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Review of entomopathogenic microsporidia biodiversity in the Trabzon Region, Türkiye

Hilal YILDIRIM[*] [1], Çağrı BEKİRCAN[2], Onur TOSUN[3]

ORCID: 0000-0002-6072-5543;0000-0002-5968-7359;0000-0002-6763-5671

[1] Department of the Crop and Animal Production, Espiye Vocational School, Giresun University, Giresun, Türkiye
[2] Department of the Chemistry and Chemical Processing Technology, Maçka Vocational School, Karadeniz Technical University, Trabzon, Türkiye
[3] Department of the Veterinary Medicine, Maçka Vocational School, Karadeniz Technical University, Trabzon, Türkiye

Abstract

Purpose: Entomopathogenic microsporidia are obligate intracellular parasites that play an important role in the biological control of insect pest. In recent years, there has been increasing interest in using entomopathogenic microsporidia for biological pest control as an alternative to chemical methods. The Trabzon region possesses a rich ecosystem, comprising coastal areas, mountainous regions, high plateaus, forests, streams, and diverse wildlife. This ecological heterogeneity is a key driver of the region's high biodiversity in both flora and fauna. Given this richness, it is essential to document the biodiversity of entomopathogenic microsporidia in the area. To date, no study has been conducted to compile a list of entomopathogenic microsporidia recorded from Trabzon province. The aim of this study was to reveal and document the diversity of microsporidia that have been recorded from Trabzon region to date.

Method: This article was prepared using recently published studies on entomopathogenic Microsporidia in Turkey, particularly from Trabzon province, along with relevant literature. All sources used to obtain data are listed in the results section**.**

Findings: To date, numerous microsporidia species have been recorded from insect orders with high species diversity in the Trabzon region, including Hymenoptera, Hemiptera, Lepidoptera and Coleoptera. While some of these microsporidia have been identified in beneficial insects, such as bees and predatory species, the majority have been recorded from insect pests of economically important plants. Several studies have also highlighted the influence of geographical structure and climatic conditions on microsporidia biodiversity. In this context, the diversity of entomopathogenic microsporidia in the Trabzon region is discussed with particular reference to the area's topographical features.

Conclusion: To date, the entomopathogenic microsporidia recorded from both beneficial and harmful insects in Trabzon provide evidence of the wide pathogen diversity in the region. These findings also highlight the considerable potential for further research in this area. Owing to its distinctive geographical characteristics, Trabzon province still harbours unexplored habitats with respect to entomopathogenic microsporidia diversity. Existing studies indicate that Trabzon is a highly diverse and largely underexplored region in terms of entomopathogenic microsporidia.

Keywords: microsporidia, Trabzon, biodiversity

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Türkiye'de Trabzon bölgesinin entomopatojenik mikrosporidium çeşitliliği

Özet

Amaç: Entomopatojenik mikrosporidiya üyeleri, zorunlu hücre içi parazitlerdir. Zararlı böceklerle biyolojik mücadelede etkili bir rol oynarlar. Son yıllarda, kimyasal mücadele yöntemlerine alternatif olarak entomopatojenik mikrosporidiyaların kullanıldığı biyolojik mücadeleye olan ilgi giderek artmaktadır. Trabzon kıyı kesimi, dağlık alanlar,

[*] *Corresponding author*: Tel.: +904543101430; Fax.: +904543101431; E-mail: hilalbakiesk@hotmail.com
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yüksek yaylalar, ormanlar, akarsular ve yaban hayatıyla zengin bir ekosisteme sahiptir. Biyoçeşitliliği oluşturan temel faktör ise Ekosistemin yapısıdır. Bitkisel ve hayvansal anlamda var olan bu zengin biyoçeşitlilik, bölgede entomopatojenik mikrosporidia biyoçeşitliliğinin de ortaya konulması ihtiyacını doğurmuştur. Bugüne kadar Trabzon ilinde entomopatojenik mikrosporidiaların listelenmesine yönelik bir çalışma bulunmamaktadır. Bu çalışmada, Trabzon bölgesinde bugüne kadar kaydedilen mikrosporidiya biyoçeşitliliğinin ortaya konulması amaçlanmıştır.
Metod: Bu makalenin hazırlanmasında, Türkiye'de, özellikle Trabzon ilinden, entomopatojenik mikrosporidyumlar hakkında yakın zamanda yayınlanan makaleler ve litaratürdeki bilgiler esas alınmıştır.
Bulgular: Bugüne kadar Trabzon bölgesinden Hymenoptera, Hemiptera, Lepidoptera ve Coleoptera gibi geniş tür sayısına sahip takımlardan birçok mikrospor kaydedilmiştir. Bunlardan bazıları arılar ve predatör böcekler gibi faydalı böceklerden kaydedilirken, çoğunluğunun ekonomik önemi olan bitkilerde zararlı olan böceklerden kaydedildiği görülmektedir. Ayrıca çeşitli çalışmalarda coğrafik yapı ve iklim şartlarının biyoçeşitlilik üzerindeki etkilerine vurgu yapılmıştır. Bu bağlamda Trabzon bölgesindeki entomopatojenik mikrosporidium çeşitliliği topoğrafik yapı göz önüne alınarak tartışılmıştır.
Sonuç: Bugüne kadar Trabzon'dan hem yararlı hem zararlı böceklerden kaydedilen entomopatojenik mikrosporlar, bölgedeki geniş patojen çeşitliliğinin bir kanıtıdır. Aynı zaman da yapılacak yeni çalışmalar için bölgedeki potansiyelin bir göstergesidir. Trabzon ili coğrafyası nedeniyle entomopatojenik mikrospor çeşitliliği açısından hala keşfedilmemiş alanlara sahiptir.

Anahtar kelimeler: microsporidia, Trabzon, biyoçeşitlilik

1. Introduction

Trabzon is located in the western Black Sea Region of Turkey. The Black Sea Region ranksfirst in Turkey in terms of forest cover, accounting for 24.4% of the country's total forest area [1]. The Trabzon region comprises not only forest area but also coastal zones, mountainous regions, high plateaus and streams. These characteristics enable Trabzon to support a high level of biodiversity across all groups of living organism, including plants, animals and entomopathogens.

Microsporidia are recognized as highlyeffective biological control agents against to harmful insects [2,3]. They are unicellular and obligate intracellular parasites that belong to the Microsporidia phylum. These parasites can naturally infect various insect tissues, including the fat body, silk glands, muscles, hemolymph, hypodermis, intestine or malpighian tubules, naturally and cause systemic or cronic infections on their host. At high infection levels, microsporidian infections can be lethal [4, 5, 6, 7]. In addition, they induce detrimental effects such asshortened lifespans, reduced fecundity, impaired molting and overall loss of fitness in infected insects [3, 7, 8, 9]. The most successful and well-known microsporidium used for biological control in the United States is *Nosema locustae* Canning [2]. This pathogen, now referred to as *Antonospora locustae* (formerly *Nosema locustae* Canning) is marketed under various trade names as a commercial biopesticide against grasshoppers and related species [11, 3]. *Vairimorpha necatrix* is another microsporidium with commercial potential; it exhibits a broad host range among pest caterpillars [9]. Similarly, *Nosema algerae*, *Nosema whitei* and *Nosema pyrausta* are pathogenic to *Anopheles* mosquitoes, *Tribolium* (flour beetles) species and corn borer *Ostrinia nubilalis*, respectively [12, 13, 2, 14]. Infections caused by microsporidia in agriculture and forestry pest insects are considered desirable and beneficial, and their potential application in biological control of these pests is being increasingly investigated [7, 15, 16, 17, 18, 19, 20, 21, 22].

In contrast to the desirable infections in harmful insects, there are also equally significant undesirable infections [23, 24, 25]. Infections known as nosemosis in honey bees and pébrine in silkworms lead to considerable economic losses [23, 25]. Additionally, the infections in beneficial predatory insects that used in biological control of pests can disrupt these control efforts. Studies conducted worldwide on Microsporidia highlights the importance of detecting these pathogens in the context of pest insect management. Accordingly, the detection of microsporidia has gained increasing importance in Türkiye as well as globally. In this review, all studies on Microspora that carried out in Trabzon are summarized. These studies indicate that Trabzon represents a highly diverse and largely unexplored region in terms of microsporidian pathogens.

2. Materials and methods

The current review was performed by referring to recent literature on microsporidia that infect insects in Turkey, especially Trabzon, along with relevant literature from around the world. Moreover, studies reporting microsporidia isolated from Trabzon are listed in tabular form in chronological order according to the author's name, year of publication, host insect and size of the spores. Some selected studies performed around the world were also included for comparison purposes.

3. Results

In recent years, ten microsporidian species have been reported from various insect orders in Trabzon [7,15-24]. Although most of these species have been formally identified, several records remain at the level of unidentified or incompletely characterized taxa [17, 25]. All microsporidian studies conducted in Trabzon to date are summarized chronologically in Table 1.

Table 1. Entomopathogenic microsporidian pathogens recorded from the Trabzon region

Micropsoridian species	Host species	Fresh spore size (µm) Length x width	Author
Nosema canburensis sp.	*Graphosoma italicum* (Hemiptera: Pentatomidae)	5.32 x 3.11	[15]
Micropsoridium sp.	*Vespula vulgaris* (Hymenoptera: Vespidae)	4.57 x 2.43	[16]
Nosema fumiferanae	*Apomyelois ceratoniae* (Lepidoptera: Pyralidae)	3.29 x 1.91	[17]
Vairimorpha leptinotarsae	*Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae)	4.36 x 2.49	[18]
Nosema ceranae	*Apis mellifera* * (Hymenoptera: Apidae)	-	[23]
Vairimorpha plodiae	*Plodia interpunctella* (Lepidoptera: Pyralidae)	4.48 x 2.21	[19]
Nosema pieriae sp.	*Pieris brassicae* (Lepidoptera: Pieridae)	5.29 x 2.31	[20]
Nosema leptinotarsae.	*Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae)	4.69 x 2.43	[21]
Micropsoridium sp.	*Rhizophagus grandis** (Coleoptera: Rhizophagidae)	3.75 x 2.47	[24]
Nosema chaetocnemae sp.	*Chaetocnema tibialis* (Coleoptera: Chrysomelidae)	4.15 x 2.60	[22, 7]

*useful insects (Pollinator and predator)

Yaman and Radek (2003) reported, for the first time in Turkey, a microsporidian pathogen from the sugarbeet flea beetle**,** *Chaetocnema tibialis* Illiger, 1807 (Coleoptera: Chrysomelidae) in Samsun [26]. This beetle is an important pest of suger beet in Turkey and the worldwide. They measured spore dimension of 3.52 ± 0.41 in lenght and 2.09 ± 0.26 µm in width. Fresh spores were oval in shape. Their findings were supported by by electron microscopy, and the microsporidium was defined as *Nosema chaetocnemae.* Subsequently, the distribution of *N. chaetocnemae* was studied across 45 localities in ten Turkish provinces, including Samsun, Çorum, Trabzon, Yozgat, Gümüşhane, Tokat, Uşak, Malatya, Kayseri and Balıkesir [22]. The pathogen was detected only in Trabzon and Samsun. Furthermore, Yaman and Güner (2015) reported this pathogen for the second time in Trabzon, with an infection rate of 23.7%, compared with25.20% in Samsun.

Yaman et al. (2010) reported a micropsoridium pathogen (Microsporidium sp.) in *Rhizophagus grandis* Gyllenhall (Coleoptera: Rhizophagidae), a predatory beetle used for biological control of bark beetles, especially *Dendroctonus micans*, in Turkey [24]. Fresh spores were oval and measured 3.75 ± 0.27 µm length and 2.47 ± 0.13 µm in width (n = 60) . The isolate was not identified to species level due to the absence of vegetative stages and the lack of molecular data. Yaman et al. (2011) identified a microsporidiosis as *Nosema leptinotarsae Lipa* from Colorado patato beetle, *Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae) in Trabzon using light and electron microscopy [21]. Later, Bekircan (2020) re-identified this species as *Vairimorpha leptinotarsae* based on molecular data, particularly SSU rRNA gene sequences in addition light and electron microscopy studies [18]. Yaman et al. (2011) reported oval spores measuring 4.69 ± 0.19 in lenght and 2.43 ± 0.12 µm (n:50) in width whereas Bekircan (2020) reported spore dimension of 4.36 ± 0.43 in lenght and 2.49 ± 0.24 µm (n:250) in width [21, 18].

Yaman et al. (2014) found a new microsporidian pathogen in the gut of larvae of large white butterfly, *Pieris brassicae* (Lepidoptera: Pieridae) a major pest of cabbage in Turkey and worldwide [20]. Fresh spores of the pathogen were oval and measured as 5.29 ± 0.55 µm in length and 2.31 ± 0.29 µm in width. Based on light and electron microscopy, as well as molecular analyses, the pathogen was identified at the species level as *Nosema pieriae* sp. nov. Another report involvingLepidoptera was made by Yaman et al. (2016) [19]. They characterized a new microsporidian pathogen, *Vairimorpha plodiae,* for the first time from the Indian meal moth, *Plodia interpunctella* (Lepidoptera:

Pyralidae) well-known stored product pest, in Trabzon, Turkey. Fresh oval spores measured 4.48 ± 0.23 µm in length and 2.21 ± 0.15 µm in width in larvae of *Plodia interpunctella* collected from different stored products such as fig, apricot and hazelnut in Trabzon province. Similarly, Tosun (2020) reported a microsporidian pathogen from the date moth, *Apomyelois (Ectomyelois) ceratoniae*, Zeller, 1839 member of Lepidoptera order. The microsporidian pathogen was described on the basis of light microscopy, ultrastructural characteristics and comparative molecular analysis as *Nosema fumiferanae* TY61. Fresh spores were oval and measured 3.29 ± 0.23 µm (n = 200) in length and 1.91 ± 0.23 µm (n = 200) in width.

Tosun and Yaman (2016) investigated the prevalence and geographical distribution of the fungal pathogen, *Nosema ceranae*, which infects the Asian honey bee (*Apis cerana*) and examined the effects of temperature and humidity around the bee hives on the distribution of *Nosema ceranae* in Eastern Black Sea Region of Turkey. Fieldwork was conducted in seven provinces: Artvin, Rize, Trabzon, Giresun, Ordu, Gümüşhane, and Bayburt. Nosemosis infection was observed across all surveyed sites. As a result of the studies, *N. ceranae* infection was observed in all provinces.

Bekircan et al. (2023) detected a microsporidian pathogen from *Vespula vulgaris* Linnaeus, 1758 (Hymenoptera) belonging to the family Vespidae. Oval fresh spores were measured 4.57 ± 0.54 µm in length and 2.43 ± 0.33 µm in width [16]. Infection was observed primarilyin the midgut and was chronic. They collected the samples from Trabzon province and infection rate of the microsporidian pathogen was determined as 1.20%. This study is particularly significant, as it is the first to describe both the life cycle stages and the spore morphology of a microsporidium pathogen isolated from *V. vulgaris*. Bekircan et al. (2025) described *Nosema canburensis* sp. nov., a new microsporidia species from the Italian striped bug, *Graphosoma italicum* Müller (Hemiptera: Pentatomidae), detailing its morphology, ultrastructure, and molecular phylogeny [15]. The adults of *G. italicum* were collected on parsley plants (Apiacea family) at two localities in Trabzon province, Turkey. The ovoid to ellipsoidal spores measured 5.32 ± 0.71 µm in length and 3.11 ± 0.32 µm in width.

Consequently, eight of the ten microsporidia species reported from various insect orders in Trabzon were classified as desirable infections because they were isolated from pest insects, whereas two were classified as undesirable infections because they were obtained from predatory and pollinator insects. Collectively**,** all these studies are showing the region is highly rich in microsporidian biodiversity. The type of ecosystem also plays a significant role in this diversity [7, 22, 23].

4. Conclusions and discussion

Microsporidia are highly effective biological control agents against insect pest, as demonstrated by numerous scientific studies [27]. Their use in biological control has gained increasingly attention because they provide an alternative to chemical control methods, targets pest insects directly and may reduce the risk of environmental pollution. Several microsporidia species, including *Nosema locustae* (syn. *Antonospora locustae*) and *Vairimorpha necatrix*, have been commercially used as biopesticides for the control of insects pest [5, 9].

Numerous studies have been conducted to identify microspradian parasites in Trabzon. Research on microsporidia in the region began in 2008 and has continued to the present. Spores represent the infective stage of microsporidian pathogens and their presence provides evidence of infection. As apparent from the studies of Turkey spore size and structure determined by light and electron microscopy are as important as molecular studies for the identification of the pathogen. Therefore, spore dimensions have also been included in the Table 1.

In electron microscopy studies, spore structures such as the nucleus, spore wall, polar filament and polaroplast have been examined in detail [15, 17, 18, 19, 20, 21, 23, 24]. Following species identification, other important factors include infection rate, virulence of pathogens, host selectivity and sex differences in infection. However, climatic and geographical factors significantly influence on the variation in all these characteristics. Tosun and Yaman (2016) thoroughly investigated the effects of temperature, humidity and altitude on the distribution of nosemosis [23]. Nosemosis is an important disease of honey bees caused by microsporidia (*Nosema apis* or *Nosema ceranae*) and is widespread in Turkey and worldwide. This disease can lead to significant productivity losses in colonies and even colony collapse.

However, the occurrence and spread of the disease depend not only on the causative organism but also on environmental conditions. The results of Tosun and Yaman (2016) support this [23]. The study reported that nosemosis under natural conditions increased in direct proportion to temperature and humidity. In 2011, the overall distribution of nosemosis infection by humidity showed that the lowest infection level (2%) occurred at 13% humidity, whereas the highest infection level (56%) occurred at 82% humidity. Tosun and Yaman (2016) reported that nosemosis infection is significantly affected by temperature change, with infection rates directly proportional to temperature within apiaries. Aydın et al. (2005) emphasized that rainfall influences *Nosema* infection and that temperature and humidity are closely interrelated and co-varying [28]. Likewise, Huang et al. (2007) reported an increase in nosemosis prevalence in hot climate conditions [29]. Tosun and Yaman (2016) also explored the role of altitudinal variation alongside temperature and humidity in the occurrence of nosemosis [23]. The study indicated that a high infection rate was observed at low altitude, whereas a low infection rate was observed at high altitude. This pattern is likely due to reduced temperature

and humidity at higher elevations, in contrast to the warmer and more humid conditions at lower elevations [23]. They also indicated that temperature and humidity play a role in the seasonal (monthly) distribution of the microsporidium infection, as reported in many studies [28, 30, 31, 32].

Climate change influences the distribution, spread and occurrence of insect-pathogenic organisms and the disease nosemosis is also influenced by climate change [33, 34]. Tested two isolates of *Nosema ceranae* (the other factor of Nosemosis) from France and Spain and found that parasites from different geographical origins can have different effects on *Apis mellifera*, suggesting differences in virulence. Similarly, Yaman and Güner (2015) compared the morphological and infection characteristics of two isolates of *Nosema chaetocnemae* Yaman and Radek (2003), collected from Samsun and Trabzon, in order to evaluate the populations of *Chaetocnema tibialis* from these two localities from a taxonomic perspective [7, 26]. The results of the study demonstrated significant differences between the two isolates in terms of spore size and infection rates. In the Samsun population of *Chaetocnema tibialis*, the microsporidian pathogen caused an average infection rate of 44.3%, whereas in the Trabzon population it caused an infection rate of 23.7%. They reported that the microsporidian isolate from Samsun may result in higher infection rates in the biological control of *Chaetocnema tibialis* and may therefore be more effective than the isolate from Trabzon. They also reported that markedly different infection levels in the same host supports the hypothesis that the microsporidian pathogen causing infections in the Samsun and Trabzon populations of *C. tibialis* may represent different species [7]. Yaman (2017) emphasized the diversity of entomopathogens in the Kastamonu region and how important the region's geographical location and climate are in the formation of this diversity [35].

Up to date, studies on microsporidia recorded from Trabzon province indicate that Trabzon represents a highly rich region in terms of microsporidian pathogens. Identification of the microsporidium pathogen from Trabzon accordingly Turkey could potentially be useful for the biological control of insect pest. On the other hand, determining of natural pathogens of insects allows the assessment and comparison of the pathogen biodiversity in insect, regions and countries, and provides insight into the effects of biotic and abiotic factors on their occurrence, distribution, spread, and virulence. Therefore, not only in Trabzon but across all regions of Turkey, the presence and distribution of microsporidia that cause diseases in insects, as well as the effects of geographical and ecological factors on their presence and distribution, should be studied and evaluated.

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