Eucalyptus infestation by *Leptocybe invasa* in Uganda

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Abstract

Very little is known about *Leptocybe invasa* Fisher & LaSalle, a new fast-spreading alien pest infesting *Eucalyptus* in several countries. This study examined *L. invasa* infestation on *Eucalyptus* germplasms in different agroecological zones of Uganda. The incidence and severity of the pest infestation were higher in hotter and drier agroecological zones than in cooler and wetter zones. There were direct negative relationships between altitude and *L. invasa* infestation on *Eucalyptus* species. No infestation was observed on any *Eucalyptus* species in stands at altitudes ranging from 1938 to 2452 (the maximum encountered) m above sea level. *Leptocybe invasa* infestation occurred on all *Eucalyptus* species encountered (*Eucalyptus grandis*, *Eucalyptus camaldulensis*, *Eucalyptus saligna*, *Eucalyptus robusta*), except *Eucalyptus maidenii* that escaped attack because it was located outside the ecological range of the insect. The incidence and severity of *L. invasa* infestation was generally higher on clonal hybrids *E. grandis* × *E. camaldulensis* than on *E. grandis* × *Eucalyptus urophylla*. Research on host germplasms, *L. invasa* biology and ecology, impact of the pest infestation and possible control strategies are suggested to facilitate the development of sustainable management strategies.

Key words: Alien pests, altitude, *Eucalyptus, Leptocybe invasa*

Résumé

On sait très peu de choses sur *Leptocybe invasa* Fisher & LaSalle, une nouvelle espèce nuisible très invasive qui infeste les *Eucalyptus* dans plusieurs pays. Cette étude a examiné l'infestation par *L. invasa* des germoplasmes d'*Eucalyptus* dans différentes zones agroécologiques d'Ouganda. L'occurrence et la gravité de l'infestation par cette espèce nuisible étaient plus élevées dans les zones agroécologiques plus chaudes et plus sèches que dans les zones plus fraîches et plus humides. Il y avait des relations négatives directes entre l'altitude et l'infestation des espèces d'eucalyptus par *L. invasa*. On n'a observé aucune infestation de quelque espèce d'eucalyptus que ce soit dans les plantations allant de 1938 à 2452 mètres d'altitude (la plus haute altitude à cet endroit). L'infestation par *Leptocybe invasa* touchait toutes les espèces d'eucalyptus rencontrées (*Eucalyptus grandis, E. camaldulensis, E. saligna* et *E. robusta*) à l'exception d'*E. maidenii* qui a échappé à cette attaque parce qu'il était situé en dehors de l'aire de dispersion écologique de cet insecte. L'occurrence et la gravité de l'infestation par cette espèce nuisible étaient plus élevées chez les hybrides clonés d'*Eucalyptus grandis* × *E. camaldulensis* que chez les hybrides *E. grandis* × *E. urophylla*. Des recherches sur les germoplasmes hôtes, sur la biologie et l'écologie de *L. invasa*, sur l'impact de l'infestation par cette espèce nuisible et sur d'éventuelles stratégies de contrôle sont suggérées ici pour faciliter le développement de stratégies de gestion durables.

Introduction

Dwindling supply of wood from natural forests and increasing demand for various wood products in the tropics imply that plantation forests will continue to be a major source of wood products for the foreseeable future. However, woodlots and forest plantations, especially monocultures of genetically similar trees, are highly vulnerable to insect pests and diseases (Wingfield *et al.*, 2001; Cock, 2003) because of the increasing emergence of new insect pest and disease problems on plantation trees in the tropics. For example, outbreaks of the conifer aphid, *Cinara cuppressivora* Watson and Voegtlin, on cypress in eastern and central Africa (Murphy, 1998; Day *et al.*, 2003), the sirex wood wasp, *Sirex noctilio* Fabricius, on pines in South Africa (Tribe, 2003; Hurley, Slippers & Wingfield, 2007), and now the blue gum chalcid, *Leptocybe invasa*, on

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Eucalyptus species in many countries in Africa, Asia, the Middle East and Europe (Mutitu, 2003; Mendel *et al.*, 2004; Nyeko, 2004, 2005; EPPO, 2006) illustrate how such pest problems raise serious concerns to developers of tropical tree plantation enterprises.

Eucalyptus species are the most widely planted exotics in the tropics with several species grown in over 80 countries (Wylie & Floyd, 1998). The popularity of *Eucalyptus* species is attributable to them being generally adaptable, fast growing with the potential for producing sawn wood and processed wood products, high calorific value fuelwood and a variety of environmental and ornamental uses (Poore & Fries, 1989). In Uganda, many agencies promote the planting of *Eucalyptus*, which farmers consider an important source of construction materials, fuelwood and income (Nyeko, Mutitu & Day, 2007).

Leptocybe invasa is a new taxon of Australian origin that was first recorded in the Middle East in 2000 (Mendel *et al.*, 2004). The adult of the insect is a very small (1.0–1.4 mm long) black wasp (Mendel *et al.*, 2004). It lays eggs in the bark of shoots, petiole or the midribs of leaves of *Eucalyptus* species. The eggs develop into minute, white, legless larvae within the host plant. The developing larvae induce coalescing galls to form on the host plant tissue (Mendel *et al.*, 2004). Small circular holes, indicating exit points of adults, are common on the galls. Severely infested trees show gnarled appearance, stunted growth, lodging, dieback and sometimes tree death (Mendel *et al.*, 2004; Nyeko, 2005). *Leptocybe invasa* infestation is more severe on nursery seedlings and young (1–3 year old) plantations than on older trees (Mutitu *et al.*, 2005; Nyeko, 2005). Several suitable hosts of the insect have been reported, including *Eucalyptus camaldulensis, Eucalyptus grandis, Eucalyptus globulus, Eucalyptus gunii, Eucalyptus saligna, Eucalyptus tereticornis, Eucalyptus otyoides, Eucalyptus robusta, Eucalyptus bridgesiana* and *Eucalyptus viminalis* (Mendel *et al.*, 2004; Nyeko, 2004), and the hybrid clones GC 10, GC 12, GC 14, GC 522 and GC 784 (Mutitu *et al.*, 2005).

In Uganda, *L. invasa* infestation on *Eucalyptus* species was first reported in December 2002 from Kasese district. Since then, several concerns have been raised about the pest infestation on *Eucalyptus* in the country (Nyeko *et al.*, 2007). However, very little is known about the pest and no specific control recommendations exist. The objective of the study was to determine the distribution and magnitude of *L. invasa* infestation on *Eucalyptus* germplasms in different agroecological zones in Uganda. Specifically, the study: (i) compared the incidence and severity of *L. invasa* infestation on *Eucalyptus* germplasms (species and clones) in different ecological zones; (ii) compared the pest infestation on different *Eucalyptus* germplasms; and (iii) examined the relationship between altitude and the pest infestation. Such information is important for the development of sustainable management strategies for the pest.

Materials and methods

Study sites and Eucalyptus *germplasms*

This study was conducted from January to February 2006 in eleven districts located in seven agroecological zones of Uganda (Table 1). Only *Eucalyptus* stands established from 2003 to 2005 or coppices from stumps of trees cut in this period were selected for this study for ease of examining the shoots and because of the fact that *L. invasa* infestation is most severe on young trees (<3 years old). In total, 154 stands were examined for the incidence and severity of *L. invasa* infestation (Table 1). The stands included five *Eucalyptus* species (*E. grandis*, *E. camaldulensis*, *E. saligna*, *E. robusta* and *Eucalyptus maidenii*) and eleven clonal hybrids. The clones examined included *E. grandis* × *E. camaldulensis* (GC) and *E. grandis* × *Eucalyptus urophylla* (GU) hybrids: GC 540, GC 550, GC 578, GC 784, GC 796, GC 578, GU 7, GU 8, GU 21, GU 607 and GU 609. The clones were planted in the mother garden at the Uganda National Forestry Resources Research Institute at Kifu, Mukono district and a nearby field (*c.* 10 km). Whereas all the clones were available for scoring in the mother garden, only five (GU 7, GU 8, GU 609, GC 514 and GC 578) were assessed in the field. All the clones examined originated from South Africa.

Field methods

The incidence and severity of *L. invasa* in each stand were scored on a total of 60 trees per *Eucalyptus* species or clone. The incidence of *L. invasa* infestation on a tree was scored based on the absence or presence of galls induced by the pest. The gall severity was scored visually on the following scales: (i) none (trees with no visible gall); (ii) minor (trees with galls in less than 25% of total shoots); (iii) moderate (trees with galls in 25–50% of total shoots); and (iv) severe (trees with galls in more than 50% of total shoots). Every seclected stand was divided into three blocks of roughly equal size. In each block, a plot of twenty trees was

Table 1 Characteristics of agroecological zones where *Eucalyptus* stands were sampled

Agroecological zone*	Districts sampled	Mean annual rainfall (mm)	Mean annual temperature (°C)	No. stands sampled	Altitude (masl) range of stands sampled
Eastern	Kumi, Tororo	900–1300 Bimodal	18–32	27	1057–1347
Eastern Highlands	Mbale, Sironko	1000–2100 Bimodal	15–32	34	1086–2039
Lake Albert crescent	Masindi	1100–1500 Bimodal	16–30	6	1077–1137
Lake Victoria Crescent	Masaka, Mukono	1750–2000 Bimodal	12–29	5	1157–1279
Southern Drylands	Ntungamo, Isingiro	under 1000 Bimodal	18–32	32	1250–1809
Southern Highlands	Kabale	1000–1500 Bimodal	10–23	30	1804–2452
West Nile	Arua	1000–1200 Unimodal	20–25	20	1023–1260

*Classification according to the Uganda National Agricultural Research Organization (Mukiibi & Tizikara, 2001).

randomly established, and all trees in the plot were scored for incidence and severity of *L. invasa* infestation. In stands of mixed *Eucalyptus* species and/or clones, only species and/or clones with at least 30 trees were scored. In cases where the total number of trees per species was <60, but at least 30 trees available, all trees of the species within the stand were scored. Coppices from one stump were scored as one tree irrespective of their total number.

Additional data were collected on the altitude of each stand using the Global Positioning System. For every stand, the altitude was determined at one point either within the stand (if canopy is open) or in a nearby (not more than 20 m from the stand edge) open space outside a stand with closed canopy.

Data analysis

Pivot Table in Microsoft Excel computer software was used to calculate the total number of trees sampled in each stand, number of trees infested by *L. invasa* (incidence) and the number of trees in each severity class of *L. invasa* infestation per plot. Analysis of Variance (ANOVA) in Minitab statistical package was used to test the effect of agroecological zone on *L. invasa* infestation and the variability in *L. invasa* infestation between *Eucalyptus* germplasm within agroecological zones. Interactions between agroecological zones and *Eucalyptus* germplasms could not be tested because not all germplasms occurred in all agroecological zones. For each *Eucalyptus* germplasm, the percentage infestation incidence (percentage of trees infested by *L. invasa*) per plot was calculated in Microsoft Excel computer software and analysed using (ANOVA). Similarly, the average severity per plot was calculated and analysed using ANOVA. The incidence and severity data were square root- and $\log_{10}(x + 1)$ – transformed (Nyeko, 2005), respectively after checking for distribution using the Anderson–Darling test, that detects departure from normality in the high and low values of a distribution (Minitab Inc., 2000). The means of *L. invasa* gall incidence and severity were compared among ecological zones and *Eucalyptus* germplasms using the Least Significant Difference at 5% probability level in order to test the significance of the variation of the pest infestation among agroecological zones and *Eucalyptus* germplasms.

Simple linear regression analysis was used to determine the relationship between stand altitude and the magnitude of *L. invasa* infestation on *E. grandis, E. camaldulensis* and *E. saligna*; the three widely planted *Eucalyptus* species. *Leptocybe invasa* damage index per stand was calculated by multiplying the mean percentage incidence and severity of infestation, and subjected to regression analysis in order to show the relationship between stand altitude and the magnitude of *L. invasa* infestation.

Results

Leptocybe invasa *infestation in different agroecological zones and* Eucalyptus *species*

Overall 11,196 trees were examined, the majority (70%) were *E. grandis* followed by *E. camaldulensis* (14%), eleven *Eucalytpus* clones (8%), *E. saligna* (6%), *E. robusta* (2%) and *E. maidenii* (1%). *Leptocybe invasa* infestation on *Eucalyptus* species was observed in all the agroecological zones studied, except southern highlands. Significant variations in the incidence of *L. invasa* infestation were observed among

Table 2 The incidence and severity of *Leptocybe invasa* infestation on *Eucalyptus* species in different agroecological zones of Uganda

Eucalyptus species and agroecological zone	Total sample	Incidence (%)	Average severity	Severity class (% of total sample)			
				1	2	3	4
Eucalyptus grandis							
Eastern Highlands	2040	23.9[b]	1.5[b]	76.2	9.5	5.4	8.9
Southern Highlands	1620	0.0[d]	1.0[d]	100.0	0.0	0.0	0.0
Southern Drylands	1520	43.8[c]	1.8[c]	55.5	20.6	10.2	13.7
Eastern	1380	61.1[a]	2.4[a]	38.9	16.4	14.8	29.9
West Nile	780	90.3[e]	3.2[e]	9.7	15.9	19.1	55.3
Lake Albert crescent	360	65.3[a]	2.3[a]	34.7	25.6	18.1	21.7
Lake Victoria Crescent	180	78.9[ae]	2.5[a]	28.3	29.4	22.2	27.2
Eucalyptus camaldulensis							
Southern Drylands	1182	65.1[a]	2.3[a]	34.9	27.7	14.4	22.9
Eastern	240	91.3[b]	2.7[a]	8.8	43.3	20.8	27.1
West Nile	180	80.0[b]	2.8[a]	20.0	17.8	27.8	34.4
Eucalyptus saligna							
West Nile	240	52.5[a]	1.9[a]	47.5	27.5	15.8	9.2
Eastern	240	34.6[a]	1.4[a]	65.4	31.7	2.9	0.0
Southern Drylands	60	8.3[a]	1.1[a]	91.7	8.3	0.0	0.0
Southern Highlands	60	0.0[a]	1.0[a]	100.0	0.0	0.0	0.0
Eastern Highlands	40	0.0[a]	1.0[a]	97.5	2.5	0.0	0.0
*Eucalyptus robusta**							
Southern Drylands	60	73.3	2.2	26.7	45.0	11.7	16.7
Southern Highlands	60	0.0	1.0	100.0	0.0	0.0	0.0
*Eucalyptus maidenii**							
Southern Highlands	60	0.0	1.0	100.0	0.0	0.0	0.0

*Statistical test not performed because of insufficient number of stands sampled. For each incidence and average severity, mean values followed by the same superscript letter within a column are not significantly different at 5% probability level. See text for definition of severity classes.

the agroecological zones on *E. grandis* ($F_{6,125} = 46.63$; $P = 0.000$) and *E. camaldulensis* ($F_{2,25} = 5.73$; $P = 0.009$), but not *E. saligna* ($F_{4,6} = 1.03$; $P = 0.463$) (Table 2). However, significant variations in the severity of *L. invasa* infestation among the agroecological zones were observed on *E. grandis* ($F_{6,125} = 45.06$; $P = 0.000$), but not *E. camaldulensis* ($F_{2,25} = 3.19$; $P = 0.058$) and *E. saligna* ($F_{4,6} = 1.71$; $P = 0.265$). The highest incidence and severity of the pest infestation on *E. grandis* occurred in West Nile zone, with most of the trees having galls in more than 50% of total shoots (severity class 4) (Table 2). *Eucalyptus camaldulensis* had similarly high incidence and severity of *L. invasa* infestation in West Nile and eastern agroecological zones.

The incidence and severity of *L. invasa* infestation was significantly higher on *E. camaldulensis* than on *E. saligna* in all the agroecological zones where the species co-occurred (Table 3). Similarly, *E. grandis* had higher incidence and severity of the pest infestation than *E. saligna* in all the ecological zones, except the eastern highlands (Table 3). *Eucalyptus robusta* showed higher incidence of the pest infestation than *E. grandis* and *E. saligna* in the southern drylands. *Eucalyptus maidenii* occurred only in Kabale district (southern highlands) where no *L. invasa* infestation was observed on any of the *Eucalyptus* species.

Relationship between Leptocybe invasa *infestation and altitude*

The altitude of sampled stands ranged from 1023 m above sea level (masl) in West Nile zone to 2452 masl in the southern highlands (Table 1). Significant negative relationships were observed between altitude and *L. invasa* damage on *E. grandis* ($P < 0.001$) and *E. camaldulensis* ($P = 0.003$), which occurred over a wide range of altitudes (Fig. 1a,b). The relationship between altitude and *L. invasa*

Table 3 Variation in the incidence and severity of *Leptocybe invasa* infestation on *Eucalyptus* species within agroecological zones of Uganda

Eucalyptus species and agroecological zone	Total sample	Incidence (%)	Average severity	Severity class (% of total sample)			
				1	2	3	4
Eastern							
Eucalyptus grandis	1380	61.1[a]	2.4[a]	38.9	16.4	14.8	29.9
Eucalyptus camaldulensis	240	91.3[b]	2.7[a]	8.8	43.3	20.8	27.1
Eucalyptus saligna	240	34.6[c]	1.4[b]	65.4	31.7	2.9	0.0
$F_{2,28}$-value		6.50	9.52				
P-value		0.005	0.001				
Eastern highlands							
Eucalyptus grandis	2040	23.9[a]	1.5[a]	76.2	9.5	5.4	8.9
Eucalyptus saligna	40	0.0[a]	1.0[a]	97.5	2.5	0.0	0.0
$F_{1,33}$-value		0.70	0.62				
P-value		0.410	0.438				
Southern drylands							
Eucalyptus grandis	1520	43.8[a]	1.9[a]	55.5	20.6	10.2	13.7
Eucalyptus camaldulensis	1182	66.2[b]	2.3[a]	34.9	27.7	14.4	22.9
Eucalyptus saligna	60	8.3[c]	1.1[b]	91.7	8.3	0.0	0.0
Eucalyptus robusta	60	73.3[b]	2.2[a]	26.7	45.0	11.7	16.7
$F_{3,45}$-value		8.98	4.24				
P-value		0.000	0.010				
West Nile							
Eucalyptus grandis	780	90.3[a]	3.2[a]	9.7	15.9	19.1	55.3
Eucalyptus camaldulensis	180	80.0[a]	2.8[a]	20.0	17.8	27.8	34.4
Eucalyptus saligna	240	52.5[b]	1.9[b]	47.5	27.5	15.8	9.2
$F_{2,17}$-value		19.77	13.31				
P-value		0.000	0.000				

For each incidence and average severity, mean values followed by the same superscript letter within a column are not significantly different at 5% probability level. See text for definition of severity classes.

damage on *E. saligna* ($P = 0.200$) was, however, not significant (Fig. 1c), apparently because most stands of this species were found at low altitudes (<1400 masl). No *L. invasa*-induced gall was observed on any *Eucalyptus* stands examined at altitudes ranging from 1938 to 2452 masl (the maximum encountered), which occurred in the eastern and southern highlands (Table 1 and Fig. 1).

Variations in Leptocybe invasa *infestation between* Eucalyptus *clones*

Marked differences were observed in the incidence and severity of *L. invasa* infestation between *Eucalyptus* clones. In the mother garden at Kifu (Mukono district), the infestation occurred in seven of the eleven clones examined (Table 4). The incidence and severity of the infestation at this site were significantly higher on GC 784 and GC 540 than the other clones. Although clones GC 796 and GC 550 showed high gall incidence in the mother garden, the severity of infestation on trees of these clones was minor (<25% shoot infestation). Clones GU 7 and GU 8, which had no galls at the mother garden, showed high incidence of infestation in the field. In contrast, clones GU 609 and GC 578 were infested at the mother garden but not in the field. The severity of infestation was, however, generally minor (severity class 2) on all infested clones in the field. Casual observations indicated that the leaves, petioles and shoots (*L. invasa* oviposition sites) of GU 7 and GU 8 plants were much smaller in the mother garden than in the field. In addition, the galls observed on the clones were very small and most of them had no *L. invasa* emergence holes.

Discussion

This study indicates that *L. invasa*, which was first observed in Uganda in December 2002, has spread rapidly and

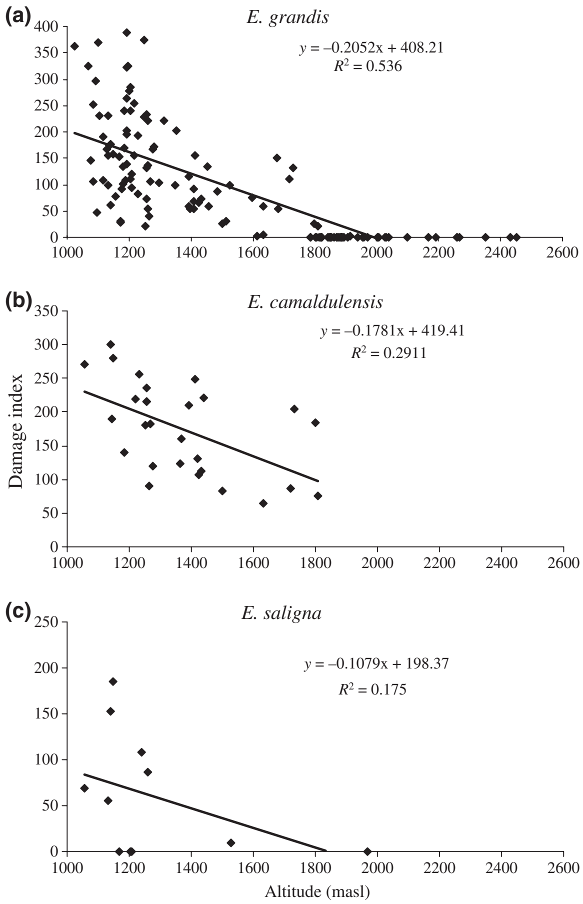

Fig 1 Relationships between altitude and *Leptocybe invasa* damage on *Eucalyptus* species in Uganda

covered a wide range of ecological zones in the country. Mendel *et al.* (2004) similarly reported a rapid spread of the pest in Israel, and attributed it to fast population growth of the pest, its thelytokous reproduction (producing females only), mulivotinous development (overlapping generations) and the absence of its principal natural enemies. It is also possible that the extensive coverage of *Eucalyptus* species, poor species-site matching and the general lack of control over the movement of planting materials in Uganda facilitated the rapid spread of *L. invasa* in the country.

The occurrence of *L. invasa* in nearly all the agroecological zones examined in this study indicates that the insect can thrive under a wide range of ecological conditions. It was, however, clear that *L. invasa* infestation on *Eucalyptus* is influenced by altitude. Bird & Hodkinson (2005) observed a similar altitudinal effect on *Craspedolepta nebulosa* and *Craspedolepta subpunctata*, and concluded that these psyllid species are unable to establish viable populations above their upper altitudinal range limits, despite the presence of their host plant. Many factors can affect insect herbivore performance along an elevation gradient, including plant phenology, plant secondary compounds, leaf traits, abundance of natural enemies and variation in abiotic conditions related to elevation (Koptur, 1985; Kudo, 1996; Hodkinson, 1997). Bird & Hodkinson (2005) demonstrated that altitudinal limits of *C. nebulosa* and *C. subpunctata* are climatically determined and are not a result of failure of the species to disperse to higher elevations. This may well apply to *L. invasa*, as its infestation on *Eucalyptus* was observed in stands at low altitudes bordering the highlands. One distinct feature of the Southern Highlands ecological zone where *L. invasa* infestation was absent is the cool temperatures (mean annual temperatures of 10–23°C), which may have directly affected the development, survival, range and abundance of the insect (Bale *et al.*, 2002), and thus the low infestations (Alonso, 1999). Mendel *et al.* (2004) observed that in Israel, the activities of *L. invasa* resumes only after the cold period, when the average maximum temperature has risen above 20°C. Reports on the relationship between temperature and *L. invasa* survival and infestation are scanty. Detailed studies of thermal requirements of *L. invasa* will contribute to elucidating whether temperature affects the survival of the insect.

Leptocybe invasa infestations observed on *E. grandis*, *E. camaldulensi*, *E. saligna* and *E. robusta* in this study concur with earlier reports that these species are suitable hosts for the pest (Mendel *et al.*, 2004; Mutitu *et al.*, 2005; Nyeko, 2005). However, the absence of *L. invasa* on *E. maidenii* contrasts with the report by the European and Mediterranean Plant Protection Organisation (EPPO, 2006) that the species is a host to *L. invasa*. In this study, *E. maidenii* was encountered only in the southern highlands where *L. invasa* infestation was absent on all *Eucalyptus* species examined. It is possible that *E. maidenii* escaped the pest attack by virtue of its location in an agroecological zone that was not invaded by the pest. This emphasises the need to evaluate host species under various environmental conditions to ascertain their pest resistance or susceptibility. This information is important for the tree farmers who have invested in *Eucalyptus* plantations as enterprises.

The high incidence and severity of *L. invsasa* infestation observed on GC 784 in this study corroborates the results of Mutitu *et al.* (2005) that this clone is highly preferred by

Table 4 The incidence and severity of *Leptocybe invasa* infestations on mother garden and planted *Eucalyptus* clones in Mukono district, Uganda

				Severity class (% of total sample)			
Eucalyptus clone	Total sample	Incidence (%)	Average severity	1	2	3	4
Mother garden							
GC 784	44	99.3[a]	3.5[d]	2.3	9.1	27.3	61.4
GC 540	60	95.0[a]	2.7[e]	5.0	26.7	63.3	5.0
GC 796	60	75.0[b]	2.0[a]	25.0	55.0	15.0	5.0
GC 550	60	61.7[c]	1.7[c]	38.3	55.0	6.7	0.0
GU 609	60	13.3[d]	1.2[b]	85.0	15.0	0.0	0.0
GU 607	60	11.7[d]	1.1[b]	88.3	11.7	0.0	0.0
GC 578	60	3.3[de]	1.0[b]	96.7	3.3	0.0	0.0
GU 8	60	0.0[e]	1.0[b]	100.0	0.0	0.0	0.0
GU 7	60	0.0[e]	1.0[b]	100.0	0.0	0.0	0.0
GU 21	60	0.0[e]	1.0[b]	100.0	0.0	0.0	0.0
GC 514	40	0.0[e]	1.0[b]	100.0	0.0	0.0	0.0
$F_{10,21}$-value		110.76	123.35				
P-value		0.000	0.000				
Field planted							
GU 7	60	100.0[a]	2.0[ab]	0.0	100.0	0.0	0.0
GC 796	60	78.3[b]	2.1[a]	21.7	51.7	23.3	3.3
GU 8	60	73.3[b]	1.7[b]	26.7	73.3	0.0	0.0
GU 609	30	0.0[c]	1.0[c]	100.0	0.0	0.0	0.0
GC 578	60	0.0[c]	1.0[c]	100.0	0.0	0.0	0.0
$F_{4,9}$-value		68.44	0.000				
P-value		28.28	0.000				

For each incidence and average severity, means followed by the same superscript letter within a column are not significantly different at 5% probability level. See text for definition of severity classes.

the insect. Generally, the incidence and severity of *L. invasa* infestation varied among *Eucalyptus* clones, with GU (*E. grandis* × *E. urophylla*) hybrids showing less infestation than the GC (*E. grandis* × *E. camaldulensis*) hybrids, especially in the mother garden at Kifu. The susceptibility of the clones to *L. invasa* infestation is apparently influenced by the parent species. Whereas *E. grandis* and *E. camaldulensis* have been reported as suitable hosts of *L. invasa* (Mendel *et al.*, 2004), *E. urophylla* is not preferred by the insect (Mutitu *et al.*, 2005). Similarly, Mendel *et al.* (2004) observed that *L. invasa* successfully established on *E. grandis* × *E. camaldulensis* hybrid but not the hybrid *Eucalyptus torwood* (*E. torguata* × *E. woodwardii*) whose parent species are rejected host plants. However, reports of studies that have examined the reasons for such resistance and susceptibility of *Eucalyptus* germplasms to *L. invasa* are lacking in the literature. Nevertheless, such variations in host susceptibility indicate an opportunity for selecting *Eucalyptus* germplasms for resistance against *L. invasa*. Researchers, tree breeders and farmers need to know this in order to develop and/or promote *Eucalyptus* germplasms resistant to the pest. The main challenge here is to identify the genes responsible for the resistance, which could be resolved through molecular studies.

Conclusions and recommendations

This study has demonstrated that *L. invasa* infestation on *Eucalyptus* species is widespread in Uganda. The infestation is more prevalent and severe in hotter and drier agroecological zones than in cooler and wetter ones. Significant variations in the incidence and severity of the pest infestation were observed among *Eucalyptus* germplasms. *Eucalyptus grandis, E. camaldulensis* and *E. robusta* showed remarkably high susceptibility to *L. invasa* as were clones GC 784, GC 540 and GC 796, and may thus not be suitable for planting in agroecological zones favourable to the pest. In contrast, GC 578 was resistant to the pest. Such variations in host susceptibility indicate an opportunity for selecting *Eucalyptus* germplasms for resistance against the pest. *Leptocybe invasa* infestation decreased with increasing altitude with no infestation observed at high (1938 masl and above) altitudes.

Considering the rapid global spread of *L. invasa* and the importance of *Eucalyptus* species to individual livelihoods and national economies in the tropics, it is surprising that very little has been done to avert the threats posed by this introduced pest. In particular, research is required on various aspects of the pests and its hosts so that national and international research institutes could develop sustainable management strategies. The current study has provided single field visit results. Clearly, there is a need for long-term observations and basic ecological studies in order to generate more robust data, which could facilitate the management of *L. invasa* in the tropics. The following areas of research are recommended:

- Host characteristics: Chemical (e.g. intrinsic odours may influence host finding or acceptance), physical (e.g. leaf/twig anatomy may prevent gall formation) and physiological (e.g. germplasms escaping pest attack through fast growth and self pruning of attacked leaves) features; molecular characterization of resistant and susceptible germplasms with the aim of identifying genes for resistance.
- Biology and ecology of *L. invasa*: Reproductive capacity in relation to different environmental conditions. Variability among pest populations in different regions; life cycle under varying climatic regimes; population dynamics in relation to environmental factors in wide spatial and temporal scales.
- Impact of *L. invasa* infestation: Effect of infestation on the qualities of host product, for example, growth rates and mechanical properties of poles and timber; economic analysis of the implications of the pest infestation.
- Integrated pest management strategies: Exploring the possibilities of using *L. invasa* resistant genes; identification, evaluation and introduction of natural enemies for classical biological control; evaluation of silvicultural practices such as weeding, site matching, pruning to control the pest, polyculture (growing *Eucalyptus* with other tree species or agricultural crops) versus monoculture; evaluation of *Eucalyptus* germplasms against *L. invasa* infestations in different agroecological zones.

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