highley 2001).

Generally, *C. albicans* 17/138 and *I. orientalis* were more sensitive to all investigated fungi than *C. albicans* clinical isolates. Current studies may provide the basis to determine the correlation between the interaction of Macromycetes and the degree of *Candida* strains virulence. During the experiments the polymorphism (formation pseudohyphae or/and hyphal form) of *C. albicans* clinical isolates has been established (Fig. 3): *C. albicans* 311 in co-cultivation with 17 fungi (entomophilous *C. militaris*, soil saprotrophic like *C. comatus*, *L. luscina*, *L. shimeji* and xylotrophic *F. velutipes*, *F. pinicola*, *G. applanatum*, *G. lucidum*, *G. frondosa*, *H. marmoreus*, *H. erinaceus*, *L. sulphureus*, *L. edodes*, *P. djamor*, *P. eryngii*, *P. ostreatus*, *X. radiate*), *C. albicans* 315 – with 2 fungi (soil saprotroph *M. esculenta*and xylotroph *X. radiata*), *C. albicans* 319 – with 12 fungi (entomophilous *C. militaris*, soil saprotrophic *C. comatus*, *L. luscina*, and xylotrophic *F. velutipes*,

F. betulina, *F. fomentarius*, *H. marmoreus*, *L. sulphureus*, *L. edodes*, *P. ostreatus*, *S. commune*, *X. radiate*).

Thus, all three clinical isolates of *C. albicans*

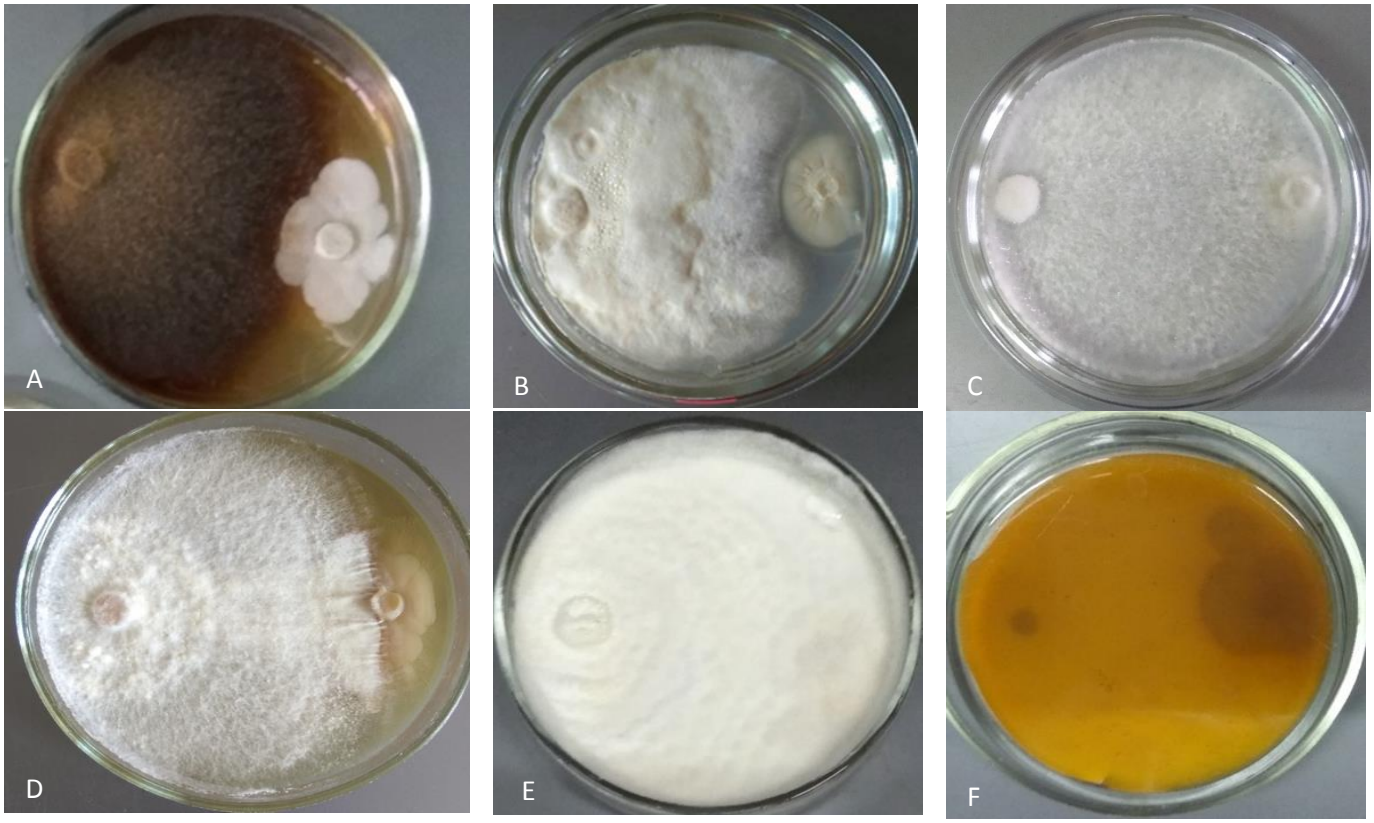

Fig. 1. Illustration of competitive interactions between mycelia of studied fungi: **A** – deadlock at mycelial contact of *M. esculenta* and *C. albicans* 315; **B** – deadlock at distance, interaction of *P. djamor* and *I. orientalis* 301; **C** – overgrowth without initial deadlock, interaction of *F. betulina* and *C. albicans* 17/138; **D** – partial replacement after initial deadlock with contact of *P. eryngii* and *C. albicans* 319; **E**, **F** – complete replacement after initial deadlock with contact of *I. litschaueri* and *C. albicans* 17/138, front and reverse sides of Petri dishes, respectively. Note: right - pathogenic fungus, left - macromycete fungus.

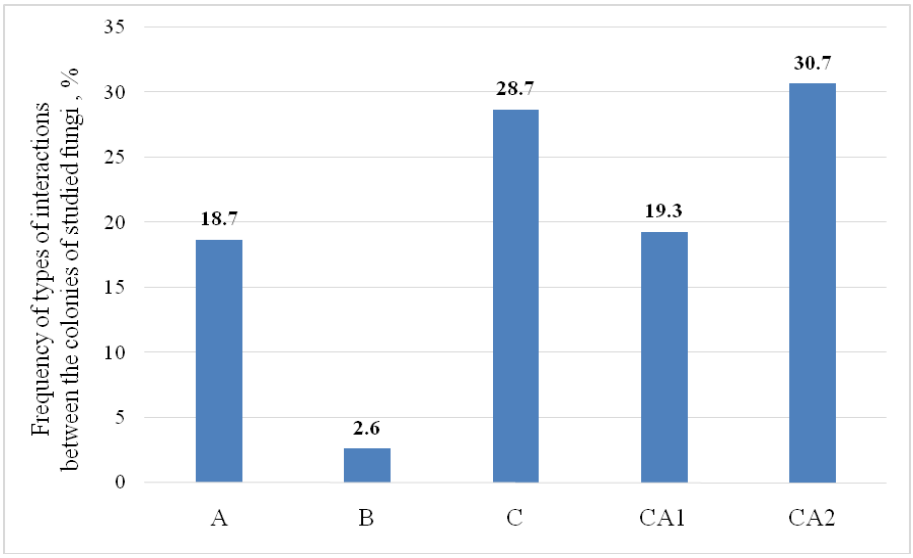

Fig. 2. Frequency of type (**A** – deadlock after mycelial contact, **B** – deadlock at a distance, **C** – overgrowth without initial deadlock) and subtype ($\mathbf{C_{A1}}$ – partial replacement or $\mathbf{C_{A2}}$ – complete replacement after initial deadlock with contact) interactions between colonies of studied fungi, expressed as percentage of the total number (450) of pairings tested.

showed polymorphism in the case of co-cultivation only with *X. radiata*. Two clinical isolates *C. albicans* 311 and 319 showed this feature with growth in dual culture with *C. militaris*, *C. comatus*, *L. luscina*, *F. velutipes*, *H. marmoreus*, *L. sulphureus*, *L. edodes*, *P. ostreatus*, *X. radiata*. It is

known that the basic function of hypha formation of opportunistic pathogens like *Candida* spp. is to invade the substrate they are adhered to. However, probably, in this case, this may be a response to a change the conditions in medium, it can become more extreme in particular, a sharp change in pH as

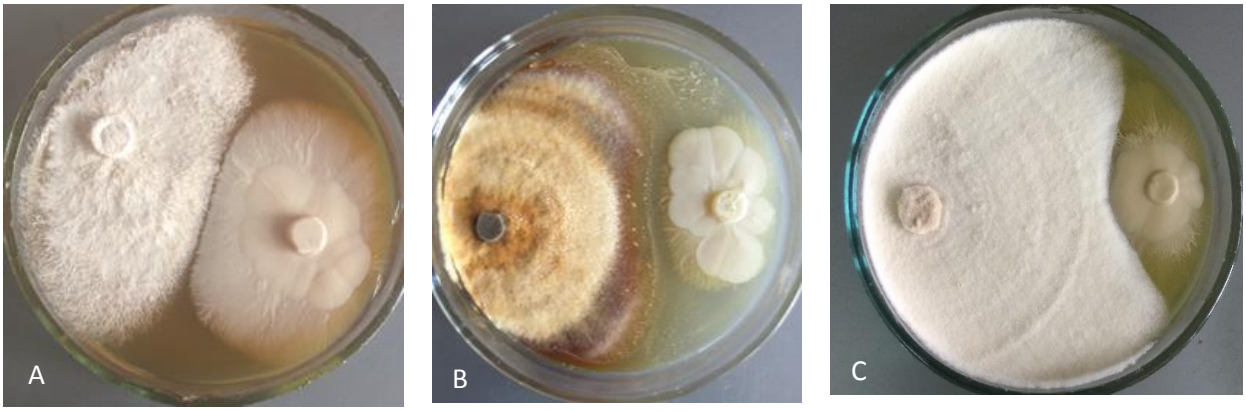

Fig. 3. Illustration of polymorphism of *C. albicans* clinical isolates (right) in co-cultivation with macromycetes (left): *H. erinaceus* and *C. albicans* 311(**A**), *X. radiata* and *C. albicans* 315 (**B**), *F. fomentarius* and *C. albicans* 319 (**C**).

a reply of the synthesis of metabolites by antagonist.

The competition or antagonism experienced during co-cultivation led to a change in the morphological characteristics of fungal colonies (Fig. 4). These changes can be mediated by the up-regulation of genes involved in antagonism (Iakovlev *et al.* 2004). The formation of a mycelial ridge of *G. frondosa* upon contact with a colony of *I. orientalis* has been established (Fig. 4A). During deadlock reaction localized aerial mycelia of *F. betulina* was produced at the interface between confronted fungi (Fig. 4B). The presence of central stria was observed in case of co-cultivation *G. applanatum* with *I. orientalis* (Fig. 4C).

After 20 days of growth, observed the appearance of fungal metabolites on *F. fomentarius* colony in the form of exudate of dark brown drops (Fig. 4D) and on *P. ostreatus* and *L. shimeji* colonies in the form of shining small golden drops of liquid (Fig. 4E, 4F). The production of analogical golden secondary metabolites was also found on edges of colonies *L. edodes* in dual culture with *Verticillium* sp. and *Pythim* sp. (Owaid 2017).

Fungus *F. fomentarius* is distinguished by its ability to form primordia in culture. However, it should be noted that this process took place more intensively in the area of *C. albicans* location (Fig. 4D). Fruit-body primordia were also reported only in pairings of *Lentinus tigrinus* with *Bipolaris sorokiniana* (Badalyan *et al.* 2002). Interaction of *C. comatus* with *C. albicans* 311 resulted in the formation of brown barrages in the antithetic zone line of interaction with the pathogen, colony morphology and color changes in the mycelia and reversume of xylotrophic fungus colony (Fig. 4G, 4H, 4J, 4K). Similar finding with brown barrages has already been reported as a resistance of *L. edodes* strain UFLA-LE5 to *Trichoderma* sp. (Santos 2019). Changes in colony color and morphology were also observed in co-cultivation of *C. comatus* with *C. albicans* 319 (Fig. 4G, 4I, 4J, 4L). It is probably that diffusion of metabolites of *Candida albicans* strains stimulated laccase activity (oxidation of polyphenols) of *C. comatus* and the producing of brown pigments in *C. comatus* hyphae by activating some general cellular mechanisms of stress resistance. It should be noted that the presence of laccase was previously established by us in 21 fungi species (Krupodorova *et al.* 2014), but only co-cultivation of *C. comatus* and *C. albicans* strains 311, 319 allowed us to reveal it. Thus, co-cultivation in our case can be considered as a biotechnological tool that allows increasing the production of *C. comatus* laccase. Obtained from *C. comatus* mycelia (strain JT-01) laccase was shown previously as antipathogenic protein that possessed antiproliferative and HIV-1 reverse transcriptase inhibitory activities (Zhao *et al.* 2014).

The enhanced activity of lignin-modifying enzymes (particular laccase, manganese peroxidase, phenol-

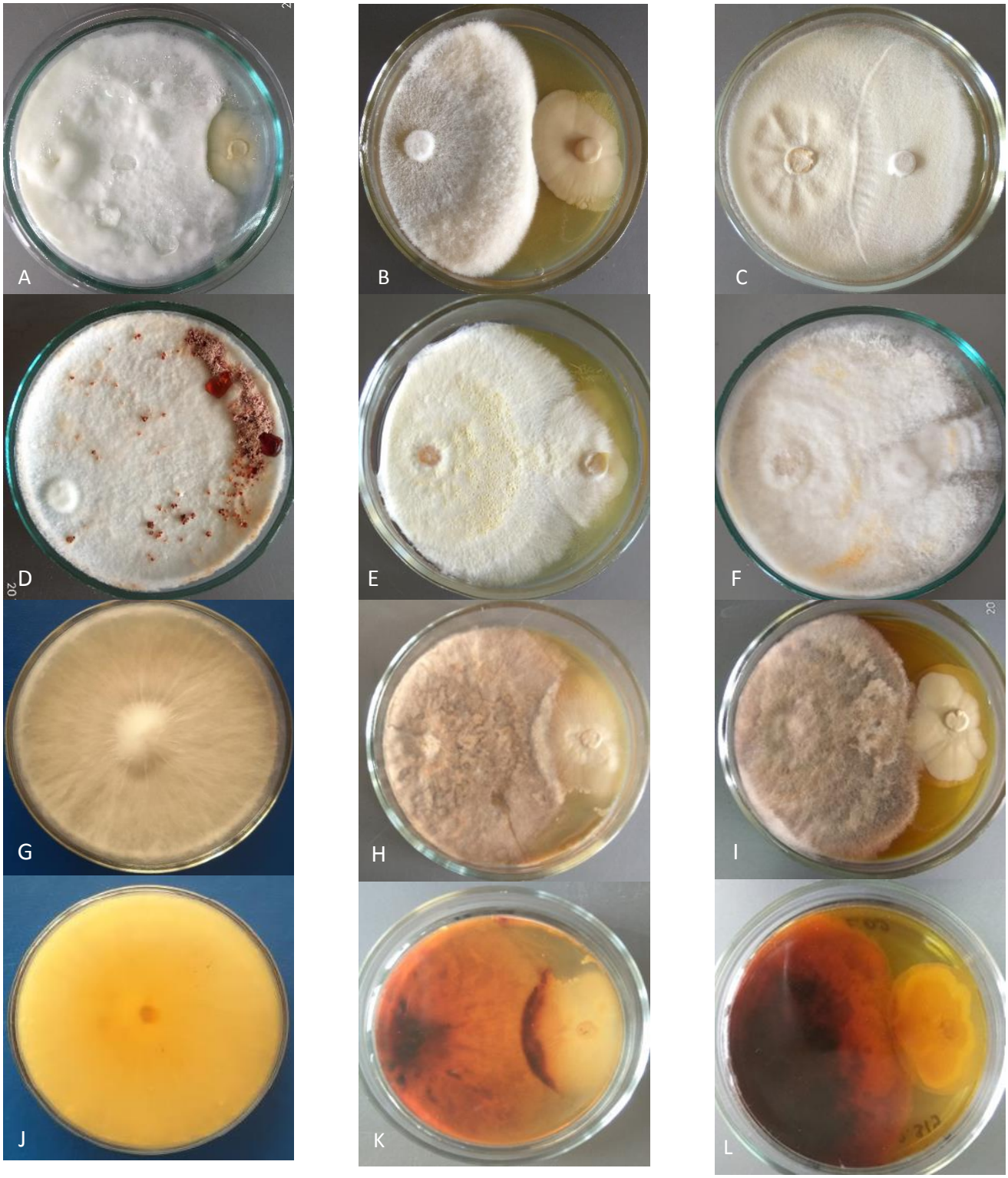

Fig. 4. Illustration the changes in the morphological characteristics of fungal colonies: the formation of a mycelial ridge of *G. frondosa* upon contact with a colony of *I. orientalis* 301 (**A**); localized aerial mycelia of *F. betulina* at the interface between confronted fungi *C. albicans* 319 (**B**); the presence of central stria in case of co-cultivation *G. applanatum* with *I. orientalis* 301 (**C**); primordia formation of *F. fomentarius* in dual culture with *C. albicans* 17/138 (**D**); producing in form shining small golden drops of liquid on colonies of *P. ostreatus* by co-cultivation *C. albicans* 311 (**E**) and of *L. shimeji* by co-cultivation with *C. albicans* 311 (**F**); formation of brown barrages in the antithetic zone line of interaction with the pathogen, colony morphology and color changes in the mycelia of *C. comatus* (**H**) and reversume of xylotrophic fungus colony (**K**) in dual culture with *C. albicans* 311; changes in front colony colour and morphology (**I**) and reversume (**L**) of *C. comatus* in co-cultivation with *C. albicans* 319. **G** and **J** - front and reversume of *C. comatus* colonies in mono culture, respectively (control). Note: right – pathogenic fungus, left – macromycete fungus.

oxidase and peroxidase activities) in fungal co-culture and the important role of these enzymes in the antagonistic interaction between species pointed out by different researchers (Li 1981; 1983; Bruce and Highley 1991; Nia 1992; Freitag and Morrel 1992; Rayner *et al*. 1994; Savoie *et al*. 1998; Hatvani *et al*. 2002; Badalyan *et al*. 2002; 2004; Uzar *et al*. 2017). In addition, dark zones can be due to melanin production. It can function as a physical barrier, preventing access by cell wall-degrading enzymes of other organisms (Bull 1970), and also it can be an important part of the protective response against mycelial invasion that allows to adapt to environmental stress or to attack of antagonists (Lee *et al*. 2008).

Generally, exudates producing as well as color changes should be considered a consequence of the fact, that co-cultivation lead to a significantly enhanced production of constitutively present compounds and/or to an accumulation of cryptic compounds that are not detected in axenic cultures of the producing strain (Marmann *et al*. 2014) and there are could be responsible for the antifungal or/and fungistatic activity.

Conclusion

The study touched on the antagonistic activity is one of the integral stages into the understanding fungal-fungal competition, physiological as well as biochemical processes of their interaction. Presented research may provide valuable insights into interspecific fungal interactions. Co-cultivation led to a change in the morphological characteristics of some Macromycete fungal colonies such as the formation of a mycelial ridge, aerial mycelia, barrages, drops of exudate, changed the colony color, and polymorphism of *C. albicans* clinical isolates. Obtained results indicate the considerable antifungal potential of studied 30 Macromycetes against *Issatchenkia orientalis* and *Candida albicans* strains. Studied fungi produced a different variety of interaction reactions: A - deadlock after mycelial contact (18.7 %), B - deadlock at a distance (2.6 %), C - overgrowth without initial deadlock (28.7 %), and subtypes C_{A1} - partial replacement (19.3 %) or C_{A2} - complete replacement after initial deadlock with contact (30.7 %). Domination of replacement (78.7 %) of pathogenic fungi by Macromycetes was established. The complete replacement was almost twice more frequent (30.7 %) than partial replacement (19.3 %). These results clearly indicate the effectiveness of Macromycetes against pathogenic fungi via contact antagonism. Performed screening allows to determining the most active mushrooms with high antagonistic index (AI): xylotrophic species *G. applanatum* (AI = 22.5), *L. edodes* (AI = 21.0), *F. velutipes*, *I. litschaueri* and *P. ostreatus* (AI = 20.5), leaf litter decay fungus *C. schevczenkoi* (AI = 21), and soil saprotroph *L. shimeji* (AI = 21). These fungi are promising species for further studies to investigate and isolate potential antifungal metabolites with strong action.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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