SEED GERMINATION AND REPRODUCTIVE STRATEGIES OF TITHONIA DIVERSIFOLIA (HEMSL.) GRAY AND TITHONIA ROTUNDIFOLIA (P.M) BLAKE

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Abstract. Seed germination and reproductive strategies of *Tithonia diversifolia* and *Tithonia rotundifolia*, two invasive species introduced into Africa from North and Central America, were studied. The aim was to determine the characteristics that make them invasive species in the continent. *Tithonia diversifolia* is a perennial and polycarpic plant reproducing both sexually and asexually while *Tithonia rotundifolia* is an annual monocarpic plant reproducing only sexually. The seeds of these species exhibit a period of dormancy before germinating. *Tithonia diversifolia* produces small sized light and numerous seeds while *Tithonia rotundifolia* produces larger sized, heavier and fewer seeds. *Tithornia rotundifolia* allocates a high proportion of of dry matter (41.6 %) and *Tithonia diversifolia* low proportion (10.5 %) to reproduction. It is concluded that small sized light and numerous seeds produced by *Tithonia diversifolia* accounts for its wide dispersal and rapid spread in colonized areas. Also its perennial habit and ability to reproduce sexually and vegetatively accounts for the species colonizing and stabilizing fast in new habitats. While the larger heavier seeds and high reproductive effort of *Tithonia rotundifolia* ensures its early vigorous start in seedling growth, quick establishment, survival for longer and to grow to more aggressive size in an environment that is starved of resources. Seed dormancy exhibited by the two species ensures they survive adverse conditions in their environment as seeds and germinate only when the environmental conditions favour the survival of their seedlings.
Keywords. *Tithonia species, reproductive strategies, seed dormancy.*

Introduction

Environmental weeds are those plants that invade natural vegetation, usually adversely affecting the survival of the native flora. These invasive plants are composed of herbs that may be annual, biennial or perennial as well as perennial vines, shrubs and trees. A large proportion of these invasive plants of terrestrial habitats are species of essentially open, sunny habitats, others are adapted to varying degrees of lower light levels as found under thickets or forest canopies. In general, invasive plants are characterized as being highly adaptable to a broad range of environmental parameters. The adaptability to varying types of substrate, levels of moisture, quality of light and temperature regimes allows them to invade a broad range of ecosystems and habitat types. They tend to be highly successful as judged, in part, by their ability to produce an abundance of seeds, that are in some cases may have a long life in the soil seed bank. Disturbance of natural ecosystems by a wide range of human actions are the primary cause for the successful spread and proliferation of these species. The ultimate result is that ecological conditions are created that promote the establishment and spread of these species that actively compete and replace native species. These invasive plants are introduced deliberately, although accidental introductions occur through arrival of livestock, as contaminants with grain and in ballast and soils. Movement within the country may involve natural dispersal (by wind or water), animal movements (native,

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domestic and feral animals disperse the seeds), vehicles, transport of soils and agricultural products and so on.

The process of individual development represents a strategic allocation of resources to conflicting ends. The concept of allocation depends absolutely on the idea that different structures or activities are alternatives, that a gain in one as a result of selection must be offset by a loss in another. Plants appear to possess only limited resources which are shared between the competing demands of maintenance, growth and reproduction. The fraction of its available resources that a plant devotes to reproduction may vary with environmental and genetic factors and is co-adapted part of the whole process that constitutes a life history [14]. Plant’s quantitative programme of resource allocation is an essential feature of its strategy. Life cycle strategy is the whole complex time and space of resource allocation by plants while reproductive strategy describes the resource allocation particularly associated with reproduction [6]. As the size of a seedling represents, both the product of the embryonic capital, the growth rate and the time elapsed since germination, both seed size and dormancy constitute important quantitative features of reproductive strategy [6].

The number of seeds produced by a plant, the number of seeds it fathers with the pollen it produces and the proportion of these offspring which survive to reproductive maturity are factors which determine how many descendants left by a genotype expressing a particular life history pattern [5]. The seed is a dormant or resting stage in the life of a plant and the stage of the life cycle at which dispersal and colonization of new areas occurs. Seeds survive adverse conditions better than growing plants and thus plants “ride out” difficult environmental circumstances in the seed state with low levels of metabolic activity and resume active growth when more favourable conditions return [8]. The survival value of these resting stages in the life cycles of plants has led to the evolution of different types of seed dormancy states, which can persist for a long time and difficult to break [3, 4, 13]. Harper [4] recognized three types of seed dormancy – innate, induced and enforced-which play slightly different roles in the regulation of germination. Innate dormancy is normally due to endogenous factors such as immaturity of embryo or the presence of inhibitors, it can be overcome with a period of after ripening or often by some seasonal stimulus, for example, photoperiod, thermoperiod. Induced dormancy develops in seeds when an adverse factor acts upon the seed and produces a suspended animation that continues after the causal factor has ceased to act. Enforced dormancy is imposed by an exogenous factor (e.g. carbon dioxide narcosis) and lasts only as long as the factor acts upon the seed.

Recently two species, *Tithonia diversifolia* and *Tithonia rotundifolia*, of the 11 species of the genus *Tithonia*, native to North and Central America have been introduced, are naturalized and have become invasive species in Africa. These two species have become naturalized in Southern Africa while *Tithonia diversifolia* has naturalized in West Africa. In these areas, the species have established themselves as serious weeds of arable crops, plantations, abandoned lawns and roadsides. They are aggressive colonizers of new sites, colonizing every available sunny space with high water table. They are alloptric, never found growing in mixed population. Opinions vary as regards their introduction and subsequent establishment. In West Africa, *Tithornia diversifolia* has been reported to be introduced as an ornamental plant [1] and with imported grains [11].

Because of the rate these species are spreading, colonizing every available open space especially along roadsides and displacing the native species in areas where they

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occur, this study was carried out to investigate the reproductive strategy and seed germination of these *Tithonia* species occurring in Africa with the aim of determining the characteristics responsible for their invasive habits.

Materials and methods

Natural populations of *Tithonia divesifolia* and *Tithonia rotundifolia* at peak growth growing in Lusaka, Zambia were used for this study. In each species population, the plants were tagged by numbering them. Four plants were randomly selected using the number tags. The plants were clipped to ground level. Each plant was separated into leaf, reproductive parts (flowers, fruits, seeds) and stem. These were oven dried at 80 ^{0}C to constant weight and weighed separately. The number of capitula (heads) per plant and seeds per head were counted. One hundred (100) seeds from each plant were oven dried at 80°C to constant weight and weighed. The number of branches per plant was counted for the four plants. The following data were recorded for each individual plant (i) dry weight of reproductive parts, (2) dry weight of leaves, (3) dry weight of stems, (4) number of heads, (5) total number of seeds, and (6) dry weight of 100 seeds. The ratio of dry weight of reproductive parts (heads, flowers, fruits, seeds) to the total dry weight of above ground tissue of all individuals of each species as the index of the fraction of total available resources allocated to reproduction was calculated. This ratio is here defined as 'reproductive effort'.

Mature seeds collected from these plant species on different dates, *Tithonia diversifolia* on 21 June 2004 and *Tithonia rotundifolia* on 30 April 2004 were subjected to germination experiments immediately. They were subjected to scarification with concentrated sulphuric acid in an attempt to break seed dormancy. Standard germination test was carried out by placing seeds taken from the flower heads on moist filter paper lined in 7-cm diameter petri-dish. Each trial had four replicates, each of twenty-five seeds. The test was carried out at ambient temperature for 30 days. Each petri-dish was placed on a bench near a window and watered regularly. Germination was recorded when the radicle emerged.

Scarification with concentrated sulphuric acid was carried out by immersing and shaking 100 seeds each in 100 ml of acid in 500 ml-conical flasks for 4, 6, 10, 15, 20, 25, 30 minutes. The seeds were rinsed thoroughly with distilled water and 25 seeds each placed in petri-dishes (4 replicates of every treatment) lined with filter papers. They were regularly watered with distilled water. Each petri-dish was placed on a bench near a window. Germination was recorded when the radicle emerged.

In all cases seeds were examined every day for 30 days and all germinated seeds were counted and removed from the dishes. Germination was expressed as percentage.

Results

Reproductive tissue production of Tithonia diversifolia and Tithonia rotundifolia.

Tithonia diversifolia is a perennial and polycarpic plant that flowers in late April/May while Tithonia rotundifolia is an annual monocarpic plant flowering in February and completes its life cycle –flowering, setting seeds and dying by the end of growing season in Zambia. It survives as seed. Tithonia rotundifolia reproduces from only seeds while Tithonia diversifolia reproduces from seeds and vegetative regrowth of basal stem when the plant is slashed. Tithonia diversifolia produces higher number of

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capitula and seeds per plant than *Tithonia rotundifolia* (Table 1). It also has higher number of number of seeds per capitulum than *Tithonia rotundifolia* (Table 1). The seeds of *Tithonia diversifolia* are smaller in size, lighter in weight and more numerous than those of *Tithonia rotundifolia* which are larger in size, heavier in weight and fewer in number (Table 1). Thus *Tithonia diversifolia* produces smaller sized lighter and more numerous seeds than *Tithornia rotundifolia*.

Table 1. *Summary of reproductive tissues production at peak growth of Tithonia diversifolia and Tithonia rotundifolia. Values are means and ±95 % confidence interval.*

Reproductive structure	Species	
	Tithonia diversifolia	**Tithonia rotundifolia**
Number of capitula per plant	755.25±286.24	128.00±12.72
Number of seeds per capitulum	179.75±2.32	133.33±5.72
Number of seeds per plant	134,451.75±49,792.14	17629.33±3843.23
Dry weight of hundred seeds (g)	0.53	1.24

Allocation of dry matter to different structures and reproductive effort of the species.

Tithonia diversifolia is shrubby branching profusely from the base without any distinguishable main stem. The mean number of branches per plant is 29±6 branches. *Tithonia rotundifolia* has a distinguishable main stem which branches a little above the ground. The mean number of branches per plant is 21.5±1.4 branches.

Tithonia diversifolia allocated highest amount of dry matter to stem production and lowest amount to leaf production while *Tithonia rotundifolia* allocated highest amount of dry matter to reproductive tissues (heads, fruits, seeds, flowers) production and the lowest amount to leaf production (Table 2).

Table 2. *Summary of allocation of dry weight (g per plant) to different structures and reproductive effort at peak growth of Tithonia diversifolia and Tithonia rotundifolia. Values are means ±95 % confidence interval.*

Structure	Species	
	Tithonia diversifolia	**Tithonia rotundifolia**
Leaf	553.84±215.86	46.89±7.74
Reproductive tissue	671.35±223.86	106.46±36.37
Stem	5146.86±1393.99	102.56±25.25
Total above-ground tissue	6372.05±1752.93	255.91±52.47
Reproductive effort	0.105	0.416

Ratio of dry weight of reproductive tissue to total dry weight of above –ground tissue adapted as the index of the fraction of total available resources allocated to reproduction (reproductive effort) in this study is 0.105 for *T. diversifolia* and 0.416 for *T. rotundifolia* (Table 2). This implies that *T. diversifolia* allocated 10.5 % and *T. rotundifolia* 41.6 % of the available resources to reproduction.

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Seed germination and dormancy of these species.

Mature *Tithonia rotundifolia* seeds collected on 30 April 2004 and subjected to germination test in distilled water for four months (May-August) did not germinate (0 % germination). When treated with sulphuric acid for 4 and 6 minutes in July and August the seeds still did not germinate. On treatment with the same acid for 10 minutes in August 2004, 12 per cent germination was recorded. However, in September and October 2004, germination test in distilled water gave 30.7 to 45 per cent germination. Scarification in concentrated sulphuric acid for 15, 20, 25, and 30 minutes in September and October 2004 gave 16, 30, 41.3 and 40.2 per cent germination respectively.

Seeds of *Tithonia diversifolia* collected in June 2004 when they were matured and subjected to germination in distilled water in June 2004 gave 16.3 per cent germination. When subjected to sulphuric acid treatment for 4, 6, and 10 minutes in July and August 2004 gave 28, 40 and 62.7 per cent germination respectively. However, germination tests in distilled water in September 2004 gave 97.5 per cent and after acid treatment for 15 and 20 minutes gave 55 and 73.3 per cent germination respectively.

However, when these seeds were planted in the field in December 2004 during the rainy season, the percentage germination was over 75 per cent for each of the two species.

The above results indicate that the seeds of these two species experience a kind and period of dormancy before germination.

Discussion

Tithonia diversifolia and *Tithonia rotundifolia* whose reproductive strategies and seed germination were investigated in this study are invasive plants introduced to Africa by humans which have become established and spread into natural ecosystems. They have also become serious weeds of arable crops and plantations in Africa. *Tithonia diversifolia* is fast colonizing fallow lands especially abandoned lawns and roadsides in the forest regions of West Africa as *Chromolaena odorata*, another introduced species into the region had done. Similar fast spreading (invasive) habit of these two species in Zambia, a southern African country where this study was carried out has been observed. The lasting and pervasive threat to natural and agricultural ecosystems in Africa by biological invasion of these species is underestimated and ignored. Their introduction into the continent has probably stopped but the species have continued to spread, naturalize and stabilize in the continent and are probably adversely affecting the composition of both native flora and fauna and altering ecosystem processes of the region.

This study shows that *Tithonia diversifolia* produces smaller sized, light weight and larger number of seeds than *Tithonia rotundifolia*. This implies that *T. diversifolia* seeds are generally likely to be more widely dispersed and have a potential of rapid colonization of sites. So that in an environment that is open and colonizable, the seeds will be at an advantage. This probably accounts for the rapid spread of *T. diversifolia*. Also, *T. diversifolia* perennial habit and the ability to reproduce sexually and vegetatively may account for the species colonizing new habitats and stabilizing fast in colonized sites. The plant coppices profusely when the stem is cut. Vegetative reproduction allows it to occupy a temporary site quickly while light seeds produced by sexual reproduction allow distance dispersal to new sites. Reported allelopathic effects [2, 15], such as secretion of compounds from the roots or leaching from the leaves that inhibit the seeds of other plants from germinating in the immediate vicinity of the plant together with dense shading may be the reason why few if any plants grow under the canopy. This is probably why *T. diversifolia* stabilizes as single or near single species stands wherever it is found growing.

The large heavier seeds of *T. rotundifolia* implies that its embryo is large and that it carries large food reserves. The large embryo and large food reserves of the seed make it possible for the seedlings to emerge as a more completely developed plantlet, survive for longer and grow to a more aggressive size in an environment that is starved of resources. Johnson and Cook [9] have reported that since major portion of the weight of a seed is food storage tissue, one may conclude that there is some optimum amount of food reserve which will normally insure the necessary seedling vigor. This probably accounts for the early vigorous start in seedling growth and the species quick establishment in an environment. The larger heavier seeds may restrict its dispersal and probably accounts for the species not being as widely spread as *T. diversifolia* though the seed dispersal of these species was not investigated in this study.

The difference in seed size and number observed in these species with *T. diversifolia* producing more seeds per plant which are smaller in size than those of *T. rotundifolia* agrees with the assertion that size (or more strictly the weight) of each propagule and the number of propagules produced per plant are normally somewhat complementary since the total amount of photosynthates available for the production of propagules is limited in each species [7, 10]. Thus, if the number of propagules produced per plant increases, the size of each propagule inevitably decreases or vice versa [16, 17].

Tithonia rotundifolia at peak growth was found to allocate more dry matter to total reproductive structures than *T. diversifolia* in this study. Hickman [7] has reported that the proportion of dry matter allocated to reproductive organs was increasingly great in successively harsher and more open habitats. Also, MacArthur and Wilson [12] reported that reproductive allocation should be highest in areas where available resources are least fully utilized and cite fugitive species as examples. In such habitats they concluded there is an evolutionary premium on filling the available resource space with offspring as rapidly as possible. Such species must have high reproductive allocation both to utilize the available resources more rapidly than other fugitive species and also ensure that propagules find new temporary environments effectively. In this study *T. rotundifolia* was found to allocate as high as 41.6 % dry matter to reproductive structures. This high reproductive allocation and fast growth ensures that *T. rotundifolia* invades new sites and utilizes available resources in such habitats. In an on going experiment, *T. rotundifolia* seeds planted on 10 December 2004 flowered on 14 February 2005; two months and one week after planting while *T. diversifolia* planted at the same time are still young plants.

Seeds of these species displayed a kind of dormancy. *Tithonia diversifolia* showed low germination (16.3 %) immediately after seed was harvested from the field but steadily increased until 4 months after harvest when 97.5 per cent germination was obtained. But the seeds of *T. rotundifolia* did not germinate immediately until 4 months (30 per cent germination) after harvest from the field. The highest germination percentage was 45 per cent after 5 months. This period of initial dormancy was completed when the seeds were stored dry at room temperature. Scarification of these seeds with concentrated sulphuric acid for varying periods did not improve the germination of these seeds especially those of *T. rotundifolia*. Thus, it is concluded that that the seeds of these species exhibit either innate dormancy due to immaturity of the

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embryos which required some period of after ripening to reach maturity or enforced dormancy due to low temperatures prevalent in Zambia between April and August. This dormancy was broken probably by seasonal stimulus specifically thermoperiod because of higher temperatures in Zambia between September and November. Seed dormancy enables plants survive adverse environmental conditions with low levels of metabolic activity and to resume active growth when more favourable conditions return. It also allows a timing of germination in a periodically fluctuating environment. Seed dormancy observed in these species ensures that they survive adverse conditions in their environment as dormant seeds only to germinate when the environmental conditions favour the survival of their seedlings.

It is concluded from this study that some of the characteristics contributing to invasive habits of *Tithonia diversifolia* and *Tithonia rotundifolia* are seed dormancy in both species, small sized light and numerous seeds production and sexual and vegetative reproduction of *T. diversifolia* and large sized seeds and high reproductive allocation of *T. rotundifolia*. Reproductive allocation was determined here using single harvest at peak growth (maturity) which Hickman [7] reported is more satisfactory than multiple harvests (at different points in the growth cycle of plants) which are difficult to integrate. The only limitation of this method was that shed plant parts during the growth cycle of these species were not determined and used in the calculation of reproductive allocation in this study.

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