

Biology, Geographical Distribution, Prevention and Control of the Enset Root Mealybug, *Cataenococcus ensete* (Homoptera: Pseudococcidae) in Ethiopia

Temesgen Addis¹ • Ferdu Azerefegne² • Tameru Alemu² • Sisay Lemawork³ • Eyob Tadesse⁴ • Mesele Gemu¹ • Guy Blomme^{5*}

¹ Southern Agricultural Research Institute (SARI), Awassa Research Centre, P. O. Box 06, Awassa, Ethiopia

² Hawassa University, Awassa College of Agriculture, P. O. Box 05, Awassa, Ethiopia

³ Plant Health Clinic, Bureau of Agriculture, Awassa, Ethiopia

⁴ Sodo University, Faculty of Agriculture, Plant Science Department, P. O. Box 138, Ethiopia

⁵ Bioversity International Uganda office, P. O. Box 24384, Kampala, Uganda

Corresponding author: * g.blomme@cgiar.org

ABSTRACT

More than 15-million Ethiopians depend upon enset for their food, fibre, animal forage, construction materials and medicines. However, the sustainability of enset-based agriculture is threatened by a number of factors. The main biotic stresses are bacterial wilt, the enset root mealybug, nematodes, fungi and other vertebrate pests like mole-rats. Enset root mealybug, *Cataenococcus ensete* is a major pest of enset (*Ensete ventricosum*) in enset growing areas of southern Ethiopia. This paper reviews the recent body of work on integrated control measures for enset mealybug (*Cataenococcus ensete*). Its focus includes: biology and description of *C. ensete*; the pest's behaviour within the enset plant; its geographical distribution; pest symptoms; mealybug dispersal methods and key means of mealybug management including prevention and cultural, biological and chemical control (including plant-extracts). The enset mealybug is difficult to control with insecticides, due to its cryptic nature, waxy-coat and life-style of forming dense colonies of multiple and overlapping generations. Besides, insecticides often prove too costly. This review should allow researchers and extension agents to make more informed choices regarding a more effective, integrated approach to control enset root mealybug.

Keywords: biological-control, chemical-control, corm, cultural-control, dispersal

CONTENTS

INTRODUCTION.....	39
BIOLOGY AND DESCRIPTION.....	40
DENSITY AND DISTRIBUTION ON ROOTS AND CORM	40
GEOGRAPHICAL DISTRIBUTION	41
DAMAGE SYMPTOMS	42
MEANS OF DISPERSAL	42
MANAGEMENT OF ENSET ROOT MEALYBUGS	43
Prevention.....	43
Cultural control.....	44
Biological control	44
Use of insecticidal plant extracts (botanicals).....	44
Chemical control	45
Integration of management and control options/methods	45
ACKNOWLEDGEMENTS	45
REFERENCES.....	45

INTRODUCTION

The genus *Ensete* falls under the order Scitaminae and Musaceae family and comprises of several species which grow in Africa and Asia (Taye 1984). Wild *Ensete ventricosum* can be found in Africa from the Ethiopian highlands all the way down to Malawi. Domesticated enset is however only cultivated in Ethiopia at altitudes ranging from 1,200 to 3,100 masl. Enset grows best at elevations between 2,000 and 2,750 masl (Quimio and Tessera 1996; Brandt *et al.* 1997; Tabogie *et al.* 2002).

Enset (*Ensete ventricosum*) cultivation has existed for many centuries as a sustainable form of agriculture in Ethi-

opia (Brandt *et al.* 1997) (Fig. 1). More than 20% of Ethiopia's population (>15 million) depends upon enset for human food, fibre, animal forage, construction materials and medicines. Kocho or fermented starch is obtained from the leaf sheets and corm, while Amicho is boiled enset corm, usually from younger plants. The fiber obtained from enset leaf sheaths is used to make bags, ropes, cordage and mats. Enset leaves and dried leaf sheaths are used as wrapping material. Enset leaves are also fed to cattle during the dry season. Some enset clones are used as local medication for different illnesses (e.g., bone fracture and diarrhea) in both humans and animals (Brandt *et al.* 1997). However, the sustainability of enset-based agriculture is threatened by a

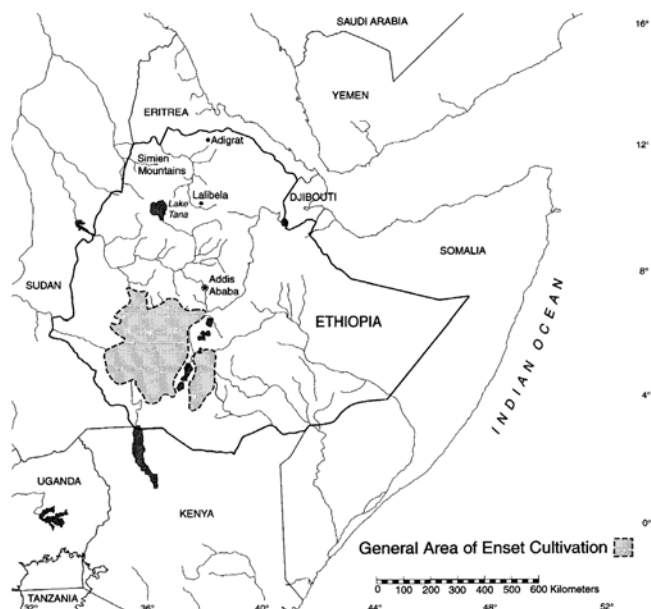


Fig. 1 The distribution of domesticated enset in Ethiopia. Reprinted from Brandt SA, Anita S, Clifton H, Terrence MCJ, Endale T, Mulugeta D, Gizachew WM, Gebre Y, Masyoshi S, Shiferaw T (1997) *The "Tree against Hunger": Enset-based agricultural systems in Ethiopia*. American Association for the Advancement of Science, Washington, DC, USA, 56 pp, ©1997, with kind permission from the American Association for the Advancement of Science, Washington, DC, USA.

number of factors. The main biotic stresses are bacterial wilt, the enset root mealybug, nematodes, fungi and other vertebrate pests like mole-rats (Addis *et al.* 2006).

In the Afro-tropical region, several mealybug species including *Dysmicoccus brevipes* (Cockerell), *Dysmicoccus grassii* (Leonardi), *Ferrisia virgata* (Cockerell), *Paracoccus burnerae* (Brain), *Paraputo anomalus* (Newstead), *Planococcus citri* (Risso), *Planococcus musae* (Matile-Ferrero and Williams), *Planococcus ficus* (Signoret), *Cataenococcus ensete* (Williams and Matile-Ferrero) and *Cataenococcus ferris* (Williams and Matile-Ferrero) have been reported on the Musaceae family, comprising the genus *Musa* and *Ensete*. The last three mealybug species were reported on enset in Ethiopia, while *P. burnerae* was reported in Kenya on *Ensete* spp. (Williams and Matile-Ferrero 1999).

Enset root mealybug, *Cataenococcus ensete* Williams and Matile-Ferrero (1999) (Homoptera: Pseudococcidae), is a major pest of enset in enset-growing areas of southern Ethiopia. It has been reported from Wonago district, Southern region, as a new record for Ethiopia (Tsedek 1988). The insect is known to attack enset in Gedeo, Sidama, Gurage, Kembata Tembaro, Hadyia, Keffa and Bench zones and Amaro and Yem districts (Addis *et al.* 2008a).

This paper reviews recent work on Integrated Pest Management (IPM) for enset root mealybug control. Its focus includes: biology and description of the enset mealybug; the pest's behaviour within the enset plant; its geographical distribution; pest symptoms; mealybug dispersal methods and key means of mealybug management including prevention (clean planting material, extension, affordable management, quarantine, hygiene and ant control), cultural control (using farmyard manure, hot water treatment or cultivation), biological control, use of insecticidal plant extracts (botanicals), and agrochemical control. This review should allow researchers and extension agents to make more informed choices regarding a more effective, integrated approach to controlling enset mealybug.

The pest attacks enset plants at any age, with infestations being most severe on 2 to 4 year-old plants (Anonymous 2001). Mealybug-infested enset plants exhibit retarded growth, loss of vigour, dried lateral leaves but green central shoot and eventually plant death (Addis 2005).

Empirical data on enset yield loss as a result of mealybug attack are scanty. According to Addis (2005), more than 30% of the sampled enset farms were infested with enset root mealybugs.

Due to their cryptic nature, waxy-coat and life-style of forming dense colonies of multiple and overlapping generations, mealybugs are difficult to control with insecticides (Blumberg and Van Driesche 2001). Also, chemical insecticides are often too costly for farmers, particularly in developing countries. These reasons, together with the demand for contaminant-free food have fostered the search for alternative methods of control (Ekesi *et al.* 1998).

Enset root mealybugs are mainly distributed to new regions and farms through infested planting materials. Production of mealybug-free planting materials is the key control measure used to manage enset root mealybugs. Enset growers usually produce enset suckers for planting for their own use, exchange with others, or sale of suckers in the markets (Bizuayehu 2002). Enset corms used for production of new suckers may be invariably infested with soil pests particularly with enset root mealybugs. Transplanting the contaminated planting materials facilitates their spread.

A number of techniques have been developed to decontaminate infested planting materials from pests and pathogens (Speijer 1999), with hot water treatment seeming amongst the most successful (Tenkouano *et al.* 2006).

BIOLOGY AND DESCRIPTION

Root mealybug is a generic term for a number of *Pseudococcidae* feeding on underground plant parts. Enset root mealybugs have an elongate-oval body covered with wax secretions on the dorsal and lateral sides. The wax secretions give the appearance of cottony, spine like projections. While these waxy secretions are not part of the mealybugs' body, they are lost with each moult.

Different development stages of enset root mealybugs are recognized:

- (1) Bright-orange to yellow-orange coloured "crawlers" or rapidly moving 1st instars, that are barely visible, being 0.5 to 2.7 mm long. They greatly resemble the adults but are significantly smaller. The biology of enset root mealybugs was studied on whole pumpkin fruits under dark room conditions at a temperature of 25 °C and a relative humidity of 60% (Addis 2005). Average duration of the first, second and third instars nymphs are 16.2 ± 0.5, 18.2 ± 0.7 and 19.8 ± 0.4 days, respectively (Addis 2005; Addis *et al.* 2008a).
- (2) 2nd and 3rd instars mealybugs begin to develop distinct lateral and caudal spines, increase in body size, and start to produce large amount of honeydew excretion (Addis 2005; Addis *et al.* 2008a).
- (3) Adult female mealybugs have an elongate-oval body covered with wax secretions on the dorsal and lateral sides (Figs. 2, 3). Adult females show pronounced cross wise grooves running down their body and give birth to live young ones on a shallow pile of waxy secretions. According to Addis (2005) and Addis *et al.* (2008a) each female mealybug produces 156 to 383 nymphs in its life time. The mean life span of an adult female mealybug is 50.0 ± 0.5 days. The total life span of mealybugs is 94-113 days. The body size of adult mealybugs ranges from 2.8 to 4.0 mm in length and 2.85 to 3.70 mm in width. The body length and width of the adult female mealybugs ranged from 2.80 to 4.00 mm and 2.85 to 3.70 mm respectively (Williams and Matile-Ferrero 1999).

DENSITY AND DISTRIBUTION ON ROOTS AND CORM

The majority of the mealybugs inhabited the roots (79%), while 21% was found on the corms (Addis *et al.* 2008b). The root density of enset as well as mealybug populations decreased with increasing soil depth. About 99% of the

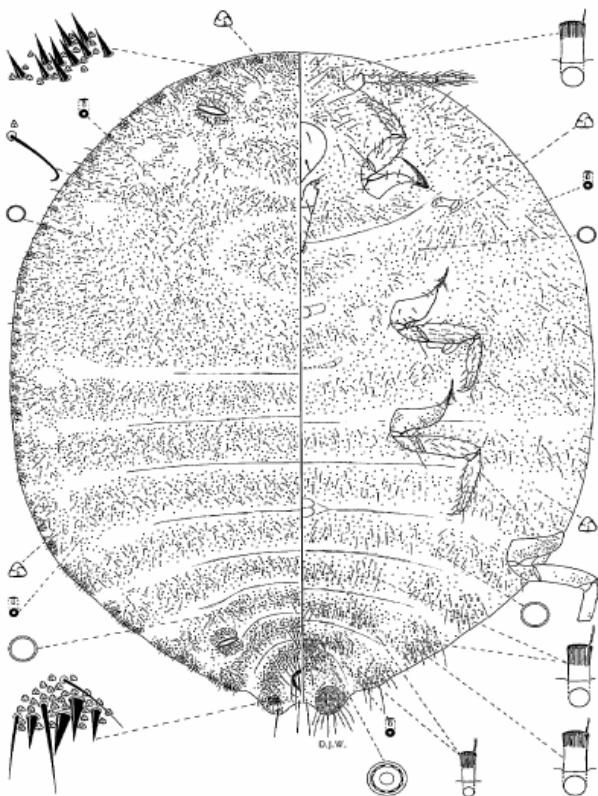


Fig. 2 Adult enset root mealybug. Reprinted from Williams DJ, Matile-Ferrero D (1999) A new species of the mealybug genus *Cataenococcus ferris* from Ethiopia on *Ensete ventricosum*, a plant infected by a virus (Hemiptera: Pseudococcidae; Musaceae). *Revue Française d'Entomologie (N.S.)* 21 (4), 145-149, ©1999, with kind permission from the Revue Française d'Entomologie.

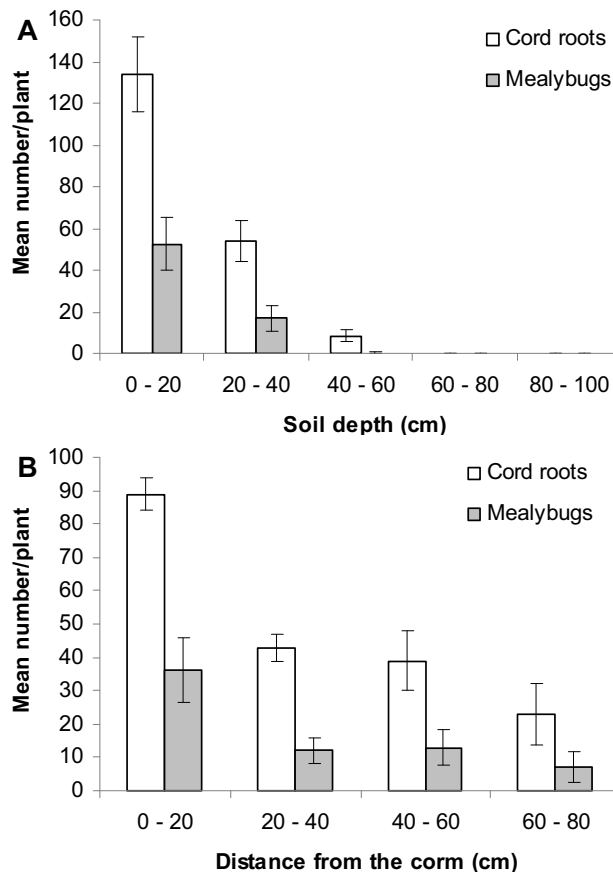


Fig. 4 Vertical (A) and horizontal (B) distribution of enset cord roots and enset root mealybugs. Reprinted from Addis T, Azerefege F, Blomme G (2008b) Density and distribution of enset root mealybugs on enset. *African Crop Science Journal* 16 (1), 67-74, ©2008, with kind permission from the *African Crop Science Journal*, Kampala, Uganda.

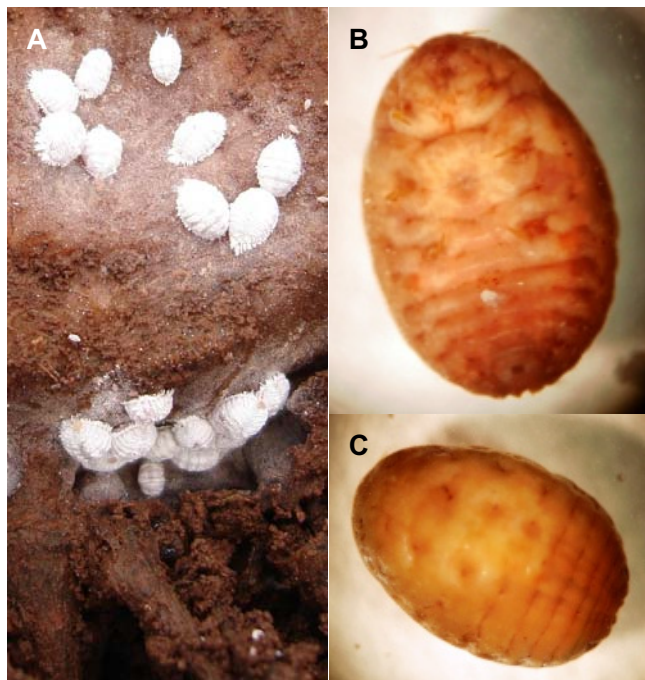


Fig. 3 Adult enset root mealybugs (with (A) and without wax coat (B) and (C)). The body length and width of an adult female mealybug ranges from 2.9 to 4 mm and 2.5 to 3.5 mm, respectively when measured with wax coat. Photos taken by Guy Blomme, Reprinted from Azerefege F, Addis T, Alemu T, Lemawork S, Tadesse E, Gemu M, Blomme G (2009) An IPM guide for enset root mealybug (*Cataenococcus ensete*) in enset production. Johnson V (Ed), Bioversity International, Uganda and France offices, 18 pp, ©2009, with kind permission from Bioversity International, Montpellier, France.

mealybugs were found in the upper 40 cm soil layer (Fig. 4A). Similarly, about 90% of the mealybugs were collected within a 60 cm radius from the plants. About 63% of the mealybugs were collected from the corm and on the roots within a 20 cm radius from the corm (Fig. 4B). Hence, sampling a 20 × 20 × 20 cm cube of soil and roots adjacent to the corm will capture a large proportion of the total root mealybug population on a plant. In addition, several plants should be uprooted to assess population densities on the corm surface especially during the dry season when mealybugs move to the corm surface due to root drying and a reduction in new root growth.

GEOGRAPHICAL DISTRIBUTION

Field surveys conducted on peasant farms showed that more than 30% of the sampled farms were infested with enset root mealybugs. Mealybugs were recorded in Sidama, Gedeo, Gurage, Bench, Kembata Tembaro, Keffa, and Hadyia zones and Amaro and Yem districts (Fig. 5). In Sidama, Gedeo, Amaro and Bench respectively 62, 67, 100 and 57%, of sites visited were infested by the root mealybugs. The highest mean number of mealybugs per plant (81) was recorded in the Gedeo zone, while the lowest number per plant (3.3) was recorded in Yem district (Addis *et al.* 2008b). The enset root mealybug infestation was found to be most serious at an elevation between 1,400 to 2,200 masl. The highest level of enset root mealybug infestation was recorded at an elevation between 1,600-1,800 masl. Enset root mealybugs were not recorded at altitudes greater than 2,600 masl and below 1,400 masl (Addis 2005; Addis *et al.* 2008a). Initial observations also indicate that the severity of enset root mealybugs is higher on Nitosols (Ethiopian mapping authority 1988).

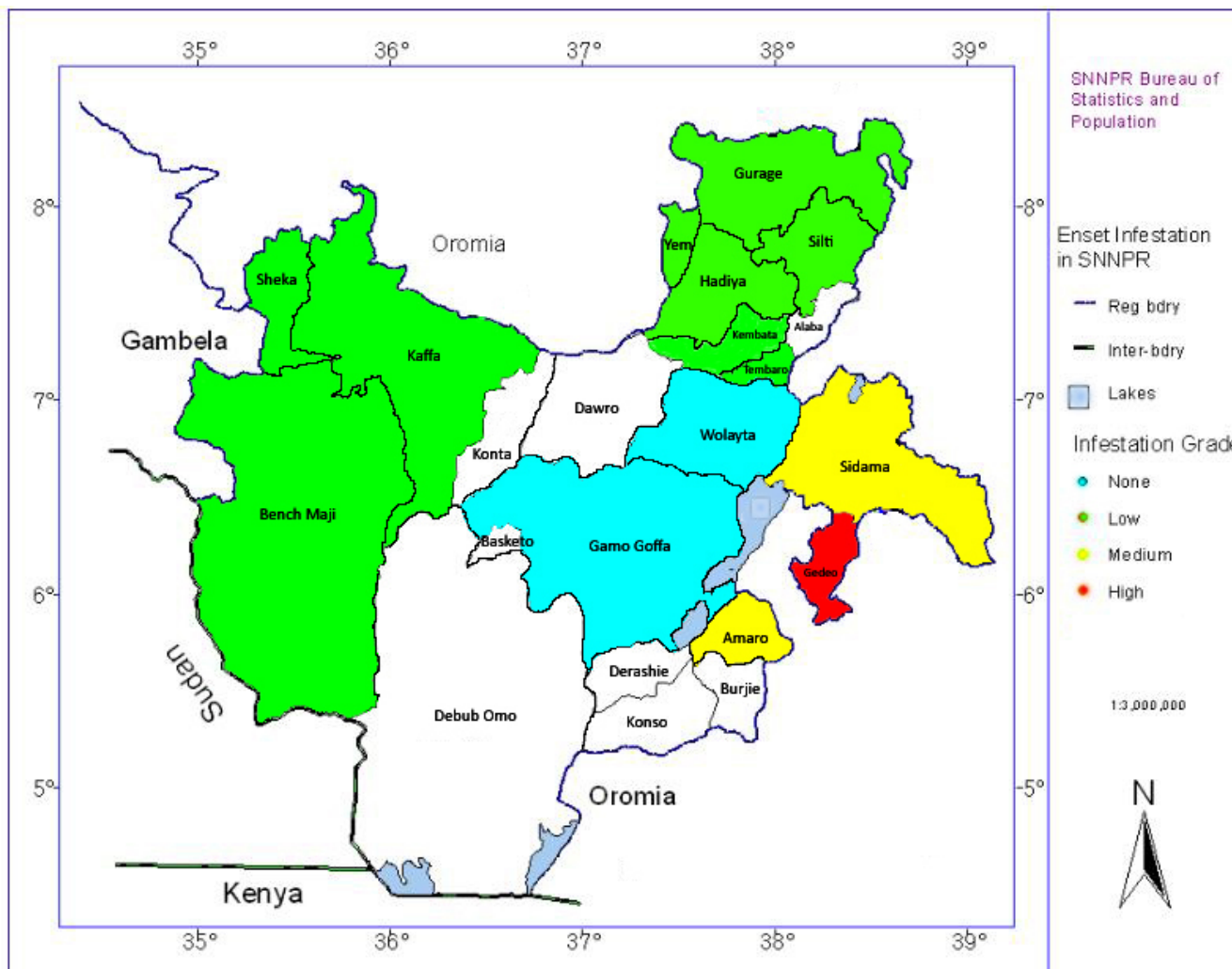


Fig. 5 Enset root mealybug distribution and degree of infestation in southern Ethiopia. Reprinted from Azerefege F, Addis T, Alemu T, Lemawork S, Tadesse E, Gemu M, Blomme G (2009) An IPM guide for enset root mealybug (*Cataenococcus ensete*) in enset production. Johnson V (Ed), Bioversity International, Uganda and France offices, 18 pp, ©2009, with kind permission from Bioversity International, Montpellier, France.

DAMAGE SYMPTOMS

Enset root mealybugs were found exclusively on the roots and corm of enset (Fig. 6). The damage symptoms by enset root mealybugs include symptoms of slow plant-growth, lack of vigour and subsequent death, especially under moisture-stress. Unlike *C. ferris* the enset root mealybug, *C. ensete* causes direct damage to enset plants where as the former transmits *Ensete* streak virus (Williams and Matile-Ferrero 1999). Infested plants displayed retarded growth where most lateral leaves were desiccated, but with a green central-shoot. All roots were found to be vulnerable to mealybugs attack. It was observed that enset plants attacked by root mealybugs have a significantly lower number of roots as compared to healthy plants. Addis *et al.* (2008b) reported that both the root and shoot fresh weight were negatively correlated with the population density of the root mealybugs ($R^2= 0.58$ and 0.92 , respectively). In addition, mealybug-damaged enset plants are more easily uprooted.

MEANS OF DISPERSAL

Enset mealybugs are dispersed by a number of different means. Crawling first instar nymphs can play a key role in dispersal within the host plant, and can be responsible for spreading the mealybug population to new host plants. Occasionally, these crawlers are observed on the lower part of the pseudostem just above the soil. Mealybugs can also be dispersed by water, when flooding occurs. However the main dispersal route is via the distribution of enset suckers



Fig. 6 Root mealybugs on enset roots and corm. Photo taken by Guy Blomme.

from infested corms, especially in nursery sites established below 2,000 masl where there is an environment conducive to mealybug reproduction (see section on geographical distribution). Planting material is commonly exchanged without discrimination of infested suckers, and subsequent transplanting of infested plants leads to further dispersal.

Out of the 163 farms surveyed in southern Ethiopia,

more than 30% were found infested with root mealybugs (Addis 2005). According to Addis (2005) most of the enset farmers (79%) produce their own suckers for planting. It was observed that it is not uncommon to purchase enset seedlings from local markets. About 20% of the farmers purchased suckers from local suppliers because they believe that suckers raised on their own farms would not perform well. Few farmers (1.2%) got suckers freely from government nursery sites. In areas where there was frequent exchange of planting materials among farmers like in Amaro, Gedeo, Sidama and Bench, there was a high level of infestation by *C. ensete* (100, 67, 62 and 57%, respectively). In contrast, in Hadyia, Gurage, Kembata Tembaro, Keffa and Yem where there was limited exchange of planting materials and farmers depend on self raised seedlings, the infestation was relatively low (17, 8, 25, 29 and 17%, respectively). The study (Addis 2005) also showed that exchange of planting materials in the absence of proper local quarantine services is an important means for spreading mealybugs to new farms and villages.

It was observed that some of the enset nurseries found in southern Ethiopia (Yirgachefe and Wonago districts) were highly infested by mealybugs (Addis 2005). It has been reported that some development organizations have been procuring suckers from these nursery sites and maintenance fields in order to distribute them to different areas of the country where farmers are trying to adopt enset production. Thus, the use of infested suckers from such centres has facilitated the distribution and spread of the insect to non-infested and new enset production areas.

The establishment of a quarantine/planting-material certification scheme could help address this problem (see section below on prevention).

Ants' activities have also been implicated in their dispersal. The literature documents many examples of the symbiotic relationship between ants and mealybugs, in which the ants protect the mealybugs to harvest their honeydew (Holldobler and Wilson 1990; Malsch *et al.* 2001). Even though the ants' species that are closely associated with enset root mealybugs are not yet identified, they were observed in association with the mealybug infestation in all places. It is known that ants play a role in the protection and dispersal of root mealybugs. Malsch *et al.* (2001) mentioned that when the mealybugs are disturbed at the time of cultivation, weeding, transplanting and harvesting, their attendant ants belonging to the genera *Pseudolasius* carry and take them to new plants or root parts. Even though dispersal of mealybugs by ants is a short distance; ants help them to find hidden places on the roots and corm, which are very difficult to reach even with insecticides. Before this was commonly known, farmers and others would sometimes attribute crop-wilt to the presence of ants, rather than the protection they afforded to the much less obvious

mealybugs. In this case, controlling the ants may also reduce levels of mealybug infestation and consequent wilt (Jahn *et al.* 2003).

Finally, mealybugs can also be transported by machinery, tools, equipment and soil movement during cultivation and repeated transplanting operations conducted at different times. Thus, appropriate hygiene measures applied to these items may also be an effective way of reducing dispersal. An enset plant may be transplanted two to five times before it is finally harvested. During transplanting, farmers pull out and re-plant all transplants including infested ones. It appears that little or no advisory services are provided by the extension agents to mitigate the distribution of the mealybugs.

MANAGEMENT OF ENSET ROOT MEALYBUGS

Prevention

The first resort for mealybug control is the use/production of clean planting material. In a study by Addis *et al.* (2008b) *C. ensete* infestation was severe only between 1,400 and 2,200 masl (Fig. 7). So, material from altitudes outside this range may offer potential for a mealybug-free source of planting material, especially if the production in these areas deploys an integrated approach to further minimize infestation risk.

Farmers' awareness of the enset root mealybug's damage symptoms and of management and control options is the key to a successful eradication of this important pest. Farmers also need training in clean enset seedling/planting material production. Therefore, extension programmes on enset management and control strategies should be strengthened so that large numbers of farmers can control the insects in established plantations, establish new enset fields with clean planting materials and stop the distribution of this pest to new enset production areas.

Quarantine measures could be designed to prevent further spread of the insect to different parts of the region. If practical, a clean-sucker certification-scheme could be developed, in which farmers who produce planting materials would be monitored. Areas and localities with a high incidence and severity of the insect should be delineated and a concerted effort should be made to stop the distribution of infested seedlings/planting materials to neighbouring areas. Farmers should get support to eradicate infested enset plants/plots and to start new plantations using clean seedlings/transplants.

Preparatory hygiene measures might also include exploiting the fact that adult female mealybugs are unable to survive for more than three weeks in the soil without any plant material/food supply. Therefore, crop rotation (during one or two cropping seasons) and/or removal of grasses and

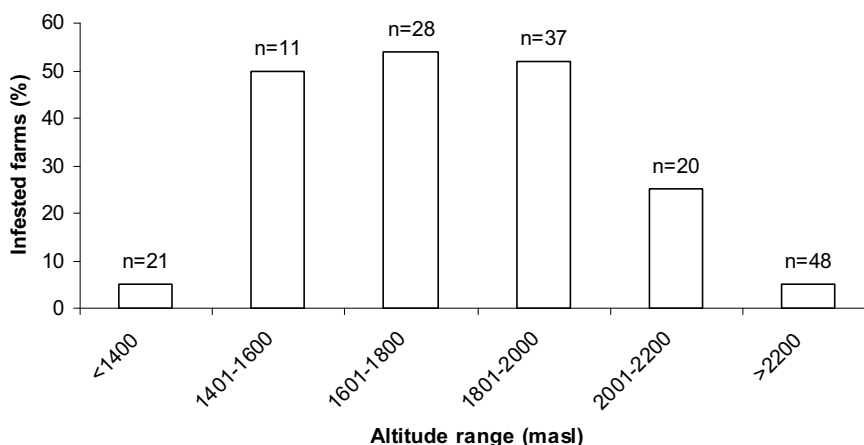


Fig 7. Effect of altitude on enset root mealybug infestation. Reprinted from Addis T, Azerefege F, Blomme G, Kanaujia K (2008a) Biology of the enset root mealybug, *Cataenococcus ensete* and its geographical distribution in Southern Ethiopia. *Journal of Applied Biosciences* 8 (1), 251-260, ©2008, with kind permission from the *Journal of Applied Biosciences*, Nairobi, Kenya.

weeds in enset fields will also help to control this pest. Infested enset plants need to be properly disposed of so that all the plant debris decays and no re-growth occurs.

Removal of ant vectors has also proven successful in reducing mealybug infestation levels in some other crops (see section Means of dispersal).

Cultural control

1. Use of farmyard manure

Farm yard manure contributes to better plant performance through improved crop nutrition (mostly nitrogen (N), but also possibly potassium (K), and even sulphur (S)). More robust plants are better able to ward off pests and diseases. Hence, the application of farm yard manure could enhance enset plant growth and make the plant more resistant to enset root mealybug attack. In addition, the manure could directly inhibit mealybug development. Farm yard manure can also improve the soil and root health conditions.

A preliminary study carried out by the Awassa Agricultural Research Centre assessed the effect of different rates (0, 5, 10, 15 and 20 kg/plant/year) of farmyard manure (obtained from cow dung) on the performance of enset in enset root mealybug infested fields. Plants which had received twenty kg per plant per year had visibly lower enset root mealybug numbers. In addition, these plants grew better and had less damage signs (Anonymous 2002). Farm yard manure should be applied when available in enset cultivation, to enhance plant growth but also as an IPM method in the control of the enset root mealybug.

2. Hot water treatment

Hot water treatments completely eliminated banana aphids, cotton aphids, mealybugs' nymphs and ants (Hara *et al.* 2001). Enset plants can be disinfested from enset root mealybugs by using hot water. Prior to hot water immersion, the pseudostem of enset plants was cut at a height of 20 cm above the corm. In addition, all the cord roots and dried pseudostem leaf sheaths were removed. Seedlings were categorized into size classes (small = <15 cm corm diameter at soil surface; medium = 16-30 cm and large = 31-45 cm), while different immersion durations and water temperatures were evaluated. Immersion of the seedlings, for all size classes, in boiling water for 10 to 30 seconds prior to planting resulted in a complete control of the root mealybugs and will also most easily be adopted by farmers (Lemawork 2008).

3. Cultivation

Adult mealybugs are unable to survive for more than three weeks in the absence of any plant material (Addis 2005; Addis *et al.* 2008b) (Fig. 8). While transplanting, planting pits should be left open for about a month so that any mealybug present in or in the vicinity of the planting hole will die of starvation. Repeated ploughing and removal of weeds and grasses in enset fields is believed to eradicate the enset root mealybug (Tadesse *et al.* 2003). Mealybugs collected from a related plant species *Heliconia* sp. were *Trochiscococcus speciosus* (De Lotto) (Homoptera: Pseudococcidae) (De Lotto 1961). Although root mealybugs were recorded on *Vernonia amigdalina*, *Discorea* spp., banana, bean, *Solanum nigrum*, *Solanum tuberosum* and some weeds and shrubs none of these mealybugs were identified as *Cataenococcus ensete* (Addis 2005). Farmers reported that the mealybug population numbers are higher in areas where eucalyptus trees are grown. This might be linked to the poor growth/vigour of enset plants in areas where eucalyptus is grown.

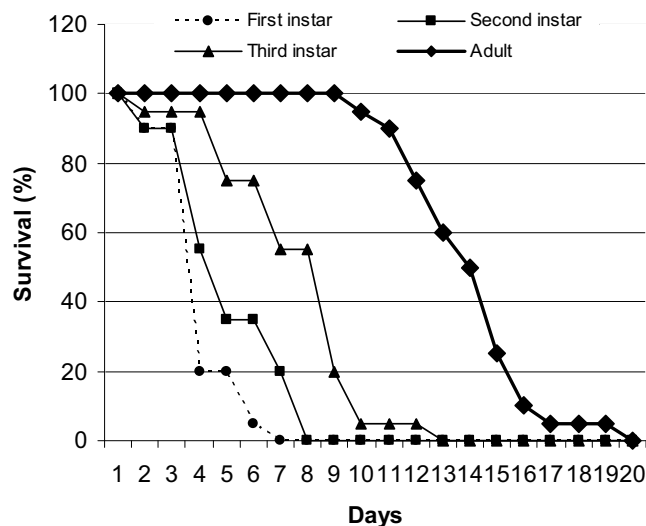


Fig. 8 Effect of food deprivation on the survival of different stages of *Cataenococcus ensete* in the soil (N = number of mealybugs evaluated). Reprinted from Addis T, Azerefegne F, Blomme G, Kanaujia K (2008a) Biology of the enset root mealybug, *Cataenococcus ensete* and its geographical distribution in Southern Ethiopia. *Journal of Applied Biosciences* 8 (1), 251-260, ©2008, with kind permission from the *Journal of Applied Biosciences*, Nairobi, Kenya.

Biological control

Some species of hyphomycete fungi have demonstrated insecticidal activity against a broad range of insect pests and are the main contenders for commercial production and used against homopterous pest insects (Lacey *et al.* 2001). Lemawork (2008) examined the efficacy of two *Beauveria bassiana* and two *Metarhizium anisopliae* isolates in controlling enset root mealybugs. Under field conditions, the entomopathogenic fungi, White Muscardine (*Beauveria bassiana* PPRC-56) caused the highest levels of mortality. However, the maximum mortality rate was only 54%. The isolate Green Muscardine (*Metarhizium anisopliae* Mm) was found to be least effective in controlling mealybugs (Lemawork 2008). The study showed that entomopathogens have the potential to be used in the integrated pest management of enset root mealybugs. However, there is a need to screen a larger number of isolates to identify potent entomopathogens.

Use of insecticidal plant extracts (botanicals)

Different insecticidal seed/plant-extract treatments (*Milletia ferruginea*, *Azadirachta indica*, *Melia azedarach*, *Phytolaca dodecandra* and *Schinus molle*) have been assessed for their effectiveness in controlling enset root mealybugs in the laboratory, in pot experiments and in farmers fields (Tadesse 2006). The study reported that a seed-water suspension of 10% *M. ferruginea* was toxic to enset root mealybugs. The dose-response bioassay of *M. ferruginea* was calculated to be $LD_{50} = 40.39 \text{ mg/5cm}^3$ of soil. With the pot experiment, drenching the soil (on which the infested young enset plants were planted) with seed-water suspensions of 10% *M. ferruginea* caused higher levels of mortality (66%) compared to the other botanicals and the untreated plants ($P < 0.05$). On the other hand, double applications of *M. ferruginea* improved its efficacy to 79%. However, *M. ferruginea* was inferior to the synthetic organophosphorous insecticide Diazinon 60% EC in both pot and dipping experiments (99% mortality rate). Drenching a seed-water suspension of 10% *M. ferruginea* into the root-zone of infested enset plants in the field was found to be effective against the enset root mealybugs. *M. ferruginea* seed water suspension was found to be superior than the other botanicals in terms of causing mortality to enset root

mealybugs (Tadesse 2006). *Milletia* trees are abundant in the area and seeds can be collected and stored for long periods. The preparation is simple and requires few technical skills. Thus, combinations of dipping young enset plants in *Milletia* solutions and drenching root-zones of infested enset plants can be used for the management of the enset root mealybugs.

Chemical control

Commercial synthetic insecticides have proven too costly for many small-scale enset growers. However, the application of Chlorpyrifos¹ 48% EC and Diazinon² 60% EC at a rate of 1.7 litres of solution (after dilution of the insecticide in 1:5 litres of water) per field-grown enset plant and poured on the root collar area, resulted in high levels of root mealybug mortality (Tadesse 2006). More than 90% of the adult mealybugs were killed within two weeks of application. For both chemicals the mortality rate reached about 98% at 45 days after application of the chemicals. On the other hand, the application of Malathion, Dimethoate, Endosulfan and Fenitrothion caused mortality rates which were lower than Chlorpyrifos and Diazinon but were still significantly higher than the control treatment (Bekele 2001). Other insecticides used to control mealybugs include: bendiocarb (also a fungicide), bifenthrin, cyfluthrin, fenpropathrin, insecticidal soap and kinoprene (Lindquist, <http://floriculture.osu.edu/archive/oct97/mealybug.html>).

It is suggested that insecticide application is done at the beginning of the dry season when mealybugs can really devastate the water-stressed enset plants.

Integration of management and control options/methods

The above mentioned management and control measures could be integrated for use by resource-poor small-scale enset farmers in Ethiopia. Prevention is almost always more cost-effective than cure. Therefore incorporating the preventive measures of extension, hygiene and quarantine are essential in any integrated programme. Informed by findings such as those described in the enset root mealybug IPM guide (Azerefege *et al.* 2009), enset nurseries should be established, perhaps at appropriate altitudes, for the production of clean seedlings/planting materials. Better hygiene measures, particularly at the nursery level, could be adopted, perhaps in conjunction with some form of quarantine and monitoring system. Boiling-water treatment should especially be included as a major disinfestation technique. Appropriate nutrition, perhaps using cow dung manure will also help in producing healthier, more robust plants.

For already infested enset plants, insecticidal plant/seed extracts could be used instead of synthetic insecticides. In the future, the use of entomopathogenic fungi may also become a realistic option. However, such an integrated approach can only be effective where management techniques are designed to be locally accessible, appropriate and affordable.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Vincent Johnson from Bioversity, France for editing and providing constructive comments during manuscript writing. The African Crop Science Journal, the American Association for the Advancement of Science, the Journal of Applied Biosciences, Bioversity International and the Revue Française d'Entomologie are greatly acknowledged for their Copyright permission to include in this paper some previously published figures.

¹ Both Chlorpyrifos and Diazinon have potential to bioaccumulate. They are toxic to freshwater and marine organisms, birds and honeybees, and considered hazardous to pollinators. (see: <http://www.abcbirds.org/abcp/programs/policy/pesticides/Profiles.html>)

² *ibid*

REFERENCES

- Addis T (2005) Biology of enset root mealybug (*Cataenococcus ensete* Williams and Matile-Ferrero) (Homoptera: Pseudococcidae) and its geographical distribution in southern Ethiopia. MSc thesis, Alemaya University, Ethiopia, 81 pp
- Addis T, Azerefege F, Blomme G (2008b) Density and distribution of enset root mealybugs on enset. *African Crop Science Journal* **16** (1), 67-74
- Addis T, Azerefege F, Blomme G, Kanauja K (2008a) Biology of the enset root mealybug, *Cataenococcus ensete* and its geographical distribution in Southern Ethiopia. *Journal of Applied Biosciences* **8** (1), 251-260
- Addis T, Blomme G, Turyagenda LF, Van den Berg E, De Waele D (2006) Nematodes associated with enset and banana in the highlands of Ethiopia. *International Journal of Nematology* **16** (2), 118-125
- Anonymous (2001) Awassa Agricultural Research Centre progress report of plant protection research division of entomology section for the year 2000. Awassa, Ethiopia, pp 18
- Anonymous (2002) Awassa Agricultural Research Centre progress report of plant protection research division of entomology section for the year 2001. Awassa, Ethiopia, pp 22
- Azerefege F, Addis T, Alemu T, Lemawork S, Tadesse E, Gemu M, Blomme G (2009) An IPM guide for enset root mealybug (*Cataenococcus ensete*) in enset production. Johnson V (Ed), Bioversity International, Uganda and France offices, 18 pp
- Bekele T (2001) Insecticidal screening against enset root mealybug *Paraputo* spp. *AgriTopia. Newsletter, Addis Ababa, Ethiopia* **16** (2), 2-3
- Bizuayehu TA (2002) Studies on Landrace diversity, *in vivo* and *in vitro* regeneration of enset (*Ensete ventricosum* Welw.). PhD thesis, Humboldt University, Verlage, Berlin, Germany, pp 1-4, 61-62
- Blumberg D, Van Driesche RG (2001) Encapsulation rates of three encyrtid parasitoids by three mealybug species (Homoptera: Pseudococcidae) found commonly as pests in commercial greenhouses. *Biological Control* **22**, 147-150
- Brandt SA, Anita S, Clifton H, Terrence MCJ, Endale T, Mulugeta D, Gizachew WM, Gebre Y, Masyoshi S, Shiferaw T (1997) *The "Tree against Hunger": Enset-based agricultural systems in Ethiopia*. American Association for the Advancement of Science, Washington, DC, USA, 56 pp
- De Lotto G (1961) New Pseudococcidae (Homoptera: Coccoidea) from Africa. *Bulletin of the British Museum (Natural History), Entomology* **10**, 209-238
- Ekesi S, Manniana NK, Ampong-Nyarko K, Onu I (1998) Potential of the entomopathogenic fungus, *Metarhizium anisopliae* (Metsch.) Sorokin for control of the legume thrips, *Megalurothrips sjostedti* (Trybom) on cowpea in Kenya. *Journal of Crop Protection* **17** (8), 661-668
- Ethiopian Mapping Authority (1988) *National Atlas of Ethiopia*, Addis Ababa, Ethiopia, 76 pp
- Hara AH, Nino-Dupont RY, Jacobsen CM (2001) Root mealybugs of quarantine significance in Hawaii. Cooperative Extension Service, CTAHR, University of Hawaii, Manoa, 4 pp. Available online: <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/IP-6.pdf>
- Holldobler B, Wilson EO (1990) *The Ants*, Springer-Verlag, Berlin, 73 pp
- Jahn GC, Beardsley JW, González-Hernández H (2003) A review of the association of ants with mealybug wilt disease of pineapple. *Proceedings of the Hawaiian Entomological Society* **36**, 9-28
- Lacey LA, Frutos R, Kaya HR, Vails P (2001) Insect pathogens as biological control agents: Do they have a future? *Biological Control* **21**, 230-248
- Lemawork S (2008) Evaluation of entomopathogenic fungi and hot water treatment against enset root mealybug, *Cataenococcus ensete*, Williams and Matile-Ferrero (Homoptera: Pseudococcidae) on enset. MSc thesis, Hawassa University, Awassa, Ethiopia, 87 pp
- Lindquist R. Mealybugs. OARDC/Department of Entomology, Ohio State University, USA. Available online: <http://floriculture.osu.edu/archive/oct97/mealybug.html>
- Malsch AKF, Kaufman E, Heckroth HP, Williams DJ, Maryati M, Maschwitz U (2001) Continuous transfer of subterranean mealybugs (Hemiptera: Pseudococcidae) by *Pseudolasius* spp. (Hymenoptera, Formicidae) during colony fission. *Insects Socioux* **48**, 333-341
- Quimio AJ, Tessera M (1996) Diseases of enset. In: Tsedeke A, Clifton H, Brandt SA, Seifu G (Eds) *Proceedings of the 1st International Workshop on Enset*, Addis Ababa, Ethiopia, pp 188-203
- Speijr PR (1999) Clean planting materials for bananas and yams. *Agriforum* **9**, 4
- Tabogie E, Tadesse M, Wolde-Michael G (2002) Enset-based farming systems survey in Kucha Woreda of Gamo Goffa zone: Constraints and future prospects. Research Report No. 48. Awassa, Ethiopia, 48 pp
- Tadesse E (2006) Evaluation of some synthetic and botanical insecticides against the enset root mealybug (*Cataenococcus ensete*) (homoptera: pseudococcidae) William and Matile-Fererro in Southern Ethiopia. MSc thesis, Hawassa University, Awassa, Ethiopia, 67 pp
- Tadesse M, Anito E, Geta E (2003) *Enset-Based Farming Systems of Masha wereda, Shaka Zone*, EARO Research Report No. 51. Addis Ababa, Ethiopia, 25 pp
- Taye B (1984) Evaluation of some *Ensete ventricosum* clones for food yield with emphasis on the effect of length of fermentation on carbohydrate and

- calcium content. *Tropical Agriculture* **61**, 111-116
- Tenkouano T, Hauser S, Coyne D, Coulibaly O** (2006) Clean planting materials and management practices for sustainable production of banana and plantain in Africa. *Chronica Horticulturae* **46** (2), 14-18
- Tsedeke A** (1988) Insect and mite pests of horticultural and miscellaneous plants in Ethiopia. Handbook, Addis Ababa, Ethiopia, 115 pp
- Williams DJ, Matile-Ferrero D** (1999) A new species of the mealybug genus *Cataenococcus ferris* from Ethiopia on *Ensete ventricosum*, a plant infected by a virus (Hemiptera: Pseudococcidae; Musaceae). *Revue Francaise d'Entomologie (N.S.)* **21** (4), 145-149