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Joint use of insects and fungal pathogens in the management of waterhyacinth (*Eichhornia crassipes*): Perspectives for Ethiopia

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ABSTRACT

Waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] remains one of the worst aquatic weeds worldwide. Its presence in Ethiopia was officially reported in Koka Lake and Awash River about 60 yr ago. Experiences worldwide indicate that the use of bioagents is the most economical and sustainable control measure for waterhyacinth. In Ethiopia, the management of this invasive weed using bioagents is still in an experimental stage. However, the use of bioagents against waterhyacinth at the national level has currently received attention, and researchers have become engaged in surveys and programs to introduce and evaluate native, as well as classical, bioagents. The mottled waterhyacinth weevil (*Neochetina eichhorniae* Warner) and the chevroned waterhyacinth weevil (*Neochetina bruchi* Hustache) are the most successful bioagents released worldwide so far. A modeling tool, CLIMEX, has been applied to predict *N. eichhorniae* and *N. bruchi* potential distribution and adaptability in Ethiopia. Accordingly, the Ecoclimatic Index and Climate Matching results suggest that these weevils could be a potential bioagent for waterhyacinth in Ethiopia. On the other hand, 25 fungal isolates were collected during the recent survey in addition to the known prevalence of the fungus *Cercospora rodmanii* Conway. This indicates the opportunity for the joint use of fungal pathogens and the waterhyacinth weevils. In the article, the use of insects and pathogens, their host specificity and their herbivory/virulence effect, as well as recent advances in the use of those bioagents to manage waterhyacinth are discussed.

Key words: classical bioagent, mycoherbicides, native bioagent.

INTRODUCTION

Waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] is one of the worst aquatic weeds in the world. It originates from the Amazon and has disseminated quickly in many tropical and subtropical countries of Latin America, the United States and the Caribbean, Africa, Southeast Asia, and the Pacific region (Julien et al. 1999, Julien 2001). Its erect, free-floating habit and showy flowers made it attractive for use in ornamental ponds and garden pools, which inevitably led to anthropogenic spread. Center et al. (2002) and Cilliers et al. (2003) reported that waterhyacinth was spread around the world primarily by people and by shared watersheds. Similarly, in Ethiopia, the weed is believed to have been introduced by people for decorative purpose. Waterhyacinth was officially reported in Ethiopia about 60 yr ago in Koka Lake and the Awash River (Stroud 1994). Infestations have now manifested on a large scale in many water bodies of Ethiopia, such as the Sobate, Baro, Gillo, and Pibor rivers, found in the Gambella area; the Abay River, just south of Lake Tana, Lake Zeway, and Lake Ellen; the Koka dam; and in reservoirs, irrigation supplies, and drainage structures of the Wonji/Shoa and Metahara sugar estates, located along the Awash River (Stroud 1994, Rezene 2005, Taye et al. 2009).

Biological control of waterhyacinth, using natural enemies, has been reported to be the most economical and sustainable method of control because it persists with little ongoing cost and no negative environmental impacts (Julien et al. 1999). There are 2 approaches used in biological control: classical biological control and nonclassical biological control. *Classical biological control* involves the introduction of natural enemies from their native range into an exotic range where the host plant has become a weed. *Nonclassical biological control* concentrates on the use of native, inundative (release of large numbers of the agent to control the target weed, e.g., mycoherbicides) or augmentative (Harley and Forno 1992, Adkins 1997, Auld 1997) natural enemies. Waterhyacinth is a primary target for classical biological control, in which natural enemies from the plant's center of origin are screened, reared, and released into the areas newly invaded by the target plant.

Insects and pathogens are known to have a controlling effect on waterhyacinth. Research into the biological control of waterhyacinth was initiated by the U.S. Department of Agriculture (USDA) in 1961, and to date 6 arthropods that attack waterhyacinth in its region of origin have been released for biocontrol in a number of countries. The most successful of these arthropods are 2 species of *Neochetina* Hustache weevils (Julien 2001): the mottled waterhyacinth weevil (*Neochetina eichhorniae* Warner) and the chevroned waterhyacinth weevil (*Neochetina bruchi* Hustache) (Coleoptera, Curculionidae). A recent study by the International Institute of Tropical Agriculture (Ibadan, Nigeria) estimated that biological control of waterhyacinth

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through the introduction, mass rearing and releasing of *N. eichhorniae* and *N. bruchi*, would yield a benefit–cost ratio of 124 : 1 in the Republic of Benin during the next 20 yr (De Groote et al. 2005). Moreover, several highly virulent pathogens of waterhyacinth have been studied and are promising candidates for biocontrol (Charudattan 2001a).

Combined use of biological control agents (*bioagents*) has been advocated as the best prospect for long-term management of aquatic weeds (Charudattan 2001a,b, Evans and Reeder 2001). In line with that, efforts are being made to assess the integration of insect pests and fungal pathogens for the management of waterhyacinth (Moran 2005, 2006, Martinez and Gomez 2007). Similarly, research is being conducted to complement the effect of weevils with other arthropods in the management of waterhyacinth (Coetzee et al. 2007).

Despite successes elsewhere with bioagents, combined and alone, in managing waterhyacinth, biological control of waterhyacinth has not yet been started in Ethiopia, and waterhyacinth continues to cause serious problems. Thus, we reviewed the use of insects and pathogens, their host specificity, and their herbivory/virulence effect against waterhyacinth, as well as recent advances in the use of those bioagents (insects and pathogens) for managing waterhyacinth. The opportunities for extending the use of those bioagents in Ethiopia were evaluated for the sustainable management of waterhyacinth in the country.

USE OF INSECTS AS BIOAGENTS OF WATERHYACINTH

Review on use of insects in waterhyacinth management

Surveys for natural enemies of waterhyacinth for use as biological control agents began in 1962. The first survey was conducted in Uruguay, from 1962 to 1965. During that period, the waterhyacinth stalk borer moth [*Xubida* (=*Acigona*) *infusellus* Walker (Lepidoptera: Pyralidae)]; 2 weevil species, *N. eichhorniae* and *N. bruchi*; the waterhyacinth mite [*Orthogalumna terebrantis* Wallwork (Acarina: Galumnidae)]; and the waterhyacinth grasshopper [*Cornops aquaticum* Bruner (Orthoptera: Acrididae, Leptysminae)] were recorded, among other species. The petiole-tunneling moth, called the waterhyacinth stem borer [*Niphograpta* (=*Sameodes*) *albiguttalis* Warren (Lepidoptera: Pyralidae)]; 7 species of petiole-boring flies [*Thrypticus* spp. Gerstaecker (Diptera: Dolichopodidae)]; and the waterhyacinth mirid bug [*Eccritotarsus catarinensis* Carvalho (Heteroptera: Miridae)] were added to the list of biocontrol agents in 1968 surveys conducted in Guyana, Surinam, and Brazil (Center 1994, Julien et al. 2001). In the early 1970s, the USDA and International Institute of Biological Control (now CABI Bioscience) released the weevils *N. eichhorniae*, *N. bruchi*, and later, the pyralid moth *Niphograpta albiguttalis*. *Orthogalumna terebrantis* and the stem-boring moth, the pickerelweed borer [*Bellura densa* Walker (Lepidoptera: Noctuidae)] were also recorded in surveys conducted in the United States in the 1960s. In 1989, the mirid *E. catarinensis* was collected in Brazil (Hill et al. 1999).

About 19 of 43 arthropod species have been identified as potential control agents because of the damage they cause or because of their narrow host range (Perkins 1974). Cordo (1999) and Center et al. (2002) have listed these species according to their priorities for biological control. Accordingly, the arthropods were categorized into 3 priority groups. The first-priority group includes agents in use worldwide, such as *N. eichhorniae*, *N. bruchi*, *Niphograpta albiguttalis*, and *O. terebrantis*. The second-priority group includes candidates recently released or under testing: *E. catarinensis*, *X. infusellus*, *C. aquaticum*, *B. densa*, paracles tenuis [*Paracles* (=*Palustra*) *tenuis* Berg (Lepidoptera: Arctiidae)], and *Thrypticus* spp. The third-priority group, includes candidates that are poorly known or of questionable specificity (mostly with no recorded common names): a bombardier beetle [*Brachinus* Weber sp. (Coleoptera: Carabidae)], a waterhyacinth moth [*Argyractis subornata* Hampson (Lepidoptera: Pyralidae)], a root-feeding rice pest [*Macrocephala acuminata* Dallas (Heteroptera: Pentatomidae)], a planthopper [*Taosa inexacta* Walker (Homoptera: Dictyopharidae)], 2 Argentine species of planthoppers [*Megamelus electrae* Muir and *Megamelus scutellaris* Berg (Homoptera: Delphacidae)], a stem miner [*Eugaurax setigena* Sabrosky (Diptera: Chloropidae)], a petiole-mining midge [*Chironomus falvipilus* Rempel (Diptera: Chironomidae)], a shore fly [*Hydrellia* sp. Robineau-Desvoidy (Diptera: Ephydridae)], and a mite [*Flechtmannia eichhorniae* Keifer (Acarina: Eriophyidae)]. The biology, host-specificity, and potential for the management of waterhyacinth for *M. scutellaris* have recently been better understood (Sosa et al. 2004, 2005, 2007a,b, Tipping et al. 2010). In addition, those findings indicated that *M. scutellaris* was highly specific to waterhyacinth and provided 70% biomass and 73% leaf reduction (Tipping et al. 2010). Hence, that bioagent would be better categorized as belonging to the second-priority group. Table 1 lists potential insects being used or recently released for the management of waterhyacinth and their types of damage.

Currently, biological control of waterhyacinth in different parts of the world relies on 2 weevil species (*N. eichhorniae* and *N. bruchi*), the pyralid moth (*Niphograpta albiguttalis*), the mite *O. terebrantis*, and the mirid *E. catarinensis* (Julien and Griffiths 1998, Julien et al. 2001, Coetzee et al. 2005). These agents reduced waterhyacinth growth and densities, plant stature, and possibly, seed production (Center and Durden 1986, Center 1994, Center et al. 1990, 1999a,b, Julien et al. 1999, Coetzee et al. 2005). Recent research has targeted *C. aquaticum* (Bownes et al. 2010a,b), *M. scutellaris* (Sosa et al. 2005, 2007a,b, Tipping et al. 2010), and other potential candidate arthropods. Therefore, details of these bioagents are reviewed below:

Neochetina eichhorniae and *N. bruchi*. *Neochetina eichhorniae* and *N. bruchi* have been released on waterhyacinth in 30 and 27 countries, respectively (Center et al. 2002). Both have been subjected to extensive screening. They have been tested against 274 plant species in 77 families worldwide (Julien et al. 1999). In Africa, these weevils were released in Benin, Burkina Fasso, Congo Cote d'Ivoire, Egypt, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe (Cillers et al. 2003).

Table 1. Status of arthropods for the management of waterhyacinth.

Species	Type of Damage	Status
N. eichhorniae Warner (Coleoptera: Curculionidae)	Adults feed on foliage and petioles; larvae tunnel in petioles, stolons, and crown	In use in North America, Australia, Africa, and Asia (Julien and Griffiths 1998)
N. bruchi Hustache (Coleoptera: Curculionidae)	Adults feed on foliage and petioles; larvae tunnel in petioles, stolons, and crown	In use in North America, Australia, Africa, and Asia (Julien and Griffiths 1998)
N. albiguttalis Warren (Lepidoptera: Pyralidae)	Larvae tunnel in petioles and buds	In use in North America, Australia, Africa, and Asia (Julien and Griffiths 1998)
O. terebrantis Wallwork (Acarina: Galumnidae)	Immature tunnel in laminae	In use in North America and Africa (Julien and Griffiths 1998)
E. catarinensis Carvalho (Heteroptera: Miridae)	Nymph and adult feed on leaves	Released in Zimbabwe, Zambia, Malawi, Benin, South Africa, and China; however, established in Malawi and South Africa (Coetzee et al. 2005)
X. infusellus Walker (Lepidoptera: Pyralidae)	Larvae tunnel in laminae and petioles	Released in Australia, Thailand, and Papua New Guinea (Julien et al. 2001b). Recent study indicated that this agent can be used in areas where Pickerelweed is not present or considered important relative to waterhyacinth problem (Stanley et al., 2007)
C. aquaticum Bruner (Orthoptera: Acrididae, Leptysminae)	Nymph and adult feed on leaves	In South Africa, a release permit granted in 2007; in addition, potential impact assessment showed this insect could contribute to a reduction in the density and spread of waterhyacinth (Bownes et al. 2010a,b)
B. densa Walker (Lepidoptera: Noctuidae)	Larvae tunnel in petioles and buds	Current study confirmed that *B. densa* prefers plants in the Pontederiaceae, such as wild taro [*Colocasia esculenta* (L.) Schott]. Hence, it is recommend that it be used within North America only (Center and Hill 2002)
P. tenuis Berg (Lepidoptera: Arctiidae)	Larvae and adult feed on leaves	Polyphagous in laboratory testing. It developed readily on tropical pickerelweed (*Pontederia rotundifolia* L.), and joyweed (*Alternanthera* Forssk.), canna (*Canna* L.), spongeplant (*Limnobium* Rich.), and arrowhead (*Sagittaria* L.) species Rejected for further studies (Cordo 1999)
Thrypticus spp. (7 species) (Dipterous: Dolichopodidae)	Larvae tunnel in petioles	The mining flies *Thrypticus truncatus* Bickel & Hernández and *Thrypticus sagittatus* Bickel & Hernández reproduce on waterhyacinth and are host specific (Hernandez 2008). Their effect on the host is under investigation. A number of potential fungal pathogens were found in association with the larvae of these 2 flies (Hernández et al. 2007)
M. scutellaris Berg (Homoptera: Delphacidae)	Nymph and adult feed on laminae and petioles	In America, a release permit was granted in 2010 and release has been conducted in selected locations (Tipping et al. 2010)

Neochetina eichhorniae and *N. bruchi* are the most successful bioagents used for the control of waterhyacinth. In East Africa (Uganda), the 2 weevils, at 5 yr after release in Lake Victoria, experienced a rapid build-up in population (average, 17 to 25 weevils plant^{-1}), which reduced weed biomass about 80% (Ogwang and Molo 2004). Those results were later repeated on the Kenyan and Tanzanian shores (Mallaya et al. 2001, Ochiel et al. 2001). Similarly, in West Africa (Benin), the weevils reduced the waterhyacinth cover from 100% to 5% within 8 yr (Ajuonu et al. 2003). In northern Africa (Egypt), *N. eichhorniae* and *N. bruchi* were released in August 2000 on 2 lakes. By July 2002, waterhyacinth on Lake Edko was reduced by 90% (Cillers et al. 2003). That success in Africa was reaffirmed in Mexico, where a 20 to 80% reduction of the waterhyacinth population occurred within 2 to 3 yr after release (Aguilar et al. 2003).

Niphograpta albiguttalis. Julien and Griffiths (1998) reported that *N. albiguttalis* had been released in more than 10 countries; however, its establishment has been confirmed only in Australia, South Africa, the Sudan, the United States, Thailand, and Malaysia.

Orthogalumna terebrantis. Although the *O. terebrantis* mite has infested various populations of waterhyacinth for considerable periods, it has not contributed to control of the weed (Julien 2001). The mite was first released in Zambia in 1971 and then, in India, during 1986. It is present in Mexico, Cuba, Jamaica, the southern United States, and South America and has spread from Zambia to Malawi, Mozambique, South Africa, and Zimbabwe (Julien and Griffiths 1998).

Eccritotarsus catarinensis. The mirid *E. catarinensis* has been released in South Africa at about 18 sites since 1996 (Hill et al. 1999) and has established at 15 sites. Subsequent evaluations have demonstrated that it affects waterhyacinth growth (Coetzee et al. 2007) and competitive ability (Coetzee et al. 2005, Ajuonu et al. 2009), by reducing the plant's overall vigor. *Eccritotarsus catarinensis* has also been released in Zimbabwe, Zambia, Malawi, Benin, and China but only established in Malawi (Coetzee et al. 2009). It was, however, rejected for release in Australia because of possible damage to populations of native monochoria [*Monochoria vaginalis* (Brum. f.) Kunth] (Stanley and Julien 1999). In South Africa, feeding, oviposition, and nymphal development of the mirid were recorded on pickerelweed (*Pontederia cordata* L.), an important aquatic plant in North America but a potential weed in South Africa. The release of this agent in the field confirmed that pickerelweed was not part of the mirid's realized host range. *Eccritotarsus catarinensis* is emerging as an effective agent in areas of medium to low nutrient status with a warm climate and would be considered for release in other areas (Coetzee et al. 2009).

The present review of potential insect bioagents of waterhyacinth indicated that, although a large number of arthropods have been identified and found in association with waterhyacinth, only 6 are in use or confirmed for release. There is a clear and distinctive difference in the success of these agents in different parts of the world.

Among the 6 arthropods, the 2 weevils exhibited the best success in the tropics, especially in the eastern and western parts of Africa, where great success was recorded within 3 to 10 yr. Besides the 2 weevils, success was recorded with the use of the moth *Niphograpta albiguttalis*. The success recorded from these well-established bioagents was unsatisfactory in temperate regions. Accordingly, researchers in South Africa and the United States have made efforts toward evaluating other potential herbivores, such as *E. catarinensis* and *C. aquaticum* (Coetzee et al. 2005, Bownes et al. 2010b). Consequently, great achievements have been realized with the use of the mirid in South Africa, which may promote its use in the United States (Coetzee et al. 2009).

The relatively stable performance of the 2 weevils in tropical regions, such as Papua New Guinea (Julien and Orapal 1999), Benin (Ajounu et al. 2003), on Lake Victoria in Uganda, and in Tanzania and Kenya (Mallya et al. 2001, Ochiel et al. 2001, Ogwang and Molo 2004) indicates a potential for use of these weevils in Ethiopia. Williamson (1996) reported that, when deliberate introductions of natural enemies are made for biological control, they should be species or strains from climatically matched area. There should be a prerelease assessment of the weevil efficacy and adaptability, and a confirmatory host-specificity study should be conducted on the indigenous and economical crops of the country. Success of biological control agents appears to depend on their abundance, distribution, and per capita damage (McClay and Balciunas 2005). Unfortunately, there is currently no reliable approach for accurately predicting postrelease abundance of a species before release. However, several methods have been developed to estimate distribution range and per capita damage of the biological control agent. Modeling tools, such as CLIMEX, enable us to predict an organism's potential distribution in the area of introduction (Sutherst et al. 2000). Experimental studies in quarantine or at rearing sites enable us to test plant responses to herbivory and to quantify the effect of potential biological control agents before their release. Accordingly, climate matching between Ethiopia and those tropical regions in Africa where the weevils were successfully used, such as Uganda, Sudan, Benin, and others, allowed the development of an index of similarity. The index was generated based on maximum and minimum temperature, rainfall, and rainfall distribution. Details of the model result are presented in the section "Opportunities to use the *Neochetina* weevils in Ethiopia."

Herbivory effect of the *Neochetina* weevils

As observed in the above section, the waterhyacinth weevils are being used in different parts of the world with variable success. However, herbivory effects of these bioagents vary when used alone and in combination with one another.

Center et al. (2005) reported that *N. eichhorniae* and *N. bruchi* exhibited different herbivory effects on waterhyacinth biomass and ramet development, but when the plant was in flower, both species performed similarly. Biomass yield declined because o herbivory, with *N. bruchi* inducing greater reductions than *N. eichhorniae* did, and both weevil species restricted flowering by similar amounts. Herbivory by the 2 waterhyacinth weevils decreased waterhyacinth competitive performance by 98% at 10 wk. In that finding, the performance of *N. bruchi* looks better than that of *N. eichhorniae* alone and equivalent to it when combined with *N. eichhorniae*. However, because the experiment was executed under high-nutrient conditions, the similarity of the herbivory effect exhibited by *N. bruchi* alone and when combined with *N. eichhorniae* could have resulted from the positive effect of nutrients to *N. bruchi*. Moreover, success was also achieved with the use of both species where *N. eichhorniae* establishment was relatively higher (Van Thielen et al. 1994, Center et al. 1999b, Ajuonu et al. 2003). The combined use of the 2 weevils has better herbivory impacts on waterhyacinth than does either one alone. The relative establishment of the weevils' density depends on plant, nutrient, and herbivory interaction. In addition, it suggests a synergy potential between the 2 weevils and other bioagents (insects or pathogens) in the management of waterhyacinth.

Opportunities to use the *Neochetina* weevils in Ethiopia: Prediction using the CLIMEX model

The "Match Climate" function of the computer program CLIMEX compares long-term meteorological data for each of the selected "Away" locations, with the climate of the "Home" locations used to determine the nominal level of similarity between the locations, as suggested by Sutherst et al. (2004). Overseas tropical locations, where good control of waterhyacinth using the 2 waterhyacinth weevils has occurred, were climatically matched with Africa (Ethiopia) locations (Figure 1). Those climatic matches showed that, at a similarity match of 0.7 to 1, large areas of the Rift Valley of Ethiopia were similar to Bangalore (India), Khartoum (Sudan), Kampala (Uganda), Kisumu (Kenya), Cotonou (Benin), and some other locations in West Africa. This indicates that the prevailing climatic conditions in the Rift Valley of Ethiopia could be a suitable area for the weevils.

Climate modeling was also used to determine whether climate would be a limiting factor for establishment and spread of waterhyacinth weevils in Ethiopia. Based on the known distribution of the 2 *Neochetina* weevils in the native range (Figure 2A) and data about their biology, the potential geographic distribution was analyzed in relation to climate. The results indicated that the waterhyacinth weevils could permanently inhabit western and eastern parts of Africa (Figure 2B). The hot and wet areas in Ethiopia would be the most suitable. This climate-matching approach provides confidence that the projected distribution of the weevils in Ethiopia would be realistic and robust.

Among the different parameters, the CLIMEX moisture parameter was not computed for this analysis because the natural host-plant, waterhyacinth, requires standing water for its growth and development. In addition, the present analysis pointed out that stress at extreme cold and hot temperatures has affected the adaptability and survival of the weevils. In agreement with this, Deloach and Cordo (1976) and Julien et al. (2001) reported that the developmental period required by the 2 *Neochetina* weevils varied

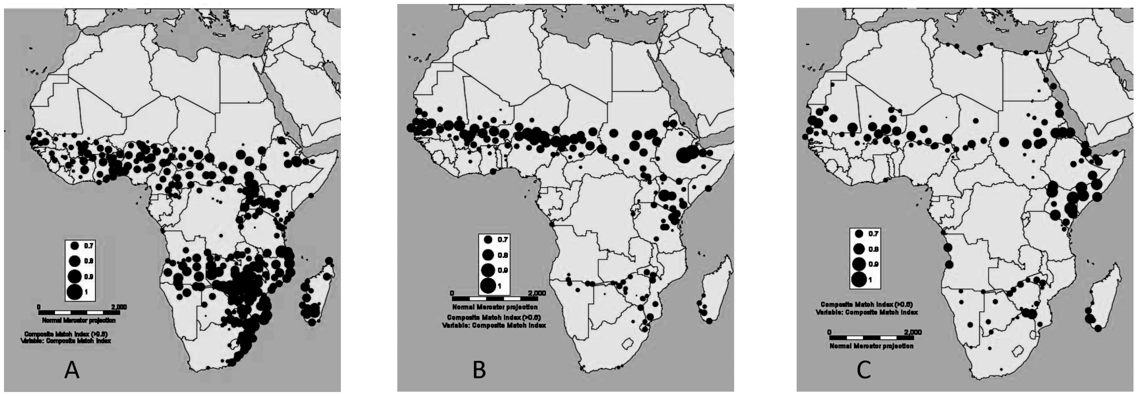


Figure 1. Climate match between (A) Bangalore and Africa, (B) Khartum and Africa, (C) Kampala and Africa using the "Match Climates" function at 60 to 100% levels of similarity.

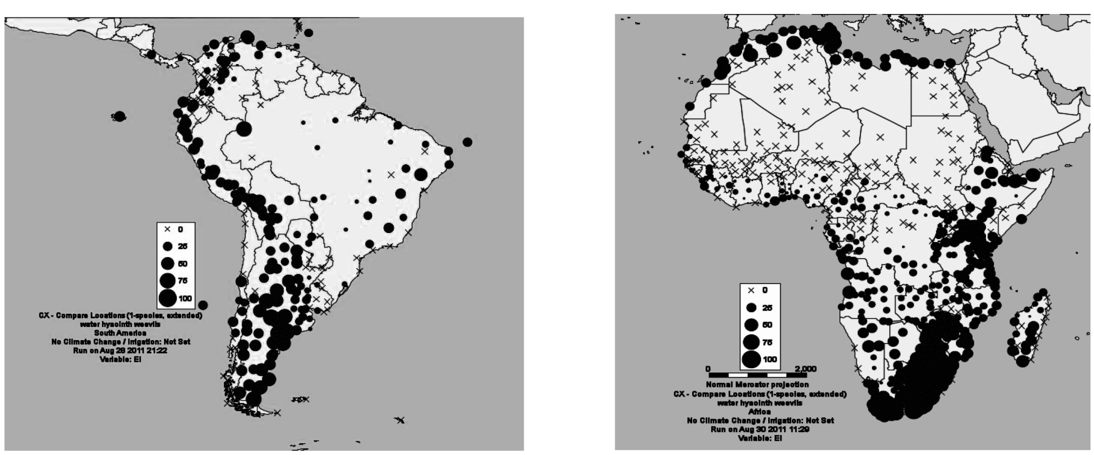
from country to country and from region to region depending on the prevailing climatic conditions. Data on the developmental threshold and degree-day requirements (CLIMEX PDD parameter) indicates that the 2 weevils would complete a number of generations per year (> 4.5). In agreement with that, Coetzee et al. (2007) reported successful establishment of the agents if the bioagent had > 1 generation yr^{-1}.

On the other hand, prediction of the weevils' distribution or adaptability in scenarios for climate change in Africa by + 3 C rise in temperature resulted in an increase in the potential range in northern and eastern parts of Ethiopia. A species climate-response model, based on the Ecoclimatic Index (EI) and results from Climate Matching suggested that the 2 known waterhyacinth weevils could be valuable bioagents of waterhyacinth in Ethiopia. The success achieved in the western and eastern part of Africa with the use of the 2 weevils indicates a good potential for the use of those agents in Ethiopia. The other important factor that could influence the performance of *Neochetina* weevils against waterhyacinth relates to their sensitivity to low plant quality, as suggested by various authors (Wright and Stegeman 1999, Center et al. 2002, 2005, Moran 2006). However, plant-quality analysis indicated that most of waterhyacinth-prone areas of Ethiopia had adequate nutrient levels for growth and development of waterhyacinth (Y. Firehun, unpub data) thereby indicating plant quality would not be a limiting factor for establishment of the bioagents.

PATHOGENS AS BIOCONTROL STRATEGY

Review of fungal pathogens isolated from waterhyacinth

Biological control of weeds using plant pathogens has gained acceptance as a practical, safe, and environmentally beneficial weed-management method applicable to agroecosystems (Charudattan 2001b). Use of plant pathogens has been shown to be highly effective against waterhyacinth under experimental conditions (Shabana 1997, Shabana et al. 1997). The fungal pathogen *Cercospora piaropi* Tharp. has been extensively studied (Freeman and Charudattan 1984, Charudattan et al. 1985) and was patented by the University of Florida (Conway et al. 1978). It has been released in South



A B

Figure 2. The known and predicted geographic distribution of *Neochetina* weevils in (A) South America and (B) Africa, based on positive values of Ecoclimatic Index (EI). Locations marked with a cross have an EI value of zero. The climatic favorableness of each location is proportional to the area of the circle.

Africa as classical biocontrol agent for waterhyacinth (Morris et al. 1991). Worldwide, several efforts have been made to assess pathogens found in association with waterhyacinth, and some of them have been evaluated and/or in use either as classical or inundative biological control agents (Charudattan 2001a).

In Florida, during a 1973 survey, 30 species of fungi were found in association with waterhyacinth (Conway et al. 1976a). Among those species, *Acremonium zonatum* (Sawada) W. Gams, *Bipolaris stenospila* (Drechsler) Shoemaker, and *C. piaropi* were found to be pathogenic to the weed (Conway et al. 1974, Conway 1976a,b). In a survey conducted in Sri Lanka, 15 fungal pathogens were reported to have coevolved with waterhyacinth (Hettiarachchi et al. 1983). Among those, *Myrothecium roridum* Tode, *C. piaropi*, *Curvularia tuberculata* B.L. Jain, *Septofusidium elegantulum* (Pidopl.) W. Gams, and *Phaeotrichoconis crotalariae* (M.A. Salam & P.N. Rao) Subram. were capable of producing leaf spots on healthy waterhyacinth leaves. For the last 3 species, this phenomenon was recorded for the first time.

Similarly, in Sudan, 21 fungal and 3 bacterial pathogens were isolated, of which *Phoma sorghina* (Sacc.) Borema, Dorenb., & Kesteren, and *Bacillus* Fischer sp. were reported for the first time as potential pathogens of waterhyacinth (Abdel-Rahim and Tawfiq 1984). Martinez and Charudattan (1998) reported that 17 native fungal genera were prevalent in Mexico, and *A. zonatum*, *Alternaria* Nees sp., *C. piaropi*, *Fusarium* Link sp., and *Verticillium* Nees sp. were highly damaging to waterhyacinth. Evans and Reeders (2001) undertook a survey of fungal pathogens of waterhyacinth in the Upper Amazon Basin of Peru and Ecuador. The results indicated that there were many mycobiota associated with waterhyacinth in the Upper Amazon Basin, contrary to the findings of Barreto and Evans (1996). However, among the potential fungal pathogens reported to have excellent pathogenicity in waterhyacinth, *Alternaria eichhorniae* Nag Raj & Ponnappa, *A. zonatum*, and *C. piaropi* were not isolated (Evans and Reeder 2001). In India (Kerala), Praveena and Naseema (2004) reported 21 fungal pathogens in association with waterhyacinth, of which 17 were pathogenic. Moreover, among the pathogenic fungi, *Myrothecium advena* Sacc. was a new report for waterhyacinth.

In Egypt, El-Morsy (2004) reported 22 fungal isolates from waterhyacinth of which *Alternaria alternate* Nag Raj & Ponnappa, *Drechslera hawaiiensis* (Bugnic.) Subram. & B.L. Jain, *Drechslera australiensis* (Bugnic.) Subram. & B.L. Jain, *Drechslera halodes* (Drechsler) Subram. & B.L. Jain, *Rhizoctonia solani* J.G. Kuhn, and *Ulocladium atrum* Preuss were pathogenic. From these, *D. hawaiiensis* and *U. atrum* were isolated from waterhyacinth for the first time. In China, from a survey conducted in 2003 and 2004, nine pathogenic fungi of waterhyacinth were isolated (Ding et al. 2008). Among them, 2 pathogens were reported to have the potential as biocontrol agents for the management of waterhyacinth. In general, more than 90 plant pathogens coevolved with waterhyacinth, and several highly virulent fungal pathogens are known to cause diseases of waterhyacinth. Table 2 provides a list of mycobiota recorded on waterhyacinth in different parts of the world.

Potential fungal pathogens and their host range: Comparative analysis

Several fungal pathogens have been reported to attack waterhyacinth in various parts of the world. Among the known pathogens, *A. zonatum*, *Alternaria alternata* (Fr.) Keissl., *A. eichhorniae*, *Bipolaris* spp., *Drechslera spicifera* (Bainier) Subram., *Fusarium chlamydosporum* Wollenw. & Reinking, *Fusarium pallidoroseum* (Cooke) Sacc., *Fusarium equiseti* (Corda) Sacc., *Helminthosporium* Link spp., *C. piaropi*, *M. roridum*, *Myrothecium advena*, *R. solani*, and *Uredo eichhorniae* Gonz. Frag. & Cif. have been tested and confirmed to be highly virulent pathogens (Table 3). Of these, *A. zonatum*, *A. alternata*, *A. eichhorniae*, *C. piaropi*, *M. roridum*, and *Myrothecium advena* have been studied intensively as biocontrol agents and have been shown to be effective under experimental conditions (Shabana et al. 1995a,b, 1997, 2000, Charudattan 2001a,b, Martinez and Gutierrez 2001, Mohan et al. 2003, Praveena and Naseema 2004). Details about the distribution, pathogenicity, and host specificity as well as their potential as biocontrol agent of waterhyacinth for the selected pathogens are reviewed below.

Acremonium zonatum. Reports indicate that *A. zonatum* is prevalent in Australia, the United States, the Sudan, South Africa, Nigeria, many countries of Asia, Central America, and South America (Abdel-Rahim and Tawfiq 1984, Charudattan 1990, 1996, 2001a, Morris et al. 1999). Among those countries, pathogens isolated from the Sudan, Nigeria, and Mexico showed highly virulent reaction against waterhyacinth (Abdel-Rahim and Tawfiq 1984, Martinez and Charudattan 1998, Oknowo et al. 2008). Host-specificity assessments indicated that *A. zonatum* was a pathogenic reaction to sorghum-sudangrass (*Sorghum vulgaris* var *Sudanese* Hitche.) and cultivated tobacco (*Nicotiana tabacum* L.) in Sudan and waterlettuce (*Pistia stratiotes* L.) in Mexico among the 31 plant species tested (Abdel-Rahim and Tawfiq 1984; Martinez and Gutierrez 2001). Charudattan (2001a) reported *A. zonatum* as one of the potential fungal pathogens that could be used as a bioherbicide agent in areas where the strains are pathogenic to the waterhyacinth but not to plants having economic and ecological importance (e.g., Mexico).

Alternaria alternata. This fungus has been described as a pathogen of waterhyacinth in Australia (Galbraith and Hayward, 1984), Egypt (Shabana et al. 1995a,b, El-Morsy 2004, El-Morsy et al. 2006), Bangladesh (Bardur-ud-Din 1978), and India (Aneja and Singh 1989, Mohan et al. 2002, 2003). This pathogen has been evaluated as a nonefficient biocontrol agent (Bardur-ud-Din 1978, Aneja and Singh 1989). Recently, the pathogen was evaluated intensively as a biocontrol agent in India and Egypt (Mohan et al. 2002, 2003, El-Morsy et al. 2006). Test results indicated that the fungus was highly virulent on waterhyacinth, leading to plant death. Its symptoms (i.e., spots and lesion) were mainly expressed on the leaves but not on the stolons. The host-range assessment result indicated that only *P. stratiotes* (both in India and Egypt) and foxtail sedge (*Cyperus alopecuroides* Rottb.) (Egypt) were susceptible to the fungus (Mohan et al. 2002, El-Morsy et al. 2006). These studies indicate that the

TABLE 2. MYCOBIOTA RECORDED ON *EICHHORNIA CRASSIPES*, WORLDWIDE (AMENDED FROM EVANS AND REEDER 2001).

Fungi	Distribution[1]
Ascomycotina Ainsw. and Deuteromycotina Ainsw.	
Acremoniella Sacc. sp.	Peru
Acremonium charticola (Lindau) W. Gams	Egypt
Acremonium crotocinigenum (Schol-Schwarz) W. Gams	Australia (IMI 288071)
Acremonium implicatum (J.C. Gilman & E.V. Abbott) W. Gams	Australia (IMI 271067)
Acremonium sclerotigenum (Moreau & R. Moreau ex Valenta) W. Gams	Sudan (IMI 284343)
Acremonium strictum W. Gams	Australia (IMI 288318, 288319)
Acremonium zonatum (Sawada) W. Gams	Australia, India, Pakistan, Panama, United States, Sudan, Mexico, Nigeria (IMI 394934)
Acremonium Link spp.	Peru
Alternaria Nees sp.	Mexico, China
Alternaria alternata (Fr.) Keissler	Egypt
Alternaria eichhorniae Nag Raj & Ponnappa	Egypt, India, Thailand, United States, Kenya, Ghana, South Africa, Zimbabwe
Alternaria tenuissima (Nees ex Fr.) Wiltshire	Hong Kong
Aspergillus carneus (Tiegh.) Blochwitz	Egypt
Aspergillus niger Tiegh.	Egypt
Aspergillus sulphureus (Fresen.) Wehmer	Egypt
Asteroma DC. sp.	Peru
Bipolaris urochloae (V.A. Putterill) Shoemaker	Egypt (IMI 324728)
Bipolaris Shoemaker sp.	United States, Brazil, Mexico
Blakeslea trispora Thaxt.	Thailand
Cephalotrichum Link sp.	United States
Cercospora piaropi Tharp (=*Cercospora rodmanii* Conway)	India, Sri Lanka, United States, Mexico, United States–/India (IMI 329783), Nigeria (IMI329211), South Africa
Cephalosporiopsis Peyronel sp.	Peru
Cephalosporium Corda sp.	Ecuador, Sir Lanka
Chaetophoma Cooke sp.	Ecuador
Chaetomella Fuckel sp.	Malaysia
Cladosporium oxysporum Berk. & M.A. Curtis & Curt.	Hong Kong–/Nigeria (IMI 333543)
Cladosporium cladosporioides (Fres.) des Varies.	Egypt
Cochliobolus bicolor A.R. Paul & Parbery	India (IMI 138935)
Cochliobolus lunatus (=*Curvularia lunata*) R.R. Nelson & F.A. Haasis	Egypt (IMI 318639), India (IMI 162522,242961), Sri Lanka (IMI 264391), Sudan (IMI263783), Peru
Cochliobolus pallescens (Tsuda & Ueyama) Sivan	Peru
Coleophoma Höhn. sp.	Sudan (IMI 284336)
Colletotrichum Corda spp.	China
Coniothyrium Corda sp.	Ecuador
Curvularia affinis Boedijn	United States
Curvularia Boedijn sp.	Mexico, Ecuador
Curvularia clavata B.L. Jain	India (IMI 148984)
Curvularia penniseti (Mitra) Boedijn	United States
Cylindrocladium scoparium var. *brasiliense* Bat. & Cif.	India
Cylindrocladium Morgan sp.	Mexico
Didymella exigua (Niessl) Sacc.	Trinidad, United States
Drechslera spicifera (Bainier) Arx	Sudan
Drechslera australiensis (Bugnic.) Subram. & B.L. Jain	Egypt
Drechslera halodes (Drechsler) Subram. & B.L. Jain	Egypt
Drechslera hawaiiensis (Bugnic.) Subram. & B.L. Jain	Egypt
Epicoccum Link sp.	Mexico
Exserohilum prolatum K.J. Leonard & Suggs	United States
Fusarium acuminatus Ellis & Everhart	Australia (IMI 266133)
Fusarium equiseti (Corda) Sacc.	India/Sudan (IMI 284344)
Fusarium graminearum Schwabe	Australia (IMI 266133)
Fusarium moniliforme Sheldon	Sudan (IMI 284342), India
Fusarium oxysporum Schlecht.	Australia (IMI 288317), India
Fusarium semitectum Berk & Ravenel	Egypt
Fusarium solani (Mart.) Sacc.	Australia (IMI 270062)
Fusarium sulphureum Schlecht.	India (IMI 297053)
Fusarium pallidoroseum (Cooke) Sacc.	India
Fusarium poae (Peck) Wollenw.	Peru
Fusarium sacchari (E.J. Butler) W. Gams.	Peru
Fusarium Link sp.	Peru, Ecuador, Mexico
Fusidium Link sp.	South Africa (IMI 318345
Gliocladium roseum Bainier	Australia (IMI 278745), Ecuador
Glomerella Spauld. & H. Schrenk sp.	Ecuador
Glomerella cingulata (Stoneman) Spauld. & H. Schrenk	Sri Lanka (IMI 264392), Brazil
Helminthosporium Link sp.	Malaysia, India
Hyphomycete Fr. spp	Peru, Ecuador
Idriella P.E. Nelson & S. Wilh. sp.	Peru

Leptosphaeria eichhorniae Gonz. Frag. & Cif.	Dominican Rep., Panama
Leptosphaeria Ces. & De Not. sp.	Peru
Leptosphaerulina McAlpine sp.	United States
Memnoniella subsimplex (Cooke) Deighton	United States
Monosporium eichhorniae Sawada	Taiwan
Monilia Bonord. sp.	Mexico
Mycosphaerella tassiana (De Not.) Johanson	United States
Mycoleptodiscus terrestris (Gerd.) Ostaz.	United States
Mycosphaerella Johanson sp.	Peru
Myrothecium roridum Tode ex Fr.	India, Philippines Thailand–/Burma (IMI79771), Malaysia (IMI 277583), Nigeria
Myrothecium advena Sacc.	India
Myrothecium verrucaria (Alb. & Schwein.) Ditmar	Peru
Myrothecium Tode sp.	Brazil
Nigrospora Zimm. sp.	Mexico
Penicillium chrysogenum Thom	Egypt
Penicillium purpurogenum Stoll	Egypt
Periconia Tode sp.	Mexico
Pestalotiopsis adusta (Ellis & Everh.) Steyaert	Taiwan–/Hong Kong (IMI 119544)
Pestalotiopsis palmarum (Cooke) Steyaert	India (IMI 148983)
Phaeoseptoria Speg. sp.	Peru
Pestalotia De Not. sp.	Mexico, India
Phoma chrysanthemicola Hollós	Peru
Phoma leveillei Boerema & G.J. Bollen	Ecuador
Phoma section *Peyronellaea* (Goid. ex Togliani)	Peru
Phoma sorghina (Sacc.) Boerema, Dorenb. & Kesteren	Sudan/Australia (IMI 288313, 288311,288312, 288315, 333325)
Phoma Sacc. sp.	United States
Phyllosticta Pers. sp.	Nigeria (IMI 327627, 327628)
Pseudocercosporella Deighton sp.	Peru
Sarocladium W. Gams & D. Hawksw. sp.	Peru
Scopulariopsis brevicaulis (Sacc.) Bainier	Egypt
Stauronema Syd. & E.J. Butler sp.	Peru
Stachybotrys chartarum (Ehrenb.) S. Hughes	Egypt
Spegazzinia tessarthra (Berk. & M.A. Curtis) Sacc.	Sudan (IMI 284335)
Stemphylium vesicarium (Wallr.) E.G. Simmons	United States
Stemphylium Wallr. sp.	Mexico
Ulocladium atrum Preuss	Egypt
Verticillium Nees sp.	Egypt, Mexico
Basidiomycotina Ainsw.	
Basidiomycete Whittaker spp.	Peru, Ecuador
Basipetospora G.T. Cole & W.B. Kendr. sp.	Mexico
Blastomyces Gilchrist & W.R. Stokes sp.	Mexico
Doassansia eichhorniae Cif.	Dominican Rep.
Marasmiellus inoderma (Berk.) Singer	India
Rhizoctonia oryzae-sativae (Sawada) Mordue	Australia (IMI 289087)
Rhizoctonia solani Kuhn	India, Panama, Thailand and United States
Rhizoctonia DC. sp.	India, United States
Thanatephorus cucumeris (A.B. Frank) Donk	China, Taiwan/India (IMI 3075)
Tulasnella grisea (Racib.) Sacc. & P. Syd.	Indonesia (Java)
Uredo eichhorniae Gonz. Frag. & Cif.	Argentina, Brazil, Dominican Rep.
Chromista Cavalier-Smith	
Pythium Pringsh. sp.	United States

[1]Parenthetical numbers are the International Mycological Institute identification number.

fungus has potential as a bioagent of waterhyacinth, and its toxins may have use as a herbicide.

Alternaria eichhorniae. This fungal pathogen has been reported to occur on waterhyacinth in Egypt, Sudan, Kenya, Zimbabwe, Ghana, Uganda, Niger, Tanzania, South Africa, India, Indonesia, and Thailand (Evans and Reeder 2001, Shabana 2002). It has been shown to be fairly host-specific to waterhyacinth (Nag Raj and Ponnappa 1970, Shabana et al. 1995a) and to be capable of severely damaging and suppressing this weed (Shabana et al. 1995a,b). A good understanding of the biology and pathology of the fungus has been gained (Shabana et al. 1995a,b, 1997, 2000, 2001a,b). As a result, this fungus isolate Number 5 (Ae5) is being developed as a mycoherbicide for controlling waterhyacinth in Egypt (Shabana 2005).

Cercospora piaropi (=*Cercospora rodmanii*). *Cercospora piaropi* and *Cercospora rodmanii* Conway were both recognized as pathogens of waterhyacinth until Tessmann et al. (2001) merged the 2 species into an emended *C. piaropi*. This fungal pathogen is widely distributed worldwide (Evans and Reeder 2001). Host-specificity studies indicated the fungus is only pathogenic to waterhyacinth (Martinez and Gutierrez 2001). However, the fungus isolates are believed to exhibit pathogenic variability depending on the growth and pigmentation in the culture. Hence, diffusible pigments in culture and cercosporin production could be used as adjuncts to screen aggressiveness of the most effective

Table 3. Potential fungal pathogens of waterhyacinth.

Pathogen	Country[1]	Reference
A. zonatum	Mexico, Sudan, Australia, South Africa, Nigeria	Abdel-Rahim and Tawfiq 1984, Galbrith 1987, Martinez and Charudattan 1998, Morris et al. 1999, Oknowo et al. 2008
A. alternata	Egypt, India	Elwakil et al. 1990, Shabana et al. 1995a,b, 1997, Mohan et al. 2002, 2003, El-Morsy 2004, Ray, 2006
A. eichhorniae	Egypt, South Africa, India, Bangladesh, Indonesia, Thailand,	Nag Raj and Ponnappa 1970, Charudattan 1973, Badur-ud-Din 1978, Mangoendihardjo et al. 1978, Rakvidhyasastra et al. 1978, Shabana et al. 1995a, Shabana et al. 1997, Morris et al. 1999
Bipolaris sp.	Dominican Republic	Charudattan 1990, 1996
C. piaropi	Mexico, South Africa, Brazil, USA, Zambia, Venezuela	Julien and Griffiths 1998, Martinez and Charudattan 1998, Charudattan 2001a, Hill and Coetzee 2008
D. spicifera	Sudan	Abdel-Rahim and Tawfiq 1984
F. Fusarium chlamydosporum	India	Charudattan 1990, Aneja et al. 1993
F. equiseti	Sudan	Abdel-Rahim and Tawfiq 1984
F. pallidoroseum	India	Praveena and Naseema 2004
M. advena	India	Praveena and Naseema 2004
M. roridum	Sir Lanka, India, Malaysia, Mexico, Nigeria	Hettiarachchi et al. 1983, Charudattan 2001a, Okunowo et al. 2008
R. solani	USA, Brazil, India, Mexico, Panama, Puerto Rico, Malaysia, Indonesia	Charudattan 2001a, Praveena and Naseema 2004
U. eichhorniae	South America	Charudattan 1996, 2001a
Verticillium sp.	Mexico	Martinez and Charudattan 1998

[1]Refers to country where the pathogen were evaluated and found to be virulent against waterhyacinth.

isolates of *C. piaropi* for biological control (Tessmann et al. 2008).

The present review clearly indicated *A. zonatum*, *A. alternata*, *A. eichhorniae*, and *C. piaropi* have been well evaluated as potential bioagents for the management of waterhyacinth. Because most of these pathogens have a wide geographical distribution and produce virulent toxin or toxins, there is a good possibility they could be used as inundative bioagents. Once a native, virulent, and safe pathogen has been identified and evaluated, its use as a mycoherbicide avoids the quarantine issues associated with exotic pathogens. Charudattan (2001a,b), Bateman (2001), and Ding et al. (2008) have elaborated on the potential advantages of using of native pathogens. Thus, exploration for native fungal pathogens should continue.

Recent advances and opportunities

Recent advances using pathogens as bioagents for waterhyacinth management include the development of mycoherbicides. Modern research on mycoherbicides has focused on 2 fungal species: *C. piaropi* and *A. eichhorniae*. The fungal pathogen *C. piaropi* was developed into a bioherbicide by Abbott Laboratories[1] for waterhyacinth management. The formulation was a wettable powder that was applied with a humectant to preserve moisture and nutrients to sustain

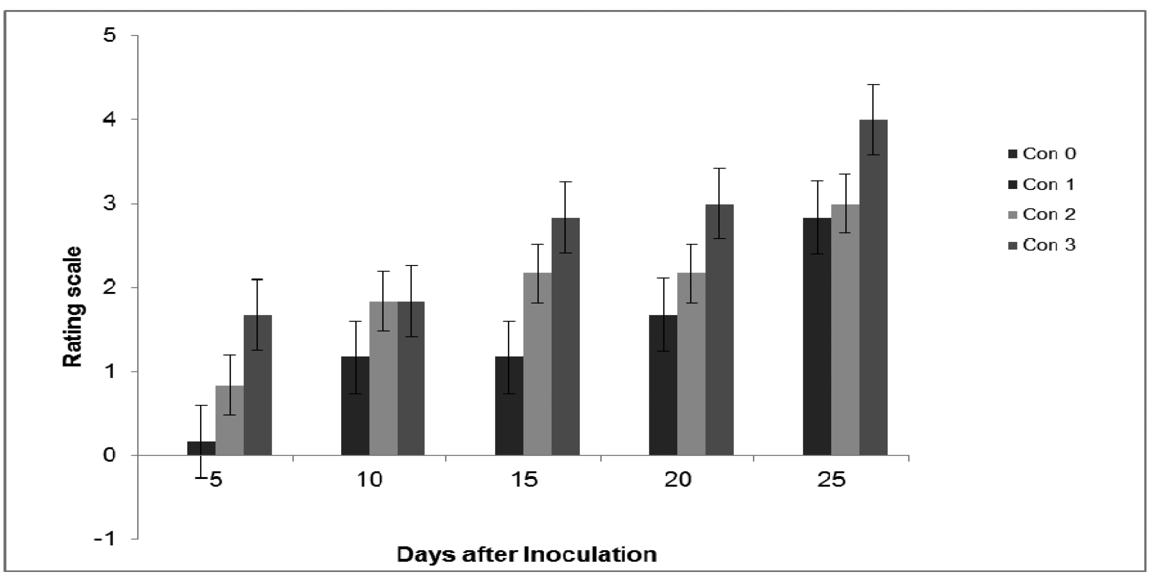


Figure 3. Disease score for 6 waterhyacinth plants treated with *Sclerotinia sclerotiorum* mycoherbicide at 3 concentrations (i.e., 7.5, 5, and 2.5 ml [0.25, 0.17, and 0.08 oz] of slurry with 15 ml of formulation), where 0 = none: no symptom (0% shoot area exhibiting disease symptom); 1 = very low: small, superficial lesions (1 to 10% shoot area); 2 = low: small, discreet lesion (11 to 25% shoot area); 3 = medium: large, systemic lesion (26 to 75% shoot area); 4 = high: significant plant necrosis (78 to 99% shoot area); and 5 = plant death (100% shoot area).

and stimulate propagule germination (Pennington and Theriot 1983). Although laboratory results appeared promising (Pennington and Theriot 1983), high infectivity was not achieved in the field, and further development of the bioherbicide was curtailed (Sanders and Theriot 1986).

Two novel mycoherbicides developed from *Sclerotinia sclerotiorum* (Lib.) de Bary and *Thanatephorus cucumeris* (=*Rhizoctonia solani*) (A.B. Frank) Donk AG 2-2 for biological control of aquatic weeds, such as waterhyacinth and waterlettuce, were patented to Meindert de Jong and Barend de Voogd in 2003. *Sclerotinia sclerotiorum*, known as a plurivorous plant pathogen, has never been observed on waterhyacinth. Plants susceptible to this pathogen include many dicotyledons. It is geographically cosmopolitan and has a broad ecological distribution. The fungus is seldom observed on monocotyledons, and never observed on aquatic species such as waterhyacinth and water lettuce. The efficacy of the mycoherbicide developed from *S. sclerotiorum*, evaluated at 3 rates, is presented in Figure 3 (Y. Firehun, unpub. data).

Researchers in Egypt have been studying the use of *A. eichhorniae* for biological control of waterhyacinth. A major obstacle with waterhyacinth was its requirement for at least 10 h of dew to allow the applied inoculum to germinate and infect and, to some extent, colonize the weed (Shabana et al. 1995a). Longer exposure to dew (e.g., 26 or 28 h) might ensure disease development, but such uninterrupted, long exposure to dew periods is not likely to occur under field conditions. Shabana (2005) demonstrated the use of oil emulsions for improving the efficacy of *A. eichhorniae* Ae5. It could be formulated in a cottonseed-oil emulsion to eliminate its dew-period requirement and still allow it to cause high disease severity and weed kill under field conditions.

Interest in the use of fungi has continued; however, recent efforts have paired fungal pathogens with insects and/or insects and mycoherbicides in integrated biological approaches. Although complete control of waterhyacinth was not achieved, Moran (2005) demonstrated that integrating weevils with *C. piaropi* in field plots increased necrosis and decreased shoot densities and leaves per plant. Waterhyacinth weevils can vector *C. piaropi* under controlled conditions, but that association does not specifically increase the severity of the fungal symptoms or lead to enhanced negative effects on plants over 1 mo. The feeding activities of weevils facilitate fungal colonization of waterhyacinth tissues. Improvements in formulation technology and in the use of additional pathogens may improve the utility of plant pathogens in waterhyacinth biocontrol. In a small reservoir in Mexico, Martinez and Gomez (2007) released approximately 9,800 weevils of *Neochetina* spp., followed by applications of the fungal plant pathogens *A. zonatum* and *C. piaropi*. Within 3 mo, the reservoir was completely free of waterhyacinth. Moran and Graham (2005) also reported a positive association between leaf scarring because of the mottled waterhyacinth leaves and necrosis. This all suggests the feasibility and commercial potential of complementing weevils with pathogens for the management of waterhyacinth.

Research gaps and opportunities for use of biological control in Ethiopia

In Ethiopia, use of classical biological control agents for the management of weeds began in the 1970s with the introduction of a weevil, *Smicronyx albovariegatus* (Coleoptera: Curculionidae) and a moth *Eulocastra argentisparsa* (Lepidoptera: Noctuidae) from India for the management of witchweed *Striga* Lour spp. However, none of them has established (Fasil 2004). Weed biological control in Ethiopia is still in the experimental stages. Few studies have been undertaken to survey, identify, and evaluate native natural enemies associated with ragweed parthenium (*Parthenium hysterophorus* L.) (Taye et al. 2004a,b) and *Striga* spp. (Fasil 2004, Rebka 2006).

Although waterhyacinth has been problematic for the past 60 yr, its management using plant pathogens and insect bioagents has seldom been attempted. A survey carried out in the Gambella region of Ethiopia in the 1970s reported the fungus *C. rodmanii*, as affecting waterhyacinth 5 to 15% (Stroud 1994). This noxious, aquatic weed has created perennial problems in irrigation structures, hydroelectric dams, lakes, reservoirs, and drainage systems located in the Rift Valley of Ethiopia. Although attempts have been made to manage this weed by mechanical methods, the weed remains a threat for different stakeholders (Electric Power Authority, sugar estates, farmers, fishers, etc.). The use of bioagents for the management of invasive weeds at a national level has recently received increased attention, and researchers have engaged in surveys, introduction, and evaluation (pathogenicity and host-specificity assessment) of native as well as classical bioagents. A survey of indigenous fungi found in association with waterhyacinth was conducted in 2009 and 2010. During the survey, 25 fungal isolates were collected. Identification and molecular characterization of the isolates is in progress at Wageningen University, Wageningen, the Netherlands. However, their pathogenicity, host specificity, and application methods will require additional research.

The prevalence of *C. piaropi* and the 25 unidentified fungal pathogens indicates there are potential native pathogens that can be used for the management of waterhyacinth. Because shortcomings with the use of pathogens as bioagents have been resolved and development of mycoherbicides is in progress, the use of fungal pathogens for the management of waterhyacinth is increasing. In Ethiopia, it is possible to implement the use of fungal pathogens as an inundative bioagent. Additionally, the prospect of the vectoring potential of the weevils is being explored. Once studies on the potential and host specificity of the existing native fungal pathogens are completed, it may be possible to use the weevils in combination with native fungal pathogens.

CONCLUSION

Several host-specific, virulent fungal pathogens, such as *C. piaropi*, *A. eichhorniae*, *A. alternata*, and others have widespread distribution. With the development of appropriate formulations, the possibility of using of pathogens as bioagents for the management of waterhyacinth has improved, which could enable development of mycoherbicides from native, virulent fungal pathogens. The success achieved in the development of mycoherbicides enhances the overall effectiveness of the fungal pathogens under different scenarios. The use of native pathogens avoids quarantine issues associated with exotic pathogens. Moran (2005), Moran and Graham (2005), and Martinez and Blandra (2007) determined there is a great opportunity to integrate potential fungal pathogens with insects for the management of waterhyacinth. In Ethiopia, exploring the use of existing native fungal pathogens as inundative bioagents and increasing mycobiota exploration, efficacy evaluation, and host-specificity assessment must be undertaken.

Neochetina eichhorniae and *N. bruchi* are considered as classical bioagents in Ethiopia because of their host specificity, past history of damage to waterhyacinth, and control of the weed in similar environments in other countries. These agents can be introduced from Sudan, Uganda, Kenya, Tanzania, or any other African or Asian countries. Based on the many success stories in Africa and elsewhere in the world with the use of bioagents for the management of waterhyacinth, it appears that similar results are possible in Ethiopia.

SOURCES OF MATERIALS

[1]Bioherbicide, Abbott Laboratories, 100 Abbott Park Road, Abbott Park, IL 60048.

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