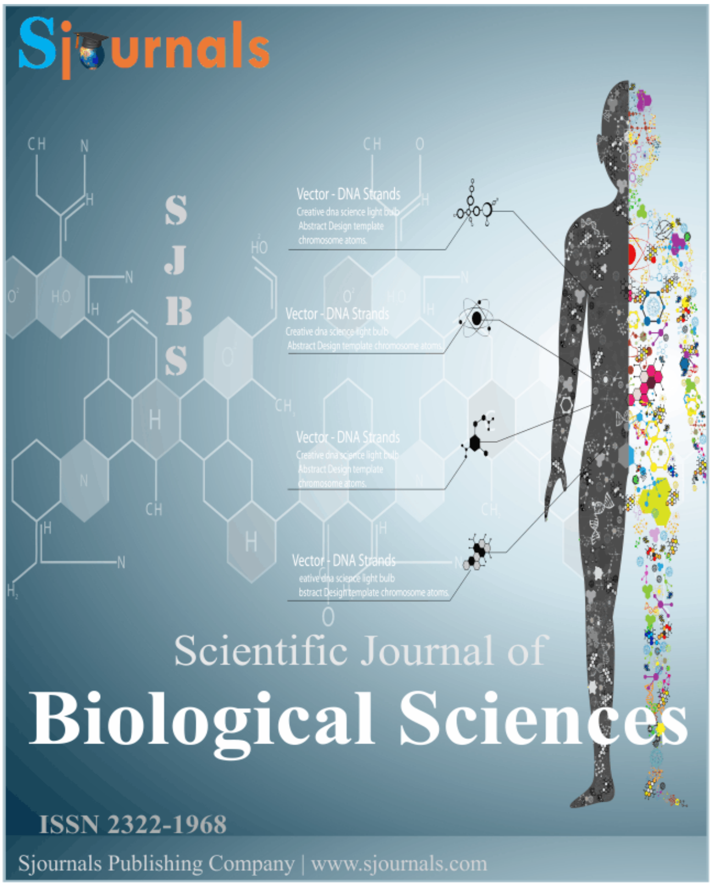
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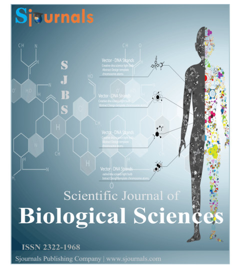

Review article

Use of microsporidia as selective parasites in aquatic and continental environments

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A B S T R A C T

Microsporidia are unicellular organisms that can function as living cell parasites. Despite the fact that entomopathogenic microsporidian fungi are unsatisfactory microbial pesticides (in exception for destroying invertebrates), they generally were used in agricultural section. Researchers shown that most of the microsporidia species have a noticeable potential to act as natural control agents, and this zenith is for their ability to distribute among living organisms by means of vertical or horizontal transmission techniques in both aquatic and continental environments. Besides being used as natural pest controllers, since some microsporidia species can damage beneficial insects, this paper would examine mechanisms of microsporidia transmission in different environments in the purpose of increasing their impact on target ecological hosts and, simultaneously, decreasing the possibility of microsporidia transmission among other beneficial creatures.

1. Introduction

Microsporidia are a renowned group of entomopathogens devoted to fungi class. They have some particular characteristics making them popular pest managers. These intracellular parasites have an acceptable ability to be a partaken of genetic relationship. There are enormous species in their phylum (Wittner and Weiss, 1999). As well-known parasites, they can infect both invertebrates and vertebrates (Franzen and Müller, 1999). Relationships among microsporidian species were studied by phylogenetic data evaluation; while, definite taxonomy of many microsporidian groups have not been discovered (Vossbrinck and De Brunner-Vossbrinck, 2005). These control agents can function as selective parasites of pest populations; indeed, they are powerful protectors of worthwhile natural resources such as woods, pastures, and forage crops (Linde, 1993). To being constant nature guards, these parasites must be persistent in the life cycle of their host communities, inasmuch as transmitting vertically, horizontally, or by means of both, depending on microsporidium-host interactions (Becnel and Andreadis, 1999; Goertz et al., 2007). Understanding microsporidian transmission types among the host descendants is therefore the most important step in studying their biology and exactly their persistency in nature. However these biological agents can be extraordinary pest controllers, they had not been interesting research paper topics during recent years, due to their categorization under the label of bio-pesticides.

Parasites and other symbionts use vertical transmission to circulate among host generations in sexual reproduction. Researches introduced vertical transmission as a cluster of direct transmission. In other words, in this type of transmission, pathogen is transmitted directly from parents to offspring and their descendants over time. Moreover, vertical transmission is reported to be a mostly used one among microorganisms being in communication with invertebrates. Transovum, transovarial (transovarian), and venereal transferences were recognized as the essential types of pathogen's vertical transmission. Both transovarial and transovum are managed by feminines, in contrast to venereal transmission corresponded to males (Becnel and Andreadis, 1999). Transovum is done via pathogen transmission located within the embryo or yolk, or attached to the surface of the egg chorion (Becnel and Andreadis, 1999). Venereal and transovarial transferences are subgroups of transovum transmission; this makes sense in that, these two types of circulation are done in the base of transovum transmission tactic. Transovarial is a transmission of pathogens to hosts' embryo in which the egg/yolk is attacked by microsporidia spores produced in infected host ovarials (Andreadis, 1999; Dunn and Smith, 2001; Solter, 2006). Subsequently, the pathogen not only can reproduce and grow in the embryo, but also may conceal to evolve and duplicate just after embryonation or hatch (Brooks, 1968; Nordin, 1975; Kellen and Lindegren, 1973). Venereal transmission provides a simplified description of spreading pathogens from infected male to female hosts and, consequently, to offspring; this type of transovum transmission must be analyzed, practically, where the adults are restricted in an area or a water volume; hence, exact confirmation of contamination caused by mating with infected males and the potentiality of pathogenic egg masses is rather arduous (Solter et al., 1991). Infection assessment experiments and contaminated spermatophores revealed that eggs could be corrupted upon fertilization and oviposition (Patil et al., 2002).

Besides vertical transmissions, horizontal transference has various pathways leading to a large influx of infected vulnerable hosts and an expansion of the polluted species in target regions. Nevertheless, microsporidia is an important group of well-known insect pathogens, it may damage some other beneficial insect species through horizontal transmission.

The application of microsporidia as natural parasites is worthwhile especially in circumstances where it is faulty to utilize chemicals, or in surveying their interactions with target hosts, and, lastly, for analyzing their unique manipulation potentiality.

2. The potential of microsporidia as natural parasites

Supporting evidences coming from researches prove that microsporidia inoculation, augmentation, introduction and establishment, and manipulation are initial approaches used for employment of these pathogens as natural pest parasitoids (Roberts et al., 1990). For example, *Nosema* pyrausta, a kind of microsporidia, was intensively considered in the role of a natural controller of a common insect pest in the European corn, *Ostrinia nubilalis*. After being known to the host, this microsporidium was established in North America as a sole momentous habitual enemy of *O. nubilalis*. This technique was applied in most parts of the United States (Andreadis, 1984; Siegel et al., 1986) and had a high record in harmfully infected *O. nubilalis* larval communities even at enzootic life stages (Andreadis, 1984). *Nosema fumiferanae* is another microsporidia species proven to have deleterious influence on host communities and, ultimately, to wipe out the spruce budworm species (Wilson, 1973); *Nosema tortricis*, is the next studied microsporidia greatly reduced the number of *Tortrix viridana* in their natural habitat (Franz and Huger, 1971). Subsequently, *N. heliothidis*, is introduced as the pathogen of *Helicoverpa zea* (Brooks and Cranford, 1978); *Thelohania solenopsae* and *Vairimorpha invictae* are determined as cruel enemies of red fire ant (Oi and Williams, 2002; Briano, 2005) and the *Nosema lymantriae*/*Vairimorpha disparis* is adopted to control the population of gypsy moth (McManus and Solter, 2003).

3. Microsporidia circulation in continental systems

Microsporidia is estimated to be the main cause of demise or menacing drawbacks in their hosts (Roberts et al., 1990). The more interesting culmination of their biology evaluations is the consideration of their inherent power as dangerous parasites and, consequently, their capabilities of controlling pest populations (Roberts et al., 1990; Federici and Maddox, 1996). There is little doubt that microsporidia engage in transovarial transmission to infect both continental and aquatic insect hosts. Studies confirmed their potential involved in the contamination of insect eggs by means of some infective primary spore production within hosts' sexual organelles-transovarial transmission (Fries, 1989; Fries et al., 1992; Iwano and Ishihara, 1991). In most continental hosts, pathogen transovarial transmission usually comprises the horizontal transmission. The pathogen could be circulated among the generations of target species and even among the body structures of other living creatures which are mostly in contact with infected insects in the framework of horizontal transmission (Dunn et al., 2001). An even more discoveries were reported in the possibility of pathogen transmission to the ovaries of collaborated plantation structures (Becnel et al., 1989). The pathogen is dispensed across plantation cells caused by infected vegetative reproduction organs (Dunn et al., 2001).

The interaction between the European corn borer (ECB), *Ostrinia nubilalis*, and *Nosema pyrausta* can be a distinctive demonstration of microsporidian transovarial and horizontal transmissions in continental systems (Solter, 2006). Fifth-instar ECB larvae complete their life cycles at the end of spring; afterwards, mature infected females mate (Sajap and Lewis, 1988) and lay eggs with possibility of one-second infected newborns (Kramer, 1959); as a result of this contamination, tremendous number of larvae would demise (Siegel et al., 1986), and survival ones will grow more slowly than uninfected larvae (Solter et al., 1990). Afterwards, summer generation larvae may be horizontally infected as a consequence of contacting with dead larvae or the waste of living contaminated ones (Anderson and May, 1981). Second or third ECB generation would survive through the winter; however, a huge death toll of overwintering larvae was reported among infected larvae as opposed to horizontally infected ones (Kramer, 1959; Siegel et al., 1986).

4. Microsporidia circulation in aquatic networks

Microsporidia have an unconventional expansion in water columns in association with aquatic arthropods life cycle. *Amblyospora,* was brought in as an assortment of *Aedes* mosquito parasite; its application under the scope of biological pesticides is regarding (Andreadis, 2005). Most of the *Aedes* mosquitoes tend to lay into the aquatic systems which are without fish or any other probable predators of their larvae. These insects have 4 main stages in their life cycle including: egg, larvae, pupae and adult. Infected feminine mosquitoes, *Aedes,* starters of infectious life cycles, contaminate their youngsters via binucleate microsporidian spores produced in their infected ovarials sheath and oviducts; meant that, these microsporidian spores are enforced to the surface of the eggs by transovum vertical transmission technique (Andreadis et al., 2013). At the next generation, survival female adults, the same type of binucleate spores are made to produce infected larvae. Then, infected masculines and feminines mate and contribute the contamination to their offspring with infected haploid spores. This process is also a vertical transmission called transovarial. Almost all resulted larvae would die, but critical point is that infected meiospores released in aquatic systems will contaminate copepods feeding on the meiospores in the slide of horizontal transmission. In a sense, copepods produce the third mononucleuted spores and release them into the water volume. These infective particles are harmful only for the mosquito larval hosts feeding on them. This would initiate a new generation of infected female mosquitoes (Andreadis, 2005).

5. Selective transmission in microsporidia life cycle

Some microsporidia species prefer horizontal transmissions, while others like vertical ones intrinsically or in the base of environmental conditions. Internal and external transmissions are subcategories of horizontal transmission. They can be held in both earthly and aquatic microsporidia life cycles living in host body structures. Internal transmission is done among parasite's generations, while external transmission circulates the parasites among other living organisms. *Amblyospora* and *Hyalinocysta* life cycles are good indicators of horizontal transmission in its external form. On the other hand, *Nosema empoascae* of the potato leafhopper (Ni et al., 1997), *Goeldichironomus holoprasinus* (Knell, 1981), and *Cougourdella sp.* (Heilveil et al., 2001) are peculiar instances of parasites that do not transmit horizontally at all.

According to the researches, microsporidia being expanded just by vertical transmission have more less chance to survive in host communities; so that, host feminization must be a chosen manner to increase parasite survival luck by the means of utilizing horizontal transmission (Dunn et al., 2001). Regardless of the fact that microsporidia species involve in continuous vertical transmission are virtually fragile and may wipe out easily (Dunn et al., 2001), there are some incessant microsporidia such as *Glossosoma* evolving through vertical transmission, however possessing a high potential for omitting their host communities just in 7 days (Kohler and Wiley, 1992).

In some senses, microsporidian species are more likely to infect especial hosts, for instance female hosts (Ironside et al., 2003a; Ironside et al., 2003b). As an clarification, infected feminine *Gammarus duebeni* with *Nosema granulosis* whether mate with contaminated or healthy males, will produce only infected females; even though, in some situations they would have some intersex individuals as a result of androgenic obstruction of reproductive glands formation in masculines (Rodgers-Gray et al., 2004).

6. Conclusion

For achieving precise and satisfactory results in analyzing parasite function among host generations, the most important point is the understanding of pathogen circulation strategies as long as gaining accurate information about parasite configuration and life cycle types. Pathogens apply unlike transmission types in aquatic and continental environments, but, basically they are expanded among one species by vertical or horizontal transmissions, and dispense among different species mostly via horizontally transmission system. Some microsporidia groups prefer just one type of transmission to protect themselves from the danger of extinction, and some others choose another type seasonally for surviving in harsh environmental conditions.

There are some beneficial reasons and restrictions in the employment of these natural pest controllers. Since it is advantageous to use them instead of chemicals, their potentiality of killing other beneficial insects like bees must be investigated. The use of microsporidia as natural bio-pesticides should be revived in scientific researches as a powerful environmental conservancy and a practical substitution of using harmful chemical pesticides; likewise, DNA manipulation of these parasites is proposed to control their horizontally transmission and specialize their selective lethality as well. Ultimately, microsporidia function as biological control agents is suggested to examine as a spontaneous occurrence, classical-biological phenomenon, and pest population reducer.

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