

## **Entomophthorales fungi parasitizing sucking insects in Egypt**

### **ABSTRACT**

Entomophthorales are insect pathogenic fungi with significant biological control potentials due to their high insect toxicity. This review focuses on the survey and morphological descriptions of entomophthoralean species attacking insect pests in Egypt. Until now 10 species of Entomophthorales fungi, belonging to three families (Entomophthoraceae, Neozygiteaceae and Ancylistaceae) have been reported to suck insects as their hosts. These fungi are widely distributed in various climatic conditions in several Governorates, representing Lower and Upper Egypt. The fungi are the only pathogens that regularly and effectively control sucking insect populations in the natural ecosystems and agroecosystems. The present review emphasizes more studies and isolations of Entomophthorales species by using modern identification techniques so that their epidemiology and control potentials can be predicated on their role against insect pests under variable climatic conditions in Egypt. The possible relationship between population densities of sucking insect pests and Entomophthorales can be further studied to explore their effective applications under variable climatic conditions in the country.

**Keywords:** biological control, Entomophthorales fungi, sucking insects, aphids

### **Introduction**

Sucking insect species considered one of major economic importance for several crops, causing plant stress, distortion, shoot stunting, and gall formation, or transmitting plant virus pathogens (Nadeem et al., 2023, Sewify, and Ezz, , 2001). Entomophthorales are insect pathogenic fungi, which have significant biocontrol potentials against insect pests. The

Entomophthorales, belonging to the Subdivision Zygomycotina and Class Zygomycetes, include six families i.e., Entomophthoraceae, Neozygitaceae, Completoriaceae, Ancylistaceae, Meristacraceae and Basidiobolaceae (Humber 1989). The most important ones are Entomophthoraceae and Neozygitaceae with 200-300 and 15 species respectively (Keller 1997).

The Family Ancylistaceae containing a genus *Conidiobolus*, includes 12 genera, the Family Neozygitaceae has two and the family Meristacnaceae has only one genus. So far, 223 species have been described, of which 195 belongs to the Entomophthoraceae family, 17 species to Neozygitaceae family, ten species to Ancylistaceae family, 35 species to the genus *Tarichium* (Barta and Cagáñ, 2006, Keller, 1987, 1991, 1997; Balazy, 1993; Eilenberg, 2002). One hundred and seventy-six Entomophthorales species are pathogenic to insects, nine species to spiders and seven of them parasitize mites (Keller, 1997). Most of the above species (34.4%) attack members of the order Diptera, followed by the members (24.3%) of Homoptera (white flies, aphids, and scale insects).

Species of Entomophthorales were also identified from other insect orders, e.g., Lepidoptera, Coleoptera, Heteroptera, Hymenoptera, Orthoptera, and Dermaptera (Keller, 1987, 1991; Balazy, 1993). Some species were also identified from Collembola (Apterygota) (Steenberg *et al.*, 1996, Keller & Steenberg, 1997).

Entomophthorales cause localized and widespread epizootics in hemipterous and homopterous insects, particularly aphids and leafhoppers, besides other insects such as grasshoppers, flies, beetles, and caterpillars (Humber, 1989, Humber, 1991, Barta & Cagáñ, 2006). Entomophthorales have shown significant biological control potential against agricultural insect pests due to their high efficiency and efficacy (Baron *et al.*, 2019). Entomophthorales fungi possess beneficial traits of insect biological control, such as easy mass production, short cycle infection, high rates of spores (germs) germination, and

instantaneous lethal effects on insect populations and mortality occurring overnight (Grygansky *et al.*, 2017). Entomophthorales fungi are promising due to their ability to mass produce and act as insect biocides (Francis *et al.*, 2022, Ramanujam *et al.*, 2014). They lead to sustainable agricultural practices, protecting ecosystems and the environment (Koiri *et al.*, 2017)

Distinguished by their prey specificity, they do not pose a threat to non-target organisms (Grygansky *et al.*, 2017). The epizootics, caused by entomophthoralean species, are most witnessed in flies, aphids, grasshoppers, caterpillars, mosquitoes, cicadas, and mites (Pell *et al.*, 2001). The rapid separation of the active conidia spores is an important characteristic of this fungal group (Olsen *et al.*, 2019). Not much attention was given to Entomophthorales fungi and the information on their biological control potentials is sparse in Egypt, although few of the earlier studies have shown their impact on insect pest populations and their effectiveness as insect biopesticidal agent (Sewify, 2000, Nada, 2006, Moubasher *et al.*, 2010, Mohamed *et al.*, 2019).

In the present review, various aspects of Entomophthorales fungi are discussed. Aspects, such as their morphology, survey, biological control potentials, and their effectiveness against insect pests have been discussed. The present review will help entomologists, horticulturists, agriculturists, and other professionals directly or indirectly associated with agriculture in Egypt.

### **Survey and distribution of Entomophthorales fungi in Egypt**

The available literature reveals 10 species of Entomophthorales fungi present in Egypt (Table 1). Those reported were *Neozygites fresenii* (Nowakowski) Batko (Fam.: eozygitaceae), *Pandora neoaphidis* (Remaud & Hennebert) Humber, *Pandora delphacis* (Hori) Humber, *Entomophthoraplanchoniana* Cornu, *Zoophthora radicans* (Brefeld) Batko, *Batkoa apiculata* (Thaxter) Humber, *Batkoa major* (Thaxter) Remaud. & S. Keller,

*Conidiobolus thromboides* Drechsler, *Conidiobolus coronatus* (Costantin) Batko and *Conidiobolus Obscures* (I.M. Hall & P.H. Dunn) Remaud. & S. Keller (Family: Ancylistaceae).

### **1. *Neozygites fresenii* (Nowakowski) Batko**

The fungus was identified based on morphological characteristics according to Humber (2005). The first record of *N. fresenii* in Egypt was on the cowpea aphids, *Aphis craccivora* Koch on fava bean plants (Fabaceae) in Giza Governorate (Sewify, 2000). The fungus was found in the aphid population from November - December 1989 (Table 1). *Neozygites fresenii* was also recorded on *A. craccivora* on fava bean plants in November 2004 and on broad beans in December 2008-2009 in Sharkia and Dakahlia Governorates (Nada, 2006; Ibrahim et al., 2011). Besides, they were also reported to be associated with greenbug, *Schizaphis graminum* (Rondani), bird-cherry aphid *Rhopalosiphum padi* (Linnaeus) on wheat plants and cabbage aphids, *Brevicoryne brassicae* (Linnaeus) on canola plants during February - March 2006-2007 in Assiut Governorate (Moubasher et al., 2010). It was also found associated with the populations of *R. padi*, *R. maidis* and *S. graminum* on wheat plants from January-February, 2013-2014 in Assiut Governorate (El-Maraghy et al., 2015; Mohamed et al., 2019) (Table 1).

### **2. *Pandora neoaphidis* (Remaud. & Hnenebert)**

The first record of *P. neoaphidis* was recorded on *R. padi* on graminaceous weeds in March in the Giza Governorate of Egypt (Sewify & Ezz, 2000). Abdel-Mallek et al. (2004) and El-Maraghy et al. (2015) reported this fungus on *R. padi*, *R. maidis* and *S. graminum* in Assiut Governorate. It was also found associated with *S. germanium*, *Acyrtosiphon pisum* Harris, Annual sow thistle, Wheat barley-Wild oat, and Clover-Chicory during January-April, 2005 in Giza Governorate and *Myzus persicae* (Sulzer) on Annual sow thistle during December 2004- January 2005 in Sharkia Governorate (Nada, 2006). The

fungus was also reported from *R. maidis*, *Metopolophium dirhodum* (Walker), and on barely any plants in Giza Governorate (El-Fatih, 2006). Ibrahim et al., (2011) recorded *P. neoaphidis* on *A. craccivora* on broad bean in December 2008 – March 2009 in Dakahlia Governorate. Moubasher et al., (2010) found this fungus associated with *S. graminum*, *R. padi* on wheat plants and *B. brassicae* on canola plants during February– March 2006–2007 in Assiut Governorate. *Pandora neoaphidis* was found associated with *Sitobion avenae* on wheat plants during December–April in El-Gharbia governorate (El-Sham & El-Sheikh, 2018), whereas on *R. padi*, *R. maidis* and *S. graminum* on wheat plants during January–February in Assiut Governorate (Mohamed et al., 2019) (Table 1).

### **3- *Pandora delphacis* (Hori) Humber**

*Pandora delphacis* was first recorded on *Empoasca decipiens* on a clover plant during January–April 2005 in Giza Governorate, Egypt (Nada, 2006) (Table 1).

### **4- *Entomophthora planchoniana* Cornu**

The fungus, *E. planchoniana* was reported for the first time in Egypt on *S. graminum* wheat, barley, and wild oats during January–February in Giza Governorate (Nada, 2006). Earlier it was found associated with *R. padi*, *R. maidis* and *S. graminum* in Assiut Governorate (Abdel-Mallek et al., 2004; El-Maraghy et al., 2015) and on *A. craccivora* on broad beans during January–March 2009 in Dakahlia governorate (Ibrahim et al., 2011). They were also found associated with *S. graminum* and *R. padi* on wheat plants and *B. brassicae* on canola plants during February– March 2006–2007 in Assiut Governorate (Moubasher et al., 2010) (Table 1).

### **5- *Zoophthora radicans* (Brefeld) Batko**

*Zoophthora radicans* was recorded first time in Egypt, parasitizing *R. padi* on maize during May in Monufia Governorate (Sewify & Ezz, 2000). It was parasitizing *R. padi*, *R. maidis* and *S. graminum* in Assiut Governorate (Abdel-mallek et al., 2004), *E. decipiens* on clover during

December 2004 –February 2005 in Giza Governorate (Nada, 2006), *S. graminum* and *R. padi* on wheat plants, and *B. brassicae* on canola plants during February- March 2006-2007 in Assiut Governorate (Moubasher *et al.*, 2010). *Zoophthora radicans* was also reported from *Sitobion avenae* on wheat plants during December-April in El-Gharbia Governorate (El-Sham and El-Sheikh, 2018), on *R. padi*, *R. maidis* and *S. graminum* on wheat plants during January - February in Assiut Governorate (Mohamed *et al.*, 2019) (Table 1).

#### **6-*Batkoa apiculata* (Thaxter) Humber**

*Batkoa apiculata* was reported in Egypt from *A. pisum* on clover and broad bean during January-February 2005 (Nada, 2006) (Table 1).

#### **7-*Batkoa major* (Thaxter) Humber**

The first record of fungus *B. major* in Egypt was on *E. decipiens* on bean plant during May-June 2003 in Giza Governorate (Nada, 2006). Ibrahim *et al.*, (2011) recorded *B. major* on *A. craccivora* in Dakahlia governorate during March and April 2009 (Table 1).

#### **8-*Conidiobolus thromboides* Drechsler**

*Conidiobolus thromboides* was recorded in Egypt from *R. padi* on maize plant in Monufia Governorate (Sewify and Ezz, 2000), from *R. padi*, *R. maidis* and *S. graminum* in Assiut Governorate (Abdel-Mallek *et al.*, 2004), from *Nezaraviridula* (L.) on Maize plant during April-June 2003 in Giza Governorate (Nada, 2006), and from *R. maidis* and *M. dirhodum* on barely plants in Giza Governorate (El-Fatih, 2006). (Table 1).

#### **9-*Conidiobolus coronatus* (Costantin) Batko**

*Conidiobolus coronatus* was recorded in Egypt for the first time from *Eriosonalanigera* (Hausm) on apple trees during May at Monufia Governorate (Sewify & Ezz, 2000). It was also recorded from *R. padi*, *R. maidis*, *S. graminum* in Assiut Governorate (Abdel-Mallek *et al.*, 2004), *Icerya seychellarum* from apple trees in Garbiya Governorate and

from *Aonidiella aurantii* on apple trees in Bany Suwayf Governorate, and grape and orange trees in Al-Fayoom and Ismailiya Governorates respectively (Ezz, 2004) (Table 1).

#### **10- *Conidiobolus Obscures* (I.M. Hall & P.H. Dunn) Remaud. & S. Keller**

The first record of *C. obscures* in Egypt was recorded on *R. padi*, *R. maidis* and *S. graminum* in Assiut Governorate (Abdel-Mallek *et al.*, 2004) (Table 1). Ibrahim *et al.*, (2011) recorded *C. obscures* from *A. craccivora* on broad beans and cowpea at Dakahlia governorate during April-June 2009.

#### **Pathogenicity of Entomophthorales fungi**

There were several reports on the pathogenicity of Entomophthorales against insects. To compare the controlling methods of the Californian aphid population in cotton, two releasing methods namely: chamber inoculation of *A. gossypii* and dried *N. fresenii*-infected cotton aphid “cadavers” and used. Both methods successfully introduced *N. fresenii* to cotton aphids and played a significant role in *A. gossypii* control (Steinkraus *et al.* 2002). The effect of three *P. neoaphidis* isolates against *Sitobion avenae* and *Rhopalosiphum padi* was studied by Saussure *et al.* (2019). Shah *et al.*, (2004) reported virulence of *P. neoaphidis* varies with aphid host species, host genotype (Stacey *et al.*, 2003; Parker *et al.*, 2017), geographic origin of the isolate (Barta & Cagán, 2009). It also varied even between isolates co-occurring in one aphid metapopulation (Sierotzki *et al.*, 2000; Barta & Cagán, 2009). Virulence of two Entomophthoralean fungi, *Pandora neoaphidis* and *Entomophthora planchoniana*, to their conspecific (*S. avenae*) and Heterospecific (*R. padi*) aphid hosts was carried out by Ben Fekih, *et al.* (2019). For the first time, the virulence of the two species of fungi was compared; both originated from *S. avenae* cadavers. The results showed that the conspecific host, *S. avenae*, was more susceptible to *E. planchoniana* infection than the heterospecific host *R. padi*. In the case of *P. neoaphidis*, Median Lethal Time 50 for *S. avenae* was 5.0 days as compared to 5.9 days for *E. planchoniana*. The LT50 for *S. avenae* was 4.9 days, while the

measured infection level in *R. padi* was always below 50 percent. Pathogenicity of *Z. radicans* against different insect pests was reported, which showed pathogenicity towards bagrada bug, *Bagrada hilaris* (Torres Acosta *et. al.*, 2016), Lepidopteran larvae (Walter *et. al.*, 2003) and whitefly *Trialeurodes vaporariorum* (Sanchez-Peña, 2002). The influence of the aphid-specific pathogen *Conidiobolus obscures* on the mortality and fecundity of bamboo aphids was carried out by Zhou *et al.*, (2013). At high concentrations of conidia, high mortalities (74-91%) caused by *C. obscures* were recorded in *Takecallistaiwanus*, *Takecallisarundinariae*, *Melanaphis bambusae*, and *Metamacropodaphis bambusisucta*.

### **Morphological features of fungi**

#### ***N. fresenii* (Figures 1-2)**

The hyphae are spherical and the primary conidia are sub-globose, with flattened basal papilla measuring 12-20  $\mu\text{m}$  x 13-15  $\mu\text{m}$  (16 x 14  $\mu\text{m}$ ) and 13-20.8  $\mu\text{m}$  x 10.4 -13  $\mu\text{m}$  (16.9 x 11.7  $\mu\text{m}$ ) for Giza and Sharkia isolates respectively. The secondary conidia, capilliconidia are almond-shaped measuring 20-30  $\mu\text{m}$  x 11-14  $\mu\text{m}$  (25 x 12.5  $\mu\text{m}$ ) and 20.8 -26  $\mu\text{m}$  x 13-15.6  $\mu\text{m}$  (13.4 x 14.3) for Giza and Sharkia isolates respectively, which are supported by capillary conidiophores of 20-30  $\mu\text{m}$  (Sewify, 2000). The resting spores were black to smoky-gray in color arising from conjugation between two spherical gametangia (Nada, 2006).

#### ***Pandora neoaphids* (Figures 3-4)**

Conidiophores are digitately branched at the apices. Primary conidia clavate to obovoid, uninucleate with basal papilla. Secondary conidia were nearly globose, whereas Rhizoids had prominent terminal discoid holdfast. Resting spores were not observed but primary conidia of *M. persicae*, *S. graminum* and *A. pisum* were of varying sizes: 15.6-23.4 x 7.8-13  $\mu\text{m}$ , 28.6-20.8 x 0.4-13  $\mu\text{m}$ , and 20.8-26 x 10.4-13  $\mu\text{m}$  respectively. The secondary conidia of *S. graminum* and *A. pisum* were 15.6-18.2 x 10.4-13  $\mu\text{m}$  and 7.8-13 x 15.6-20.8  $\mu\text{m}$  sizes respectively (Nada, 2006).

***E. planchoniana*(Figures 5)**

Conidiophores were simple, primary conidia had bell-shaped, flat papilla broad and pointed apexes with varying sizes (15.6-26 X 10.4 - 13 $\mu$ m). Secondary conidia were slightly smaller than primary conidia with variable sizes (13-18.2 X 7.8- 13 $\mu$ m) with rounded papillae. Rhizoids have the same diameter as conidiophores (Nada, 2006).

***B. apiculata*(Figures 6-7)**

Conidiophores were simple with a narrow neck between the conidium and conidiogenous cell. Primary and secondary conidia were globose, multinucleate with hemispherical papilla (Nada, 2006).

***Z. radicans* (Figures 8-9)**

Conidiophores are digitately branched with long, ovoid, and bullet-shaped conidia. The conical papilla slightly glowing or projecting when connected to the host conidia. Cystidia is untapped towards the apex but thicker than the hyphae at the base. Rhizoids had prominent terminal discoid holdfast and primary conidia of varying sizes (13 - 20.8 X 7.8 - 10.4 $\mu$ m (Nada, 2006).

***B. major* (Figures 10-11)**

Conidiophores are simple with narrow necks between conidium and conidiogenous cells. Primary and secondary conidia were globose and multinucleate. Papilla had pointed extension and rhizoids were with terminal discoid holdfasts. Resting spores were present with rhizoids having prominent terminal discoid holdfast. The fungus was recorded in *E. decipiens*, where primary conidia varied in size (23.4- 39 X 20.8- 28.6 $\mu$ m). The resting spores' size was variable (18.2- 28.6 X 18.2 -28. 6 $\mu$ m) (Nada, 2006).

***C. thromboides*(Figures 12-13)**

Conidiophores were simple and primary conidia were pyriform in shape with a basal papilla. Primary conidia were of variable sizes (26 - 39 X 31.2 - 20.8 $\mu$ m), which were isolated from *N. viridula*. The resting spores measured 26- 39 X 23.4- 36.4 $\mu$ m (Nada, 2006).

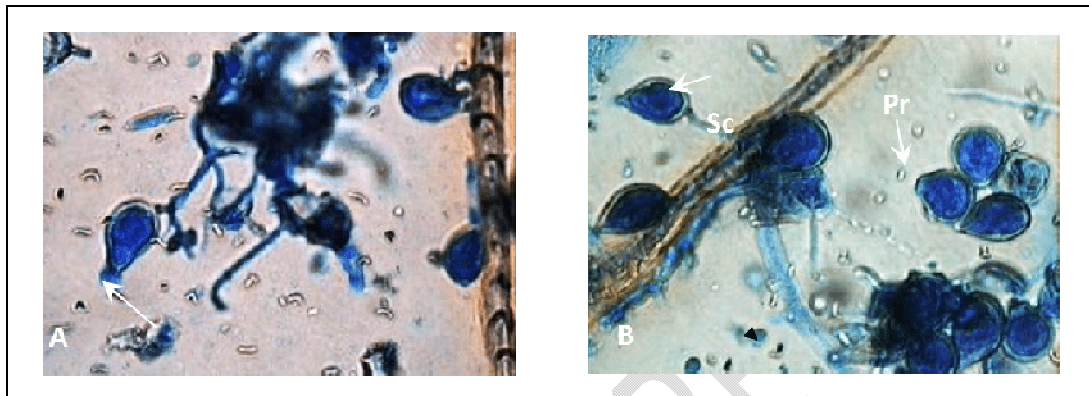


Fig. (1):Light micrographs showing *N. fressenii*infected aphid, *A. craccivora*: (A) Capilliconidia almond-shaped with a mucoid apical droplet (arrow) X1320; (B) Primary conidium with flattened basal papilla (Pr) and secondary capilliconidium(Sc) produced on capillary conidiophore arising from primary conidium X1320( Nada, 2006).

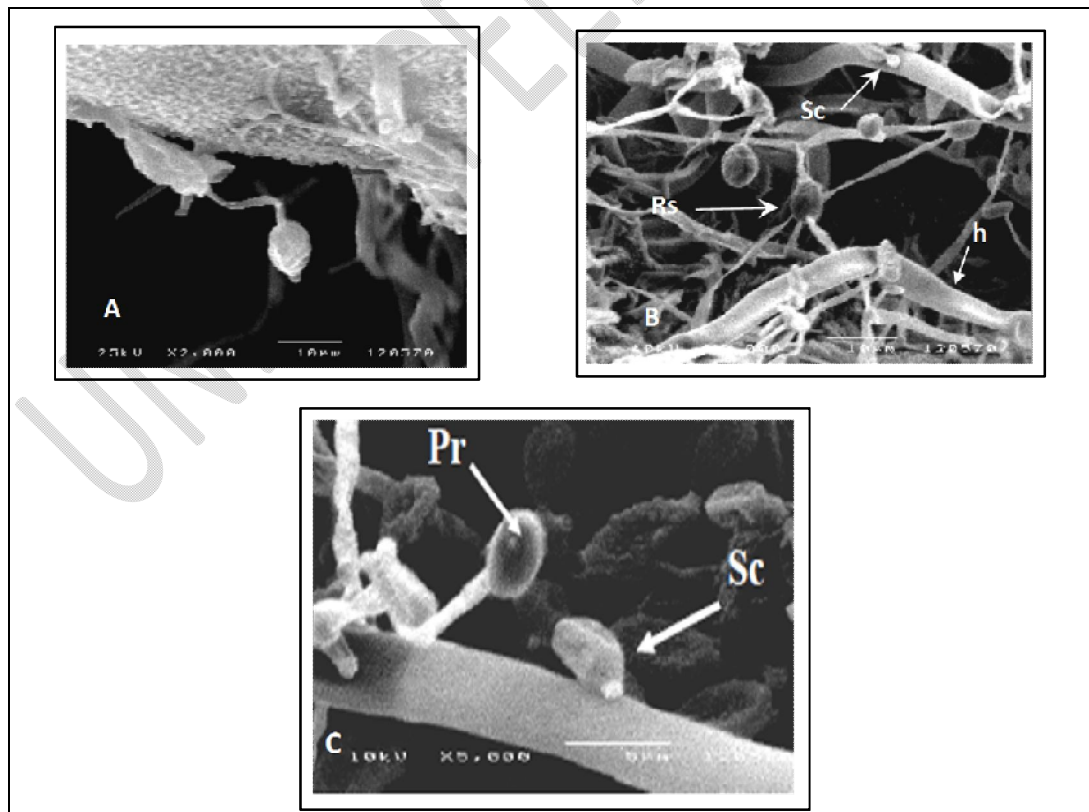


Fig. (2): Scanning electron microscopy showing *N. fresenii* infected aphid, *A. craccivora*: (A) Fungus *N. fresenii* showing secondary capilliconidium produced on capillary conidiophore arising from primary conidium X2000; (B) Fungus *N. fresenii* showing elongated hyphal body (h), capilliconidia with apical slime drop (Sc) and resting spore arising from conjugation bridge between gametangia (Rs) X2000; and (C) Fungus *N. fresenii* showing primary conidia attached to leg of *A. craccivora* X 3500.

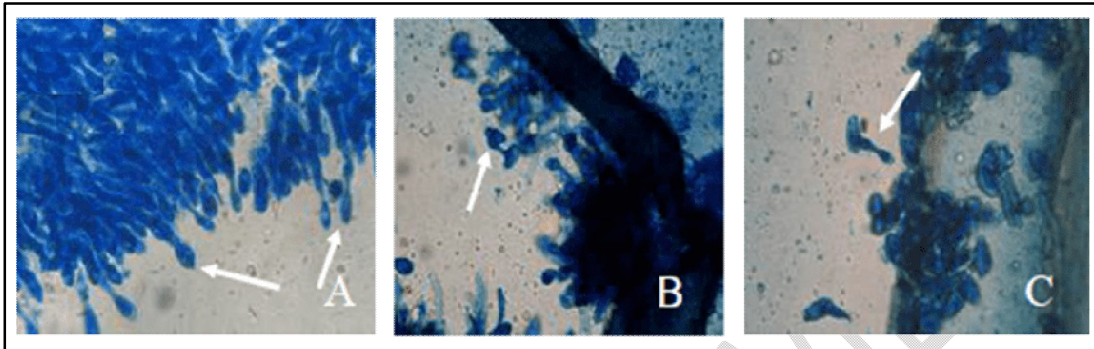


Fig. (3): Light micrographs showing *P. neoaphidis* infected aphid, *S. graminum*: (A) Conidiophores and primary conidia (arrow) of *P. neoaphidis* on *S. graminum* X600; (B-C) Primary conidia developed to secondary conidia (arrow) of fungus *P. neoaphidis* on *S. graminum* Leg X600 (Nada, 2006).

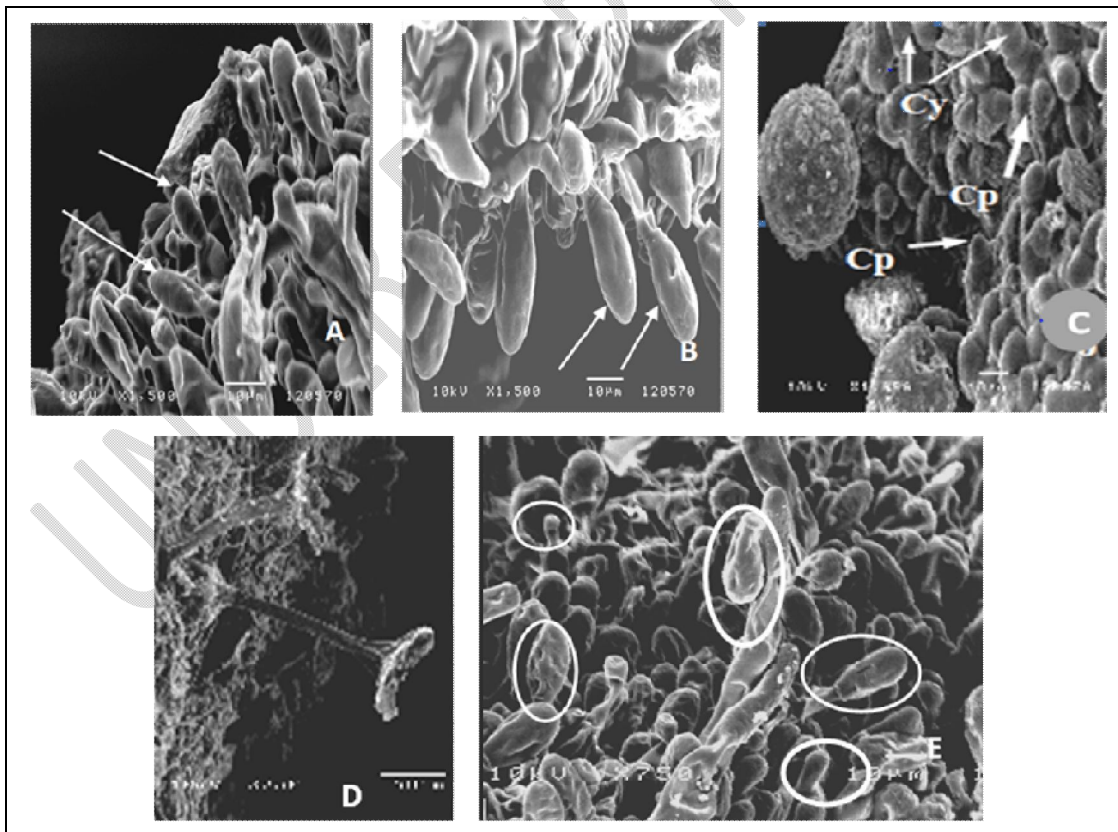
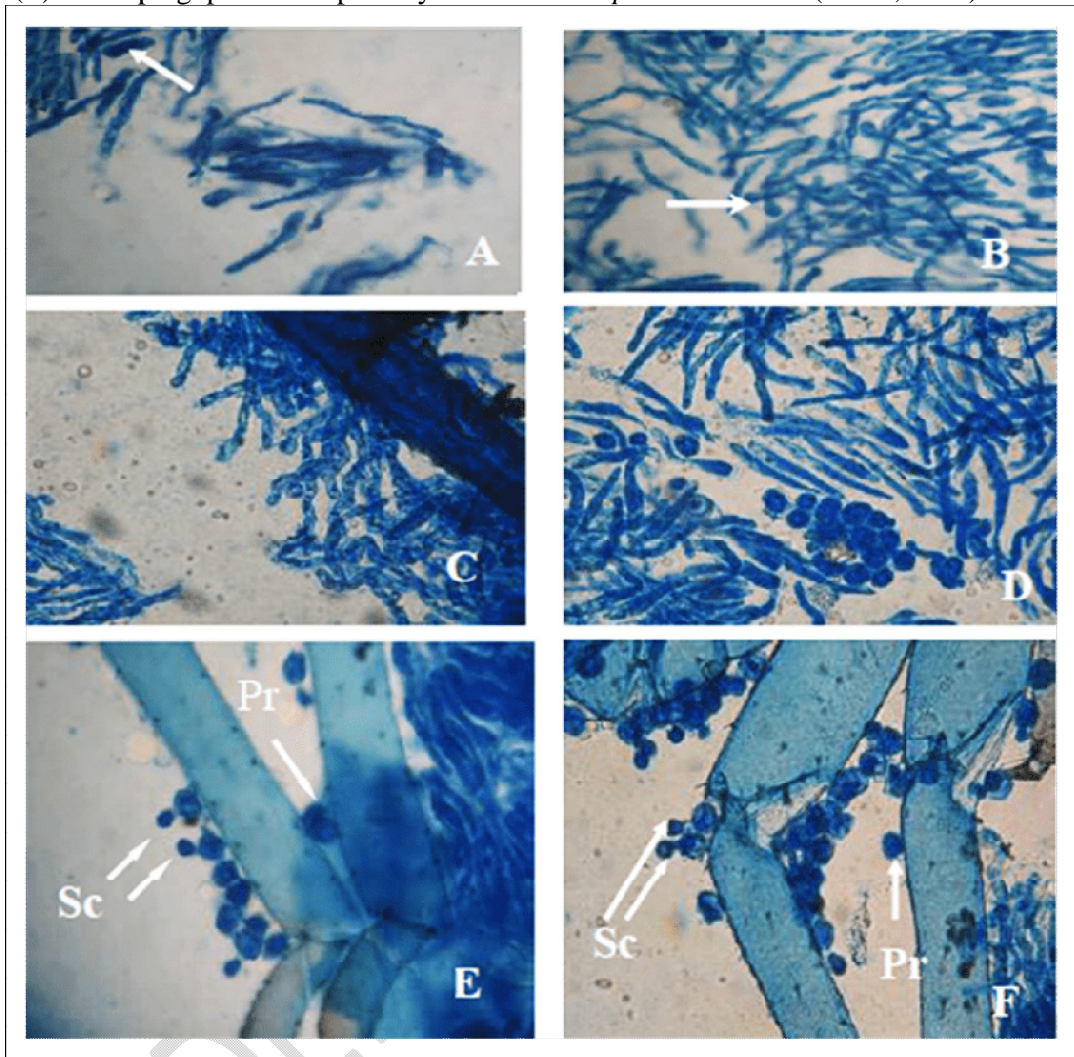


Fig. (4): Scanning electron microscopy showing *P. neoaphidis* infected aphid, *S. graminum*: (A-B) Cystidium and conidia of *P. neoaphidis* emerging from *S. graminum* head X150, 750; (C) Fungus *P. neoaphidis* showing early developing cystidia (Cy) and conidiophores

(Cp) breakthrough of the cuticle on *S. graminum*X1000, (D) Discoid terminal holdfasts of rhizoids emerging from the midventral region of infected *M. persicae*X 750; and (E)Developing process of primary conidia on *M. persicae*X1000 ( Nada, 2006).



**Fig. (5):**Light micrographs showing *E. planchoniana* infected aphid, *S. graminum*: (A) Monohyphal rhizoids with mother cell (arrow) X600; (B) Unbranched conidiophores bearing developing conidium (arrow) X600; (C) Unbranched conidiophores of *E. planchoniana* bearing developing conidium on leg of *S. graminum* (arrow) X600; (D) Unbranched conidiophores and discharged primary conidium with apiculus X600; and (E-F) Primary conidia with apiculus (arrow), broad, nearly flat basal papilla (Pr) and secondary conidia budding from the primary conidia (Sc) X600 (Nada, 2006).

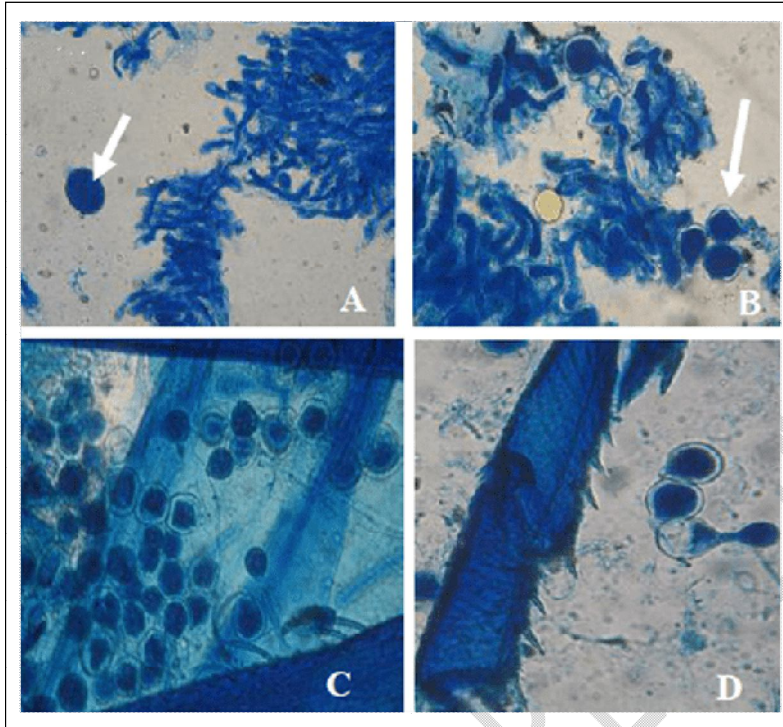


Fig. (6):Light micrograph showing *B. apiculata*infected *Ac. pisum*: (A) Fungus *B. apiculata*showing Simple conidiophores and globose resting spores (arrow) on *Ac. pisum*X600; (B) Conidiophores and globose primary conidia, discharged by papilla reversion (arrow) on *Ac. pisum*X600; (C) Aggregation of globose primary conidia attached with *Ac. pisum*wing X600; and (D) Primary conidia developing to secondary conidia X600 (Nada, 2006).

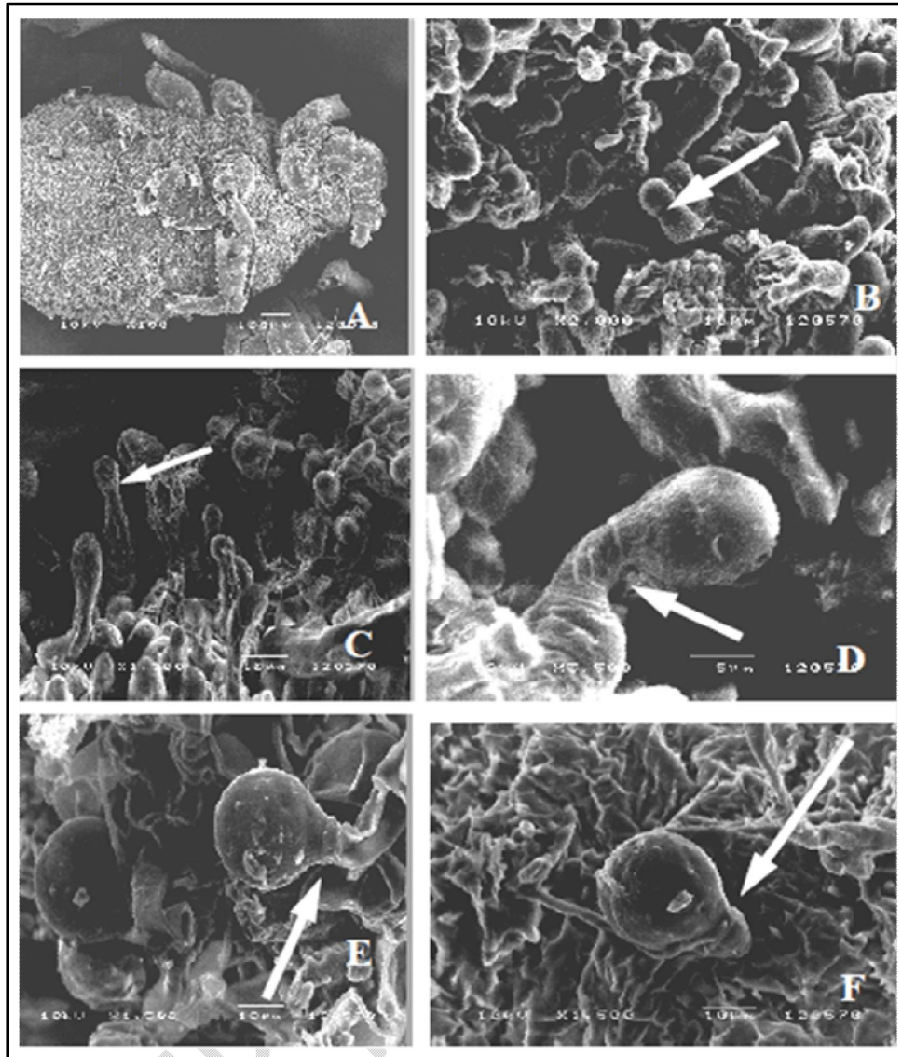


Fig. (7):Scanning electron microscopy showing *B. apiculata* infected *Ac. pisum*:(A) Conidiophores emerged through the host cuticle; (B-C) Developing conidia with narrow neck between Conidiogenous cell and conidia (arrows).(D - E) Primary conidia in the process of formation on the conidiophores (arrow). (F) Globes primary conidia discharged by papilla reversion on *Ac. pisum*(arrow) (Nada, 2006).

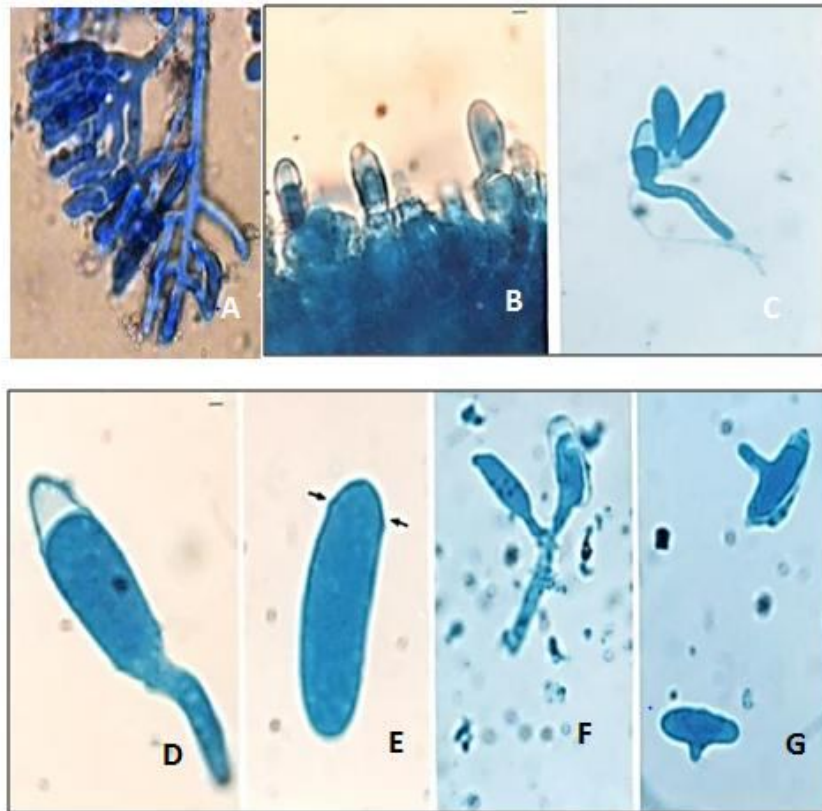


Fig. (8):Light micrographs showing *Z. radicans* infected *A. craccivora* and *E. decipiens*: (A) Branched conidiophores of *Z. radicans* on *E. decipiens*X660; (B) Emerging conidiophores and conidia from the host *A. craccivora*; (C) conidiophores and primary conidia from the host *A. craccivora*; (D-E) bullet-shaped to long ovoid conidia with a conical papilla, slight glow or projection (arrow) when the papilla is connected to the body of conidia on its host *A. craccivora*, (F) Branched conidiophores of *Z. radicans* infected *A. craccivora*, (G) Germinated primary conidia of *Z. radicans* on *A. craccivora* x1320 (Nada 2006 and Sewifyunpublished data).

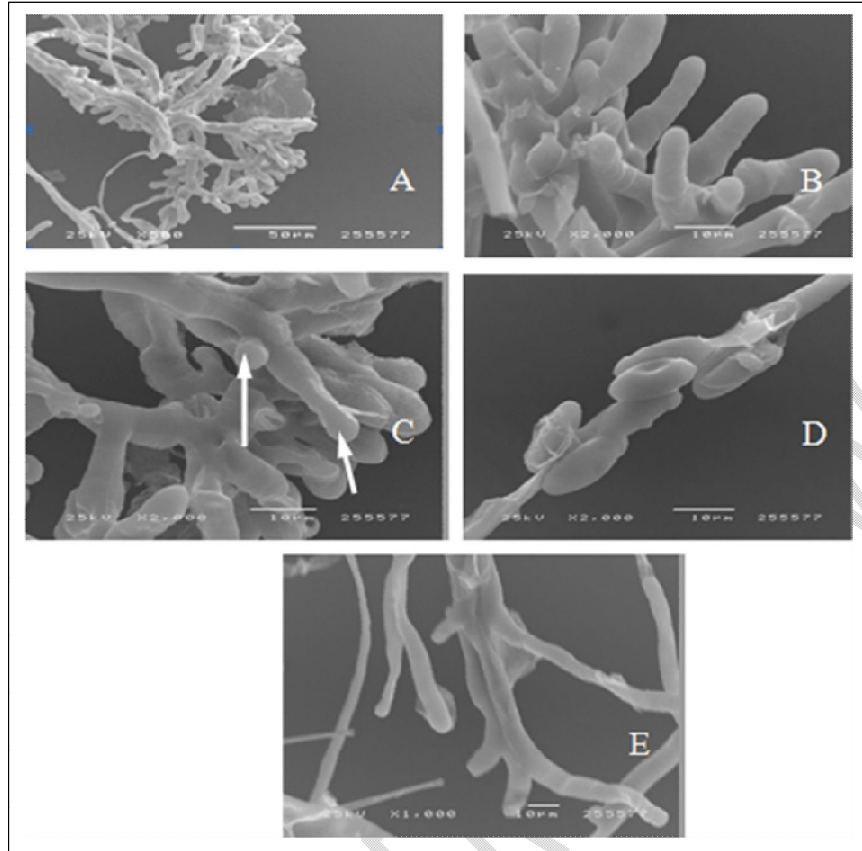


Fig. (9):Scanning electron microscopy showing *Z. radicans* infected *E. decipiens*: (A-B) Branched conidiophores of *Z.radicans* on *E. decipiens*X 500, 1000; (C) Developing process of primary conidia (arrow) of *Z. radicans* on *E. decipiens*X 2000; (D) primary conidia clavate with basal papilla rounded *E. decipiens*X 2000; and (E) Cystidium projecting from hymeniumX 1000 (Nada, 2006).

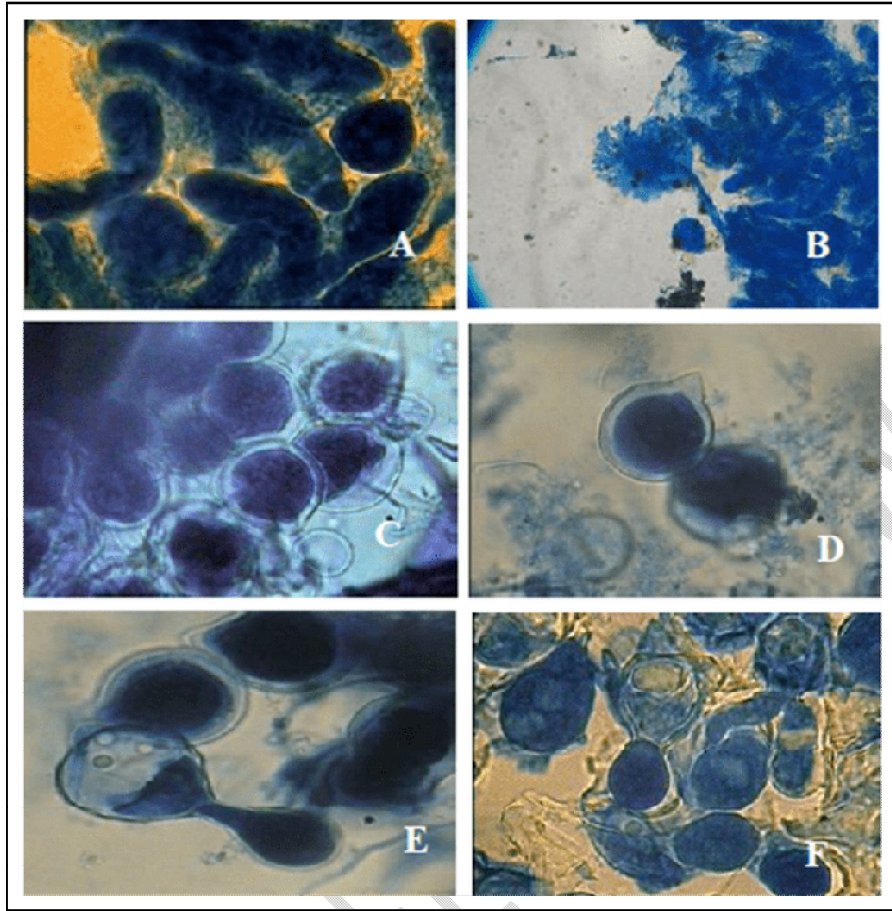


Fig. (10):Light micrographs showing *B. major* infected *E. decipiens*: (A) Simple conidiophores and globose primary conidia discharged by papilla reversion X1320; (B) Rhizoids with discoid terminal holdfasts X600; (C-D) Globosely primary conidia discharged by papilla reversion X1320; (E-F) Primary conidia developed to secondary conidia X 1320(Nada, 2006).

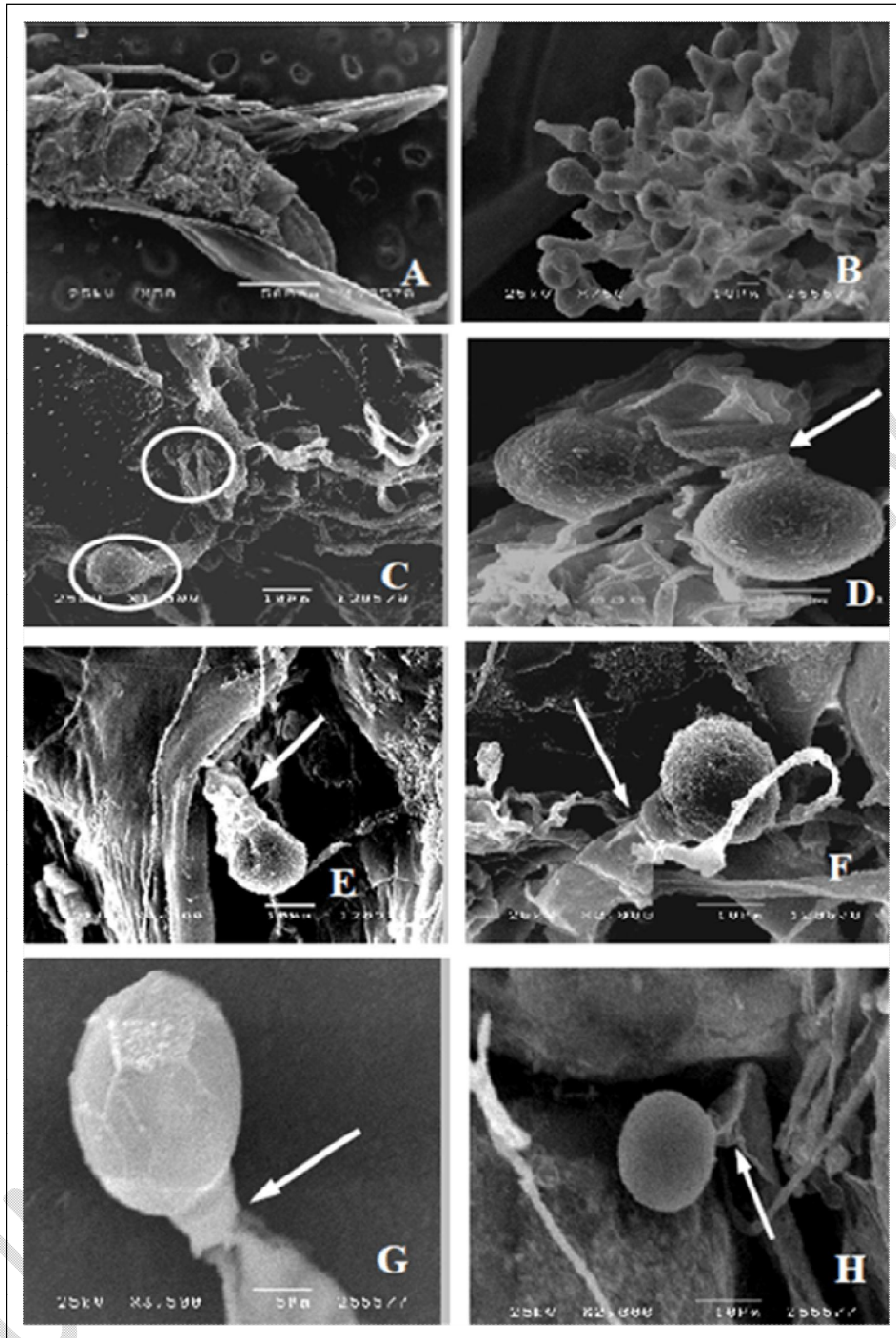


Fig. (11):Scanning electron microscopy showing *B. major* infected *E. decipiens*: (A) Overall view of mycosed *E. decipiens* with *B. major*, conidiophores emerged through the abdomen X 50; (B) Conidiophores and primary conidia of the *B. major* emerging through *E. decipiens* abdomen X 750; (C-D) Conidia of *B. major* in the process of formation on the conidiophores (arrows) X 1500, 1000; (E -F -G) Conidiophore of *B. major* ready to discharged primary conidia X 1500, 2000, 3500; and (H) Discharged primary conidia X 2000 (Nada, 2006)

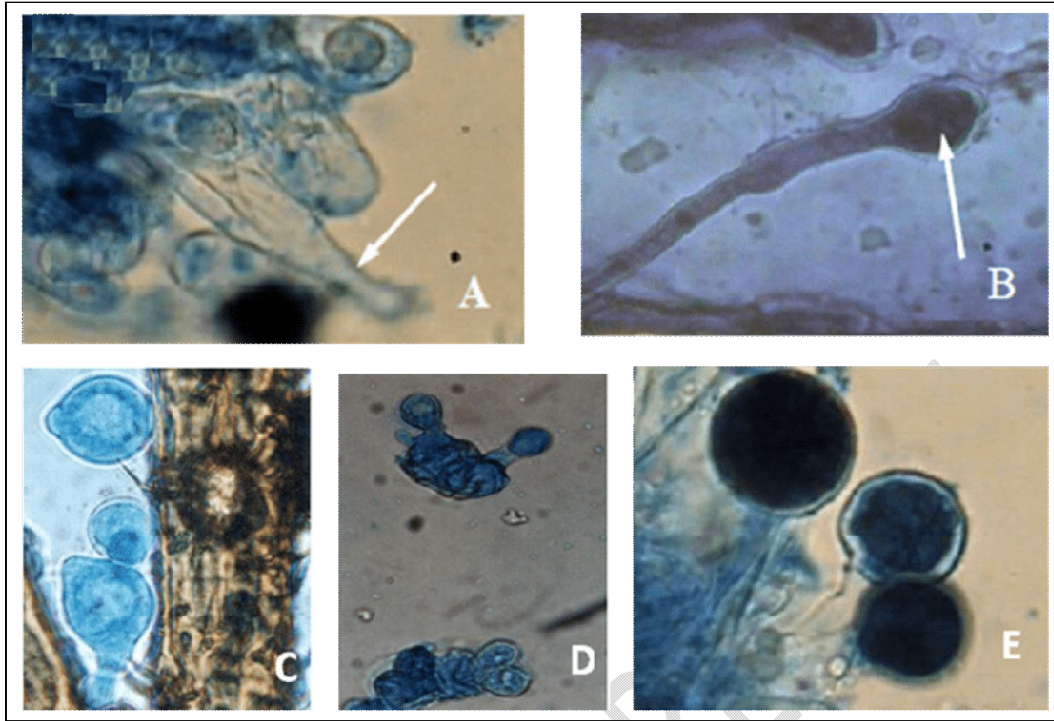


Fig. (12):Light micrographs showing *C. thromboides*infected *N. viridula*stink green bug:  
**(A)** Extended tips of Conidiogenous cells before conidia develop (arrow) on *N. viridula*X 400;  
**(B)** Developing conidia at apex of Conidiogenous cells and conidia X 400; **(C)**  
 Fungus *C. thromboides*showing conidiophores ready to discharged primary conidiumon *N.*  
*viridula*X 400 (Nada, 2006);**(D)** Globose conidia with hemispherical papilla attached with  
*R.padi* legs and **(E)** Germinated conidia on *R.padi* X 400 (Sewifyunpublished data).

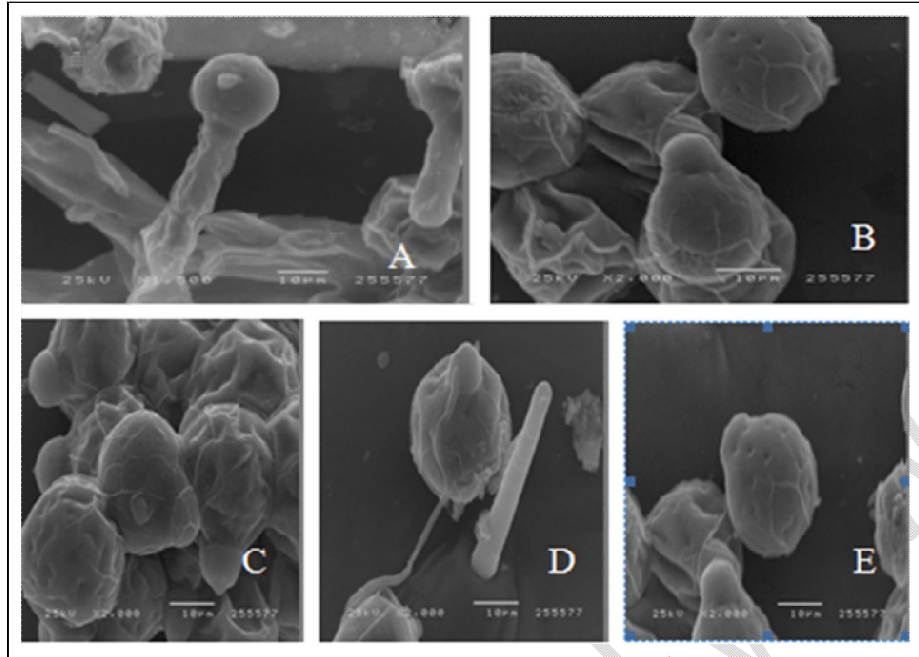


Fig. (13): Scanning electron microscopy showing *C. thromboides* infected *N. viridula* stink green bug (A) Conidia of *C. thromboides* in the process of formation on the conidiophores X 1500; (B) Conidiophore's of *C. thromboides* ready to discharge primary conidia X 2000; (C) Aggregation of the primary conidia of *C. thromboides* X 2000; and (D-E) Pyriform primary conidia discharged by papilla reversion X 2000 (Nada, 2006).

### Conclusion

This review focuses on the geographical distribution and morphological description of various entomophthoralean species, attacking sucking insects in Egypt. Up till now ten Entomophthorales fungi species belonging to three families have been recorded from sucking insects, which have served as their host. These fungi distributed in several Governorates, representing Lower and Upper Egypt, acquiring a wide range of climatic conditions. The review shows the need to do more efforts to isolate and define the group of these fungi by using modern identification techniques. Also, more studies are needed on their epidemiology and ability to predict their occurrence under climatic conditions in Egypt.

### Availability of data and materials

All data generated and/or analyzed during the present study are available in the manuscript, and the corresponding author has no objection to the availability of data and materials.

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Table (1): Entomophthorales fungi recorded from sucking insect species in Egypt

Family	Species	Host insect	Host plant	Locality Governorate	Time of occurrence	References
Neozygiteaceae	<i>Neozygitesfresenii</i> (Nowakowski) Batko	<i>A. craccivora</i>	faba bean	Giza	Nov.-Dec.	Sewify, 2000
		<i>A. craccivora</i>	broad bean	Sharkia	Nov.	Nada, 2006
		<i>A. craccivora</i>	Broad bean	Dakahlia	Dec.	Ibrahim <i>et al.</i> , 2011
		<i>S. graminum</i>	wheat plants	Assiut	Feb.-March	Moubasheret <i>et al.</i> ,2010
		<i>R. padi</i>	wheat plants	Assiut		
		<i>B. brassicae</i>	canola plants	Assiut	Feb.- March	El-Maraghyet <i>et al.</i> ,2015
		<i>R. padi</i>	wheat plants	Assiut		
		<i>R. padi</i>	wheat plants	Assiut	Jan. –Feb.	Mohamed <i>et al.</i> , 2019
		<i>R. maidis</i>	wheat plants	Assiut	Jan. –Feb.	
<i>S. graminum</i>	wheat plants	Assiut	Jan. –Feb.			
Entomophthoraceae	<i>Pandora neoaphidis</i> (Re maud. &Hennebert)	<i>R. padi</i>	graminaceous weeds	Giza	March	Sewify and Ezz, 2000
		<i>R. padi</i>	-	Assiut	-	Abdel-malleket <i>et al.</i> ,2004
		<i>R. maidis</i>	-			
		<i>S. graminum</i>	-			

		<i>S. germanium</i>	Annual sow thistle Wheat barley-Wild oat	Giza	Jan.-April	Nada, 2006
		<i>Ac. pisum</i>	Clover- Chicory	Giza	Jan.-Feb.	
		<i>M. persicae</i>	Annual sowthistle	Sharkia	Dec. - Jan.	
		<i>R. maidis</i>	barely plants	Giza	-	El-Fatih,2006
		<i>M. dirhodum</i>	barely plants	Giza	-	
		<i>S. graminum</i>	wheat plants	Assiut	Feb. – March	Moubasheret <i>et al.</i> ,2010
		<i>R. padi</i>	wheat plants			
		<i>B. brassicae</i>	canola plants			
		<i>R. padi</i>	wheat plants	Assiut	Feb. – March	El-Maraghyet <i>et al.</i> ,2015
		<i>Sitoboinavenae</i>	wheat plants	El-Gharbia	Dec.-April	El-Sham and El-Sheikh, 2018
		<i>R. padi</i> L.	wheat plants	Assiut	Jan. –Feb.	Mohamed <i>et al.</i> , 2019
		<i>R. maidis</i>	wheat plants	Assiut	Jan. –Feb.	
	<i>S. graminum</i>	wheat plants	Assiut	Jan. –Feb.		
	<i>Pandora delphacis</i> (Hori) Humber	<i>E. decipiens</i>	clover	Giza	Jan.-April	Nada, 2006
	<i>Entomophthoraplanc honiana</i> Cornu	<i>S. graminum</i>	wheat, barley and wild oat	Giza	Jan.-March	Nada, 2006
		<i>R. padi</i>	-	Assiut	-	Abdel-Mallek <i>et al.</i> ,2004
		<i>R. maidis</i>	-			
		<i>S. graminum</i>	-			
		<i>S. graminum</i>	wheat plants	Assiut	Feb.-March	Moubasheret <i>et al.</i> ,2010
		<i>R. padi</i>	wheat plants			
		<i>B. brassicae</i>	canola plants			
	<i>R. padi</i>	wheat plants	Assiut	Feb.-March	El-Maraghyet <i>et al.</i> ,2015	
	<i>Zoophthora radicans</i> (Brefeld)Batko	<i>R. padi</i>	Maize	Monufia	May	Sewify and Ezz, 2000
		<i>R. padi</i>	-	Assiut	-	Abdel-malleket <i>et al.</i> ,2004
		<i>R. maidis</i>	-			
		<i>S. graminum</i>	-			
<i>E. decipiens</i>		bean	Giza	Dec. -Feb.	Nada, 2006	
<i>S. graminum</i>		wheat plants	Assiut	Feb.- March	Moubasheret <i>et al.</i> ,2010	
<i>R. padi</i>		wheat plants	Assiut			
<i>B. brassicae</i>	canola plants	Assiut				
	<i>R. padi</i>	wheat plants	Assiut	Jan.- Feb.	Mohamed <i>et al.</i> , 2019	
	corn leaf aphid, <i>R. maidis</i>	wheat plants	Assiut			
	<i>S. graminum</i>	wheat plants	Assiut			
	<i>Batkoaapiculata</i> (Thaxter) Humber	<i>Ac. pisum</i>	clover, and broad bean	Giza	Jan.- Feb.	Nada, 2006
	<i>Batkoa major</i> (Thaxter) Humber	<i>E. decipiens</i>	bean	Giza	Dec. - Feb.	Nada, 2006
	<i>A. craccivora</i>	Broad bean	Dakahlia	March-April	Ibrhaimet <i>et al.</i> , 2011	

Table (1): Continuous

Family	Species	Host insect	Host plant	Locality Governorate	Time of occurrence	References
Ancylistaceae	<i>Conidiobolusthromboides</i> Drechsler	<i>R. padi</i>	graminaceous weeds	Giza	March	Sewify and Ezz, 2000
		<i>R. padi</i>	-	Assiut	-	Abdel-malleket <i>et al.</i> ,2004
		<i>R. maidis</i>	-			
		<i>S. graminum</i>	-			
		<i>N. viridula</i>	Maize	Giza	April- June	Nada, 2006
		<i>R. maidis</i>	barely plants	Giza	-	El-Fatih,2006
	<i>M. dirhodum</i>	barely plants	Giza	-		
	<i>Conidioboluscoronatus</i> (Costantin) Batko	<i>E. lanigera</i>	Apple trees	Monufia	May	Sewify and Ezz, 2000
		<i>R. padi</i>	-	Assiut	-	Abdel-malleket <i>et al.</i> ,2004
		<i>R. maidis</i>	-			
		<i>S. graminum</i>	-			
		<i>S. graminum</i>	wheat plants	Assiut	Feb. – March	Moubasheret <i>et al.</i> ,2010
		<i>R. padi</i>	wheat plants	Assiut		
<i>B. brassicae</i>		canola plants	Assiut			

		<i>I. seychellarum</i>	apple	Garbiya		Ezz, 2004
		<i>A. aurantii</i>	Apple	Bany Suwayf		
			Grape	Al-Fayoom		
			Guava	Ismailiya		
			Orange			
	<i>R. padi</i>	wheat plants	Assiut	Jan.- Feb.	Mohamed <i>et al.</i> , 2019	
	<i>R. maidis</i>	wheat plants				
	<i>S. graminum</i>	wheat plants				
	<i>Conidiobolus Obscures</i> (I.M. Hall & P.H. Dunn) Remaud. & S. Keller	<i>R. padi</i>	-	Assiut	-	Abdel-Mallek <i>et al.</i> ,2004
		<i>A. craccivora</i>	Broad bean	Assiut	April	Ibrahim <i>et al.</i> , 2011
		cowpea	Dakahlia	May- June	Ibrahim <i>et al.</i> , 2011	

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