SEED PRODUCTION AND VEGETATIVE GROWTH OF *Hedychium gardnerianum* KER-GAWLER (ZINGIBERACEAE) IN SÃO MIGUEL ISLAND (AZORES)

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Hedychium gardnerianum is an important plant invader in the Azores Archipelago. In this research we analysed fecundity, fertility, seed bank and vegetative growth of this herbaceous perennial at three sites at different altitudes in São Miguel Island. The mean number of spikes per hectare varied from 2.7 to 4.0×10^7. The mean numbers of fruits and seeds per hectare were 8.8×10^6 and 1.6×10^7, respectively. However, the number of seeds remaining in the soil was very low when compared to the same number at time of seed shed. Vegetative growth occurs by annual addition of one to four new corms to the rhizome. Each new corm usually originates new leaves, and eventually a spike. In general, older corms do not show leaves, working as storage organs. In *H. gardnerianum* a high seed production might be a key factor in dispersion, while vegetative growth allows a rapid establishment at new sites.

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INTRODUCTION

According to HEYWOOD (1989), in the modern floras, between 10 and 50% of the plant species are introduced. Likewise, non-indigenous plants are an important component of the Azorean vascular flora (SILVA et al. 2000; SILVA 2001). Among non-indigenous plants, some have become problematic, with a negative impact in agriculture, forestry or conservation (SILVA & SMITH 2004).

Hedychium gardnerianum Ker–Gawler (Zingiberaceae) was introduced as an ornamental in São Miguel Island in the 19th century, but later become a dominant plant with the ability to completely replace native vegetation (PALHINHA et al. 1942). Originarily of the Himalayas, it is naturalized in all the Azores islands, in Madeira Island, New Zealand, South Africa, Reunion Island and in the Hawaiian Archipelago. In New Zealand it was first planted in large scale as ornamental, but was later considered as a noxious weed (BYRNE 1992). Similarly, in Hawaii it was prised by plant nurseries, but become a serious problem, invading more than 500 hectares in Hawaii Volcanoes National Park, where it is a serious threat to humid forests (SANTOS et al. 1986; ANDERSON & GARDNER 1999). It is an herbaceous perennial, reaching 2 m height, with 30 cm long spikes and numerous aromatic red-orange flowers (PRESS & SHORT 1994). The perennial structure is formed by a variable number of corms (round and solid storage organs), arranged longitudinally, from which roots and leaves sprout. A spike develops after leaf growth in some of the corms. In the Azores, where it was probably introduced in the 19th century, it is one of the most frequent and abundant plant invaders (SILVA 2001). It is not only present along stream margins, but also in the native vegetation, from sea level up to 1000 m (SILVA 2001).

Fecundity (number of fruits per plant) and fertility (number of seeds per fruit) are often used when studying plant invaders (COUSENS & MORTIMER 1995). It is generally accepted that plant invaders have a high seed production, which is an advantage in the establishment at new sites (REICHARD 1994; REJMÁNEK 1995; CRONK & FULLER 1995). On the other hand, estimates of seed production are not commonly available for plant invaders in their new habitat. Further, the type of seed bank is an important factor for the success of plant invaders, and might be a key for their successful control (DRAKE 1998).

As previously stated, vegetative growth might be a considerable advantage for this invader, allowing it to rapidly colonize new sites, generating new individuals and promoting population growth (HOWE & WESTLEY 1997). However, estimates of vegetative growth for plant invaders in the Azores are scarce, and none refer to *H. gardnerianum* (SILVA 2001).

Considering the importance o *H. gardnerianum* as a plant invader in the Azores Archipelago, in this research we aim to: i) estimate fruit and seed production; ii) analyse the seed bank; and iii) estimate annual growth at the corm level.

MATERIALS AND METHODS

Study sites

Lombadas 1: This site is located in Ribeira Grande, at an altitude of 200 m, in a stream margin. Dominant plant species were *H. gardnerianum*, *Acacia melanoxylon*, *Rubus ulmifolius*, *Persea indica* and *Hydrangea macrophylla*.

Lombadas 2: This site is located in Ribeira Grande, at an altitude of 500 m, near a *Cryptomeria japonica* planted wood. Dominant plant species were *Acacia melanoxylon*, *Rubus ulmifolius*, *Persea indica* and *Hydrangea macrophylla*.

Carvão: This site is located in Ponta Delgada, in Carvão lake water basin, at an altitude of 710 m (in the cloud zone). Dominant plant species included *Calluna vulgaris* and other native or endemic species, including ferns and mosses.

Fecundity and fertility

At the three sites, 30 spikes of *H. gardnerianum* were collected. The following variables were analysed: spike length, number of bracts per spike, number of fruits per spike, number of fruits per bract, and number of seeds per fruit. To estimate the production of spikes per hectare, the number of spikes in 30 random samples of 4 m^2 was counted at each site. For each of the variables, we calculated the confidence interval at 95%. The number of fruits per hectare was then calculated as fruits/spike x spikes/ha, and the number of seeds per hectare as seeds/fruit x fruits/ha.

Seed bank

Ten samples of 0.25 m^2 from the upper 10 cm of soil were collected at each site, before seed shed (October of 1999) and after seed shed (January of 2000). Soil samples were divided in 30 sub-samples. Sub-samples were dry at 70ºC for 72 hours. Soil was then passed through an aluminium mesh, retaining larger particles and seeds. The mean number of seeds per square meter was calculated.

Vegetative growth

At each site, 30 groups of corms were marked and numbered. Each group consisted of a chain of connected corms. For each corm group the following variables were recorded: total length, number of corms and number of leaves. After one year, the same variables were re-measured, allowing the calculation of growth parameters.

RESULTS

Fecundity and fertility

The density of *H. gardnerianum* spikes ranged from 2.7-4.0x10^4/ha. It was higher at Lombadas 2 and lower at Carvão (Table 1). The length of the spikes and the mean number of bracts/spike were similar at the three sites (Figs. 1A and 1B). The number of fruits/bract varied from 1 to 3. The fraction of bracts with the maximum number of fruits was very small, with intermediate values for bracts with 1 or 2 fruits (Fig. 1C). A considerable percentage of the bracts had no fruits. The frequency distribution of the number of fruits/bract was similar at the three sites (Fig. 1C). However, the mean number of fruits/spike, varied between sites, with higher values at Carvão (Table 1). On the contrary, the mean number of seeds/fruit was higher at Lombadas 1 (Table 1).

Table 1
Fecundity and fertility of *Hedychium gardnerianum* at three sites in São Miguel Island. Estimate of fruit and seed production per hectare. Confidence interval of the mean at 95%: UL, upper limits; LL, lower limits.

Variable		Site		
		Lombadas1	Lombadas2	Carvão
Spikes/ha	UL	$3.7x10^4$	$4.1x10^4$	$2.9x10^4$
	Mean	$3.5x10^4$	$4.0x10^4$	$2.7x10^4$
	LL	$3.3x10^4$	$3.9x10^4$	$2.5x10^4$
Fruits/spike	UL	26.8	22.4	49.3
	Mean	22.3	17.4	43.3
	LL	17.7	12.5	37.3
Seeds/fruit	UL	15.9	12.8	13.8
	Mean	15.1	11.8	12.8
	LL	14.3	10.8	11.8
Fruits/ha	UL	$9.8x10^5$	$9.2x10^5$	$1.4x10^6$
	Mean	$7.8x10^5$	$7.0x10^5$	$1.2x10^6$
	LL	$5.9x10^5$	$4.8x10^5$	$9.4x10^5$
Seeds/ha	UL	$1.6x10^7$	$1.2x10^7$	$2.0x10^7$
	Mean	$1.2x10^7$	$8.2x10^6$	$1.5x10^7$
	LL	$8.4x10^6$	$5.2x10^6$	$1.1x10^7$

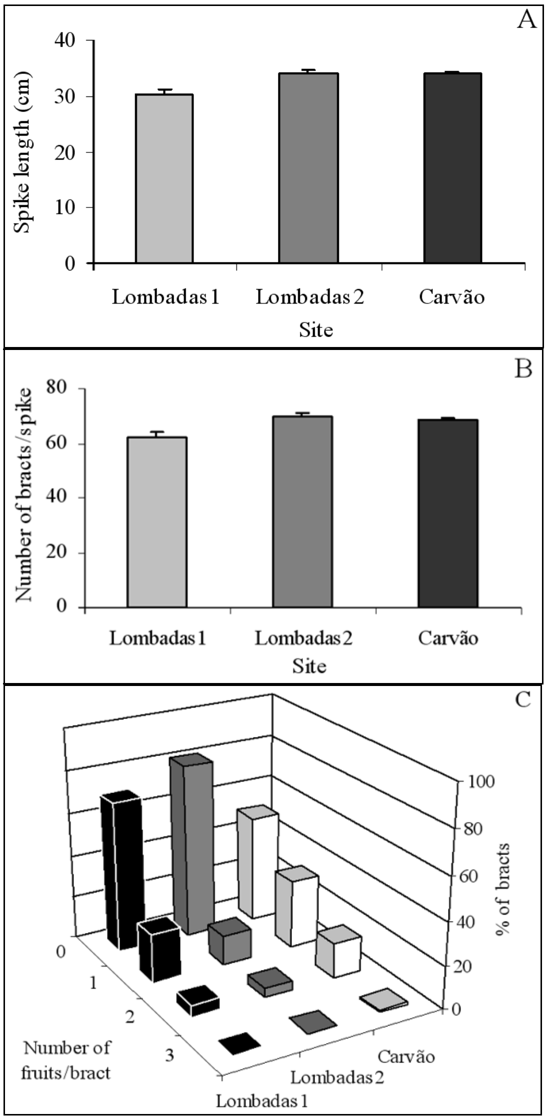

Fig. 1. Fertility of *Hedychium gardnerianum* at three sites in São Miguel Island. A) spike length (Mean + SE); B) number of bracts per spike (Mean +SE); C) frequency distribution of the number of fruits per bract.

Seed Bank

The number of seeds collected in the soil before seed shed (October 1999) was higher at Carvão, although close to Lombadas2 (Fig. 2). Regarding the second sampling season (January 2000), the number of seeds decreased considerably at the three sites, comparatively to the first sampling, with smaller values for Lombadas1.

Vegetative growth

The mean number of new corms per year ranged from 1.4 (SE = 0.10) at Lombadas 1 and Lombadas 2 to 2.2 (SE = 0.17) at Carvão (Fig. 3). In general, only one or two corms were produced per rhizome, except at Carvão, where up to three or four corms could be produced per rhizome/year. After one year, the increase in the number of corms was higher for Carvão and Lombadas 1. However, in general, growth was similar at the three sites (Fig. 3). Rhizome length increased from 2.9 cm (SE = 0.15) at Lombadas 1 up to 4.1 cm (SE = 0.18) at Lombadas 2 and 5.7 cm (SE = 0.23) per year at Carvão (Fig. 3).

The number of corms with leaves, per rhizome, ranged from 1 to 5, with an average of two (Lombadas 1, 2.4 ± 0.21; Lombadas 2, 2.1 ± 0.16; Carvão, 2.4 ± 0.21). Usually, only the corms found at rhizome ends showed leaves. Leaves fall after the growing season, thus, we didn't found an increase in the number of leaves per corm group.

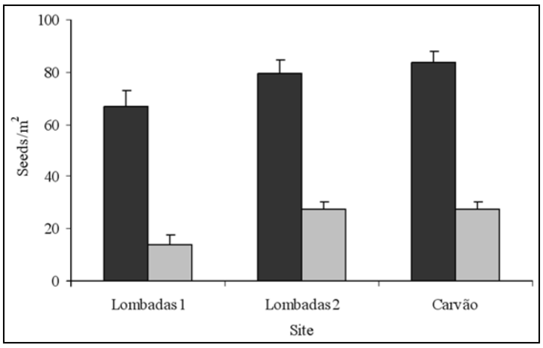

Fig. 2. Seed bank of *Hedychium gardnerianum* at three sites in São Miguel Island. Number of seeds in the upper 10 cm of soil. A first sample immediately after seed shed (October 1999, black) and three months latter (January 2000, grey). (Mean + SE).

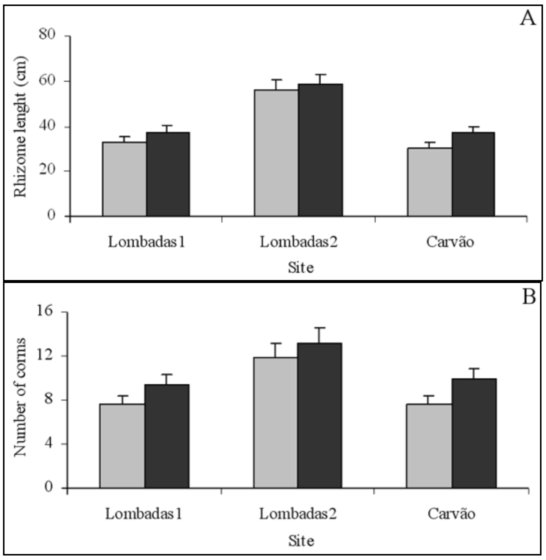

Fig. 3. Vegetative reproduction of *Hedychium gardnerianum* at three sites in São Miguel Island. A) total length of the rhizome and B) number of corms per group (Mean + SE). (First sampling 1999 – grey bars; second sampling 2000 – black bars).

DISCUSSION

According to many authors (COUSENS & MORTIMER 1995; LARCHER 1995; REES 1997), the number of seeds per fruit is the main trait to consider when analysing plant reproductive capacity. This represents plant investment in descent and is largely dependent on genetic factors and environmental conditions. In São Miguel Island the number of *H. gardnerianum* seeds per spike ranged from 300 to 500, in agreement to the estimates of BYRNE (1992), which ranged from 20 to 600, depending on the light conditions. Our estimates of *H. gardnerianum* fecundity and fertility support the idea that plant invaders establish successfully in news areas, in part, because of their high seed production (ROCHÉ et al. 1997). However, our observations in the field indicated a very low number of seedlings at the studied sites.

Seeds are a fundamental factor in dispersal, thus a high seed production might underlie an efficient dispersal strategy (COUSENS & MORTIMER 1995; REES 1997). In the case of *H. gardnerianum*, dispersal might occur by hydrochory (rain-water flushing of seeds and of detached corms) to short distances and by birds, namely the blackbird (*Tordus merula azorensis* Hart.), to longer distances. Digestion of the seeds by birds does not impair *H. gardnerianum* seed germination (BYRNE 1992; CORDEIRO 2001).

The dimensions of the spikes and the number of bracts/spike were relatively homogeneous, thus it is not advisable to infer about seed production based on these traits. Some variation between sites was found regarding fruit production, what suggests the intervention of environmental factors, namely photon flow, higher levels of which might implicate higher fruit production (ROCHÉ et al. 1997). Although the number of seeds per fruit varied between sites, seed production was relatively homogeneous, and was apparently compensated by an inverse relation with fruit production.

Seed bank has been considered as an important factor in the invasion process (COUSENS & MORTIMER 1997; REES 1997; DRAKE 1998; MAYOR & DESSAINT 1998). In the case of *H. gardnerianum*, seed shed leads to an accumulation of seeds near the mother-plant. A fraction of the seeds might be consumed by the blackbird and by rats, as seen in New Zealand (BYRNE 1992). *H. gardnerianum* seeds do not have dormancy (CORDEIRO 2001), remaining viable in the soil for a relatively short period only. The invader might thus have a transitory seed bank, in which most of the seeds germinate or die in the period of a year (HUTCHINGS 1997; ZHANG et al. 1998). This further stresses the importance of a high annual seed production as a mechanism to assure efficient dispersal.

Regarding vegetative growth, each new corm usually originates new leaves and, eventually, a spike. Many of the corms have no leaves, working as storage organs. In general, the pseudo-stem, the leaves and the spike, collapse during the winter, leaving a scar on top of the corm. Vegetative growth of *H. gardnerianum* is characterized by the development of news corms at the rhizome ends, originating a dense cover, with the soil completely crowded by corms (BYRNE 1992). This leads to a complete exclusion of native plants in areas heavily invaded by *H. gardnerianum*, and impairs regeneration of native plants in partially invaded natural areas.

It is important to stress that on all Azorean islands a cutting of native forests (for plantation of e.g. *Cryptomeria japonica* or for other purposes) is frequently followed by a potent invasion of *H. gardnerianum.* A delayed replantation of harvested Cryptomeria-plantations is also followed by a potent invasion (SJÖGREN 2001).

H. gardnerianum is ecologically versatile, with rapid vegetative growth, high seed production, and efficient dispersal by birds. Further, by vegetative growth it is capable of persisting in invaded places for long periods of time (BYRNE 1992). It becomes therefore evident that *H. gardnerianum* presents both vegetative and seed propagation capabilities that allow it to persist at invaded sites and to readily invade new areas. It is therefore urgent to develop a management strategy that will guide actions to control the dispersal of this invader and prevent the appearance of new propagation focus in the Azores Archipelago.

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