Review

The biology of Australian weeds 47. *Jatropha gossypiifolia* L.

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Name

Botanical name

The genus name *Jatropha* combines the Greek *iatros*, meaning physician, with *tropheia*, mother's milk, hinting at the medicinal properties of the plant (Parsons and Cuthbertson 2001). The species name '*gossypiifolia*' is a combination of the Latin *gossypium*, meaning cotton, and *folium*, suggesting that the leaves appear similar to those of the cotton plant (Parsons and Cuthbertson 2001). Synonyms of *Jatropha gossypiifolia* are: *Adenoropium gossypiifolium* (L.) (Pohl 1827), *A. elegans* (Pohl 1827), *J. elegans* (Klotzsch 1853), and *J. staphysagrifolia* (Miller 1754).

Common names

In Australia and America, *Jatropha gossypiifolia* L. is most commonly known as bellyache bush (Everist 1974, Dehgan 1982, Parsons and Cuthbertson 2001). Other names used in countries where it is found include: cotton-leaf physic nut, castor bean (Queensland) (Kleinschmidt and Johnson 1987), red physic nut (Burkill 1994), cotton-leaf jatropha, purging nut, Spanish physic-nut tree, wild physic nut, American purging nut, wild cassava (BoDD 2004), damar merah; jarak kosta merah, red physic nut, jarak kling, jarak ulung, kaleke bacu (Indonesia) (BoDD 2004), jarak beremah, jarak hitam, jarak merah (Malaysia) (de Padua *et al*. 1999), lansi-lansinaan, tagumbau-a-nalabaga, tuba-tuba (Philippines) (de Padua *et al*. 1999), nhao luat (Laos) (Padua *et al*. 1999), sabuu daeng, sabu lueat, salot daeng (Thailand) (de Padua *et al*. 1999), d[aaf]u kai ti[as] (Vietnam) (de Padua *et al*. 1999), red fig-nut flower, sibidigua, Tua-Tua, Badigaba, Baigaba, Benderi, Lankajada, red varendra, (India) (Parrotta 2001), purga del fraile, medicinier noir, medicinier rouge (Caribbean, Puerto Rico) (Liogier 1990), lapalapa pupa, Accra fence tree (Africa) (Irvine 1961), Pinon Negro (Peru) (Pinedo *et al*. 1997), Purgue de fraile, tua tua, piñon colarado, pinon Negro, piñon rojo, quelite del fraile, frailecillo (Latin America), and pinhão roxo (Brazil).

Taxonomy and related species in Australia

The genus *Jatropha* belongs to the tribe Jatrophieae of Crotonoideae in the family Euphorbiaceae and the genus contains approximately 186 species (Govaerts *et al*. 2000). Dehgan and Webster (1979) divided the genus into two subgenera (*Curcas* and *Jatropha*) with 10 sections and 10 subsections. They postulated that physic nut (*J. curcas* L.) is the most primitive form of the genus and that *J. gossypiifolia* evolved from the physic nut. The facultative annual growth habit (apical dominance absent) of bellyache bush is considered a more phylogenetically advanced growth habit than the arborescent growth habit (apical dominance present) of physic nut (Dehgan and Webster 1979). A taxonomic characteristic of the genus *Jatropha* is the occurrence of either latex-cells or latex vessels (Rao and Malaviya 1964).

Although most *Jatropha* species are native to the New World (the Americas), no complete revision of the Old World (Europe, Asia, and Africa) *Jatropha* exists (Heller 1996). Hemming and Radcliffe-Smith (1987) revised 25 Somalian species, all of the subgenus *Jatropha*, and placed them in six sections and five subsections. The base colour of the petals of Australian biotypes is predominantly red, which is indicative of their American origin as opposed to green to yellow, which is indicative of the Old World Taxa (Dehgan and Webster 1979).

Species of *Jatropha* that have naturalized in Australia include physic nut (*J. curcas* L.), peregrina (*J. integerrima* Jacq.), coral plant (*J. multifida* L.), Buddha belly (*J. podagrica* Hook.), and leatherstem (*J. dioica* Sesse.) (HERBRECS 1998).

In Australia, there appears to be several biotypes with morphological, phenological, and physiological differences (Pitt and Miller 1991, Bebawi and Campbell 2004). Currently three biotypes are recognized in Queensland (Bebawi and Campbell 2004). These include Queensland bronze leaf and Queensland green leaf, which occur from Rockhampton north to Cairns and Queensland purple leaf, which occurs from Cairns north to Cape York. Two distinct biotypes (Katherine green and Darwin purple) are also reported in the Northern Territory (Pitt and Miller 1991, Bebawi and Campbell 2004). Biotypes existing in Western Australia have not yet been investigated.

Detailed taxonomic, genetic and ecological studies are required to verify and establish differences among the Australian biotypes. Such studies would also help determine whether there is only one variety present or if some of the noted biotypes could in fact be different varieties. Any differences found may be important to weed control, particularly with regard to the selection of biological control agents.

Different varieties of bellyache bush exist outside of Australia (Backer and Bakhuizen van der Brink 1963, Dehgan 1982, Sreenivasa Rao and Raju 1994). For example, *J. gossypiifolia* L. var. *elegans* was listed in the flora of Java (Backer and Bakhuizen van der Brink (1963) and three varieties, *J. gossypiifolia* var. *elegans*, *J. gossypiifolia* var. *gossypiifolia* and *J. gossypiifolia* var. *staphysagrifolia* (Mill.) Müll. were identified in the United States (Dehgan 1982). Sreenivasa Rao and Raju (1994) reported *J. gossypiifolia* L. (var. *gossypiifolia* and *var. elegans* (Pohl) Müll.Arg.) from India.

Description

Bellyache bush is an erect, woody, deciduous, tropical or sub-tropical perennial shrub (Figure 1). It is diploid and the basic chromosome number is 11 ($2n = 22$) (Nanda 1962, Datta 1967, de Padua *et al*. 1999). Plants commonly grow between 2 to 3 m high (Parsons and Cuthbertson 2001), but can reach up to 4 m in height under favourable conditions (Bebawi and Campbell 2002b, Vitelli and Madigan 2004).

Bellyache bush exhibits impressive foliar, floral and stem diversity. The stems are thick, rather soft, coarsely hairy, 1–2 m long and exude a watery sap when damaged (Parsons and Cuthbertson 2001). The number of stems per plant can range from one to two or more (Csurhes 1999, Parsons and Cuthbertson 2001). Stems are green when young, turning bright crimson red at flowering in some biotypes but invariably turn 'grey' with age across all biotypes.

Leaves of bellyache bush are arranged alternately along the stem (Parsons and Cuthbertson 2001). Leaves may be bright green, dark green, bright or dark bronze, bright red or bright purplish-red depending on biotype and leaf maturity (Pitt and Miller 1991, Burkill 1994, Parsons and Cuthbertson 2001, Bebawi *et al*. 2005b). Leaf petioles are 2–7 cm long and the leaf blades are palmately 3–5 lobed, generally 45–90 × 50–130 mm in size, and more or less elliptic (Figure 2) (Wheeler 1992). The lamina is glabrous and the leaf margin is denticulate with venations ending in stipitate glandular hairs. Leaf venation is white in the green biotypes and shades of red in the other biotypes (F.F. Bebawi unpublished observations).

Inflorescences are glandular and hairy (de Padua *et al.* 1999). Flowers are pedicellate, terminal and occur in corymbose cymes. Flower bracts are linear-lanceolate with glandular margins (Dehgan and Webster 1979). Flowers are radially symmetrical and loaded with nectaries. Flowers of the Queensland biotypes are small, generally dark red or maroon with bright yellow centres. Those of the Northern Territory are dark purple with dull yellow centres in the Katherine biotype or light red with bright yellow centres in the Darwin biotype (F.F. Bebawi unpublished observations).

Male flowers are cup-shaped with a diameter of 6–9 mm. There are eight stamens all fused into a tubelike structure, connate at the base, the upper portion free with two tiers of anthers of unequal length (Reddi and Reddi 1983). There are three relatively large anthers in the upper tier and five relatively small in the lower. The anthers are dorsifixed. Pollen grains are spherical, bright yellow with a sticky, oily coating (Reddi and Reddi 1983).

Female flowers are quite similar in shape to male flowers but they are larger, with a diameter of up to 9 mm. Sepals as well as petals are larger than those on the male. Styles are 3–4, slender dilated into a capitate, bifid stigma. The stigmas are pale green and very sticky (Reddi and Reddi 1983).

There are five united sepals, which are ovate to lanceolate, acuminate with stalked capitate glands on the margins, distinctly imbricate and 4 mm long. They are green in the green biotype or with margins tinged with bronze in the bronze biotype and with purple in the purple biotype. The five petals are reddish in Queensland biotypes and Darwin biotype but dark purple in Katherine biotype, obovate and 3–5 mm long. Sepals touch at the base to form a short green tube and have stipitate marginal glands (F.F. Bebawi unpublished 2006).

The fruit of bellyache bush has three lobes (locules) (Figure 3). It is an explosively dehiscent capsule with a single seed per locule and axile placentation. It is globose, pedicellate, generally bright green and woody at maturity, turning pale green or tan when ripe (Berg 1975, Dehgan and Webster 1979, Burkill 1994, Parrotta 2001). Most fruits bear three seeds.

Bellyache bush seeds possess ant-attractant substances, are carunculate, soft, slippery and glossy (Bebawi and Campbell 2002a). The caruncle is a pale, spongy outgrowth rich in lipids, proteins, and carbohydrates (Bebawi and Campbell 2004). While seeds have a dry testa and are endospermic, contain oil, and ovoid in shape (Figure 4) (Singh 1970, de Padua *et al*. 1999), they exhibit considerable variation (Liogier 1990, Howard 1989, Burkill 1994, Parrotta 2001, Bebawi and Campbell 2002a).

When dissected, seeds have a thin, outer whitish-fleshy envelope (exotegmen) that surrounds a thin and shell-like testa (Figure 5). A longitudinal section of mature seeds show an exotegmen connected to the caruncle at the micropylar region (proximal end) of the seed by dense

Figure 2. Digitately lobed leaves of bellyache bush.

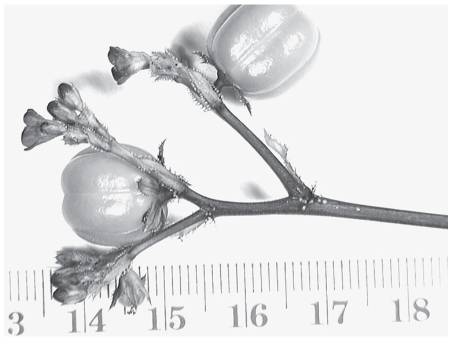

Figure 3. Infructescence of bellyache bush showing trilocular capsules. Graduated scale is in millimetres.

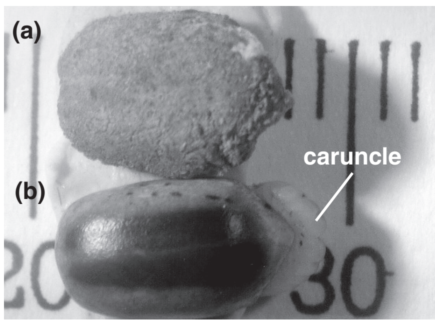

Figure 4. Bellyache bush seeds: (a) ant-discarded without caruncle and (b) intact with caruncle. Graduated scale is in millimetres.

Figure 1. Adult bellyache bush shrub (Queensland bronze leaf biotype) showing sympodial growth habit.

parenchymatous tissue (Figure 6). When the seed ripens the surrounding exotegmen fuses to the seed tegmen. The 'exotegmen' is fully transparent, shiny, and slippery when mature, and securely fused to the testa (Figure 6). The testa tegmen is below the 'exotegmen'. When the testa is removed, a white mass called the kernel is left. The kernel is enclosed in a very thin membrane (endotegmen). The kernel consists predominantly of a thick, soft, and oily endosperm (Singh 1970, Bebawi and Campbell 2004) that surrounds an embryo with two papery cotyledons in the centre (Figure 6). Seed germination is epigeal, i.e. the cotyledons appear above the ground surface.

Latex cells occur in the stem, leaf, petiole, flower parts, fruit, and in the seed coat (Rao and Malaviya 1964). Latex from the shoot apex is nearly white. Dehgan and Webster (1979) also recognized four extra-floral gland systems in the lamina, petiole, stipules and bracts in the genus *Jatropha*.

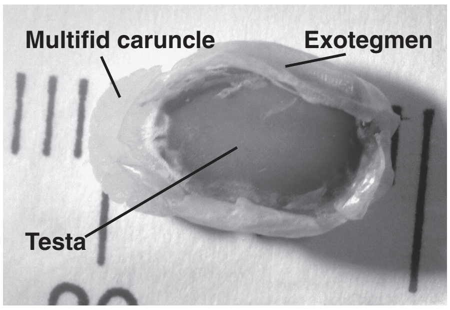

Figure 5. Immature bellyache bush seed showing crustaceous seed testa overlaid with a hard gelatinous tissue of exotegmen joined to a multifid caruncle at the proximal end of the seed. Graduated scale is in millimetres.

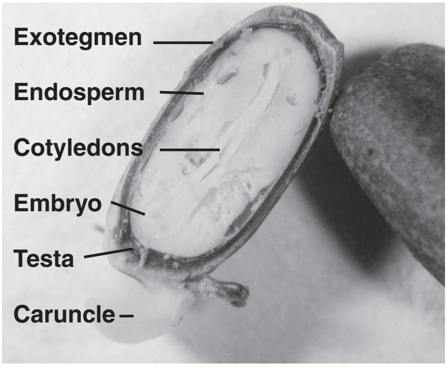

Figure 6. Median-longitudinal section of a mature bellyache bush seed showing regional distribution of internal and external seed structural components.

History

Though native to the drier islands of the Caribbean and the Venezuelan coastline (Hickman 1974, Heard *et al*. 2002), the current geographic range of bellyache bush (Figure 7) is large because of dispersal by humans for medicinal and ornamental purposes (Perry 1980, Dehgan 1982, Burkill 1994).

Bellyache bush was introduced to northern Australia in the latter part of the 1800s (Everist 1974, Pitt and Miller 1991, Parsons and Cuthbertson 2001). It was introduced to the Northern Territory in 1888 with other *Jatropha* species, probably for medicinal and ornamental purposes (Anon. 1888, Pitt and Miller 1991, Pitt 1997) and was listed as a naturalized component of Queensland's flora in 1912 (Bailey 1912). The first recorded specimen from Queensland was collected from Townsville in 1913 (HERBRECS 2004).

It has been suggested that bellyache bush infestations in Queensland originated from the Charters Towers area, probably from garden specimens planted prior to 1900 (P. Jeffrey personal communication 1998, cited in Csurhes 1999). At that time, reticulated water was unavailable in the town and local residents tended to plant very hardy plants such as bellyache bush. By the early 1920s bellyache bush was grown extensively in Queensland as an ornamental shrub.

Figure 7. World distribution map of bellyache bush indicated by (△) across all continents.

Distribution

Australia

The current distribution of bellyache bush in Australia is limited to the northern half of the continent (Figure 8) (Ashley 1995). In Northern Queensland, it is present in riparian and sub-riparian habitats of the Burdekin, Walsh, Palmer, Flinders, and Gregory Rivers and the headwaters of Lake Eyre Basin. Small scattered infestations occur in central Queensland, particularly in the Fitzroy catchment (Csurhes 1999, Barron 2004).

In the Northern Territory, bellyache bush persists in several coastal areas, but is most prevalent further inland (Csurhes 1999). Among the worst infestations in the Northern Territory are those on the Daly River catchment at Willeroo Station and Scotts Creek Station, the Gulf of Carpentaria region and the Barkly Tablelands. Other infestations occur in the McArthur River, Roper River, and Victoria River catchments (Miller and Pitt 1990).

In Western Australia, widespread, uncontrolled populations occur in the east Kimberley, with larger infestations in the Lake Argyle catchment and near Halls Creek (Parsons and Cuthbertson 2001, Anon 2005). Small controlled infestations occur in the west Kimberly region at the De Grey River, Broome, and Fitzroy River and on the Drysdale River in the north Kimberly (King and Wirf 2005).

The potential range of bellyache bush includes the entire tropical savannas (Thorp and Lynch 2000).

Outside Australia

Bellyache bush is cultivated widely in tropical countries throughout the world (Figure 7) (Burkill 1994, de Padua *et al*. 1999). In North America it is found mainly in Florida and in Mexico (Francis 2005). In South America it occurs predominantly in Bolivia, Venezuela, Ecuador, Peru, and Brazil (de Padua *et al*. 1999). It is also a common plant in the Caribbean, mainly in the Dominican Republic, Puerto Rico and Leeward Islands, as well as in the Hawaiian Islands (Csurhes 1999, de Padua *et al*. 1999).

Introduced to southern Africa, the plant has spread from Mozambique through Zambia to the Transvaal and Natal. In West Africa, it is listed in the exotic flora of Chad (Brundu and Camarda 2004), Cameroon and Ghana (Csurhes 1999).

Bellyache bush is also found throughout the warmer parts of Asia and the Pacific, particularly in Indonesia, Singapore, New Guinea and New Caledonia (Holm *et al*. 1979, Wilson 1997, de Padua *et al*. 1999, IPCS INCHEM 2004). It occurs frequently on plains but rarely in uplands and hilly areas in India and New Caledonia.

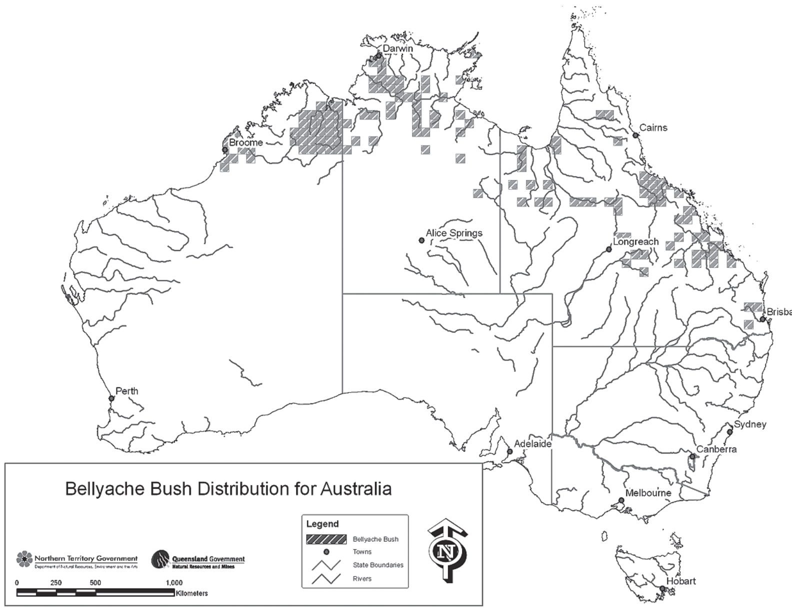

Figure 8. Current distribution of bellyache bush in Australia.

Habitat

Bellyache bush is an opportunistic colonizer of disturbed habitats and is frequently found in areas where the natural vegetation has been over-grazed or removed by human activity or floodwaters (Csurhes 1999). In Java (Backer and Bakhuizen van den Brink 1963) and Andhra Pradesh in India (Rao and Raju 1994), it has become very common along roadsides, railway tracks and eroded places. Similarly, Csurhes (1999) remarked that bellyache bush has become abundant in northern Australia along roadsides, around abandoned homesteads and near old mine sites, suggesting that colonization in such areas is probably an indicator of disturbance.

Bellyache bush is particularly well adapted to the seasonally wet/dry climate of northern Australia (Csurhes 1999). In Queensland, bellyache bush invades lowland habitats such as riparian zones, ephemeral watercourses and pastures and is also a serious invader of disturbed uplands around Townsville, North Queensland. Riparian zones are most vulnerable to bellyache bush invasion, possibly because fire often fails to penetrate riparian vegetation (Csurhes 1999).

Most naturalized populations of bellyache bush in Australia grow in areas receiving 400–1200 mm average annual rainfall, with some of the heaviest infestations found where average annual rainfall is 600–1000 mm (Csurhes 1999). Overseas in Puerto Rico, it may be found in areas receiving from 750 to about 2000 mm of annual precipitation (Liogier 1990). In wetter areas such as parts of the Northern Territory, bellyache bush has shown a 146% expansion of its area per year (Pitt and Miller 1991). However, even under dry conditions, bellyache bush is capable of spreading. For example, on a property located in the Ravenswood area of northern Queensland, a bellyache bush infestation increased in size by 76% over three years, despite the area receiving only half its average annual rainfall (Vogler and Keir 2005).

In Australia, bellyache bush grows equally well in saline and non-saline soils but seems to prefer sandy loams (Csurhes 1999). It has been found growing down to the high tide mark near Darwin. In Puerto Rico, it is more common in soils with high base saturation, such as dry areas, sites near the ocean, and soils derived from limestone (Liogier 1990).

Bellyache bush is very sensitive to frost, which damages the apices of stems (F.F. Bebawi personal observations). It may also suffer from waterlogging in poorly drained soils (Dehgan 1982) or as a result of flooding. In North Queensland, flooding of the Palmer River in March and April 2006 killed all plants that were growing in the riverbed (F.F. Bebawi personal observations).

Growth and development

Morphology

Bellyache bush stem growth habit is sympodial (Figure 1) and apical dominance is absent because branching occurs at reproductive maturity and thereafter at subsequent flowering episodes. Following germination, the primary stem (main axis) grows until flowering is initiated (F.F. Bebawi personal observations).

In its native environment, bellyache bush seldom reaches a height of more than 20–30 cm (Hickman 1974). In Queensland, plants are capable of growing to 4 m with a canopy diameter of 2 m and a basal stem diameter up to 15 cm (Bebawi and Campbell 2002b, Vitelli and Madigan 2004). Heights over 3 m have also been reported in shaded areas in the Northern Territory (Pitt and Miller 1991). The stunted form of the plant in the native range has been attributed to herbivory (Heard *et al*. 2002).

In Australia, bellyache bush is capable of attaining a height of up to 2 m in a single growing season (Dehgan and Webster 1979), particularly in areas free from competition, such as riverbeds in Far North Queensland and in the Northern Territory. In a competition trial in the dry tropics of North Queensland, bellyache bush grown on pasture-cleared plots reached average heights of 64 cm and 113 cm after the first and second year of establishment respectively (F.F Bebawi unpublished results). Similarly, in Puerto Rico bellyache bush was found to grow up to 0.5 m per year (Liogier 1990).

Bellyache bush root systems are relatively small compared with their shoot systems (Pitt and Miller 1991), with stem to root ratios increasing with age. The stem to root dry weight biomass ratio of juvenile, mature, and adult bellyache bush plants in North Queensland averaged 5.6, 6.1 and 7.1 to 1, respectively (F.F. Bebawi unpublished results).

Bellyache bush has a fleshy shallow root system with four short robust lateral roots and many fine tertiary roots (Singh 1970, Liogier 1990, Howard 1989, Burkill 1994, Csurhes 1999, Parrotta 2001). Fresh root weight of a dense infestation (20 000 plants ha^{-1}) of juvenile (up to 20 cm height), mature (20–100 cm height) and adult (>100 cm height) bellyache bush plants in north Queensland averaged 0.5, 2.8 and 10.5 t ha^{-1} (25, 137, and 523 g $plant^{-1}$), respectively. Root moisture content of juvenile, mature, and adult bellyache bush plants is relatively similar, averaging 81%, 73%, and 71%, respectively (F.F. Bebawi unpublished results).

Perennation

Whilst bellyache bush is a perennial plant, there is a paucity of information on its longevity. Observations of tagged plants in field trials indicate that plants can live for longer than six years (F.F. Bebawi unpublished 2006), with anecdotal evidence suggesting greater than 20 years.

Physiology

Bellyache bush utilizes the C_3 photosynthetic pathway (Tezara *et al*. 1998, Fernandez *et al*. 1999, Bebawi and Campbell 2002b). C_3 plants are more efficient than C_4 and CAM (Crassulacean Acid Metabolism) plants under cool and moist conditions and under normal light because they require fewer enzymes and no specialized anatomical adaptations (Rengifo *et al*. 2002).

Elevated CO_2 had no significant effect on morning xylem water potential, leaf osmotic potential, or pressure potential of bellyache bush grown under simulated seasonal drought conditions (Rengifo *et al*. 2002). Apparently, bellyache bush has the capacity to respond to elevated CO_2 and simulated drought by significantly reducing the proportional thickness of its leaf photosynthetic tissue systems (Rengifo *et al*. 2002) as well as by closing stomata (Tezara *et al*. 1998). This enhances water use efficiency and increases the photosynthetic rate. Bellyache bush may therefore exhibit increased biomass and growth rates, leading to further expansion of its current distribution, if atmospheric CO_2 increases further.

Phenology

In Australia, bellyache bush loses most of its leaves during the dry season (Figure 9). Those that remain are generally quite small and concentrated at the apices of stems (Bebawi *et al*. 2005b). The transition between the two stages is fairly rapid—plants are either in full leaf or almost leafless (Bebawi *et al*. 2005b).

In North Queensland, an average of 17 and 20 leaves per stem have been recorded during the wet season (November–April) on plants growing within sub-riparian and riparian habitats, respectively (Bebawi *et al*. 2005b). On average there is one leaf per stem in the dry season (June–August). However, along watercourses and dam walls bellyache bush plants may retain most of their leaves all year (Liogier 1990, Howard 1989, Burkill 1994, Parrotta 2001).

Flowering generally occurs from June to April in riparian zones and from September to April in sub-riparian zones of North Queensland (Bebawi *et al*. 2005b). While moisture availability appears to be a key driver of flower production, temperature may influence timing and duration (Bebawi *et al*. 2005b). In the Kimberley region of Western Australia, bellyache bush generally flowers and fruits from February to May (Wheeler 1992). In North Queensland, fruit production commences around September/October within riparian and sub-riparian zones and may last up to 10 months (Bebawi *et al*. 2005b).

Reproduction

Floral biology

Bellyache bush is capable of reaching reproductive maturity very quickly under favourable moisture conditions. In pot trials, plants flowered 55 days after germination (Bebawi *et al*. 2005c). In the field in North Queensland, the time to first flowering averaged 74 days in cleared areas, 294 days in rocky sites, and 454 days in grazed pastures (Bebawi *et al*. 2005c). It was suggested that more plants flowered in cleared areas and reached reproductive maturity earlier because of the absence of interspecific competition (Bebawi *et al* 2005c). Increasing bellyache bush density also caused exponential increases in time to first flowering (Bebawi *et al*. 2005c). At

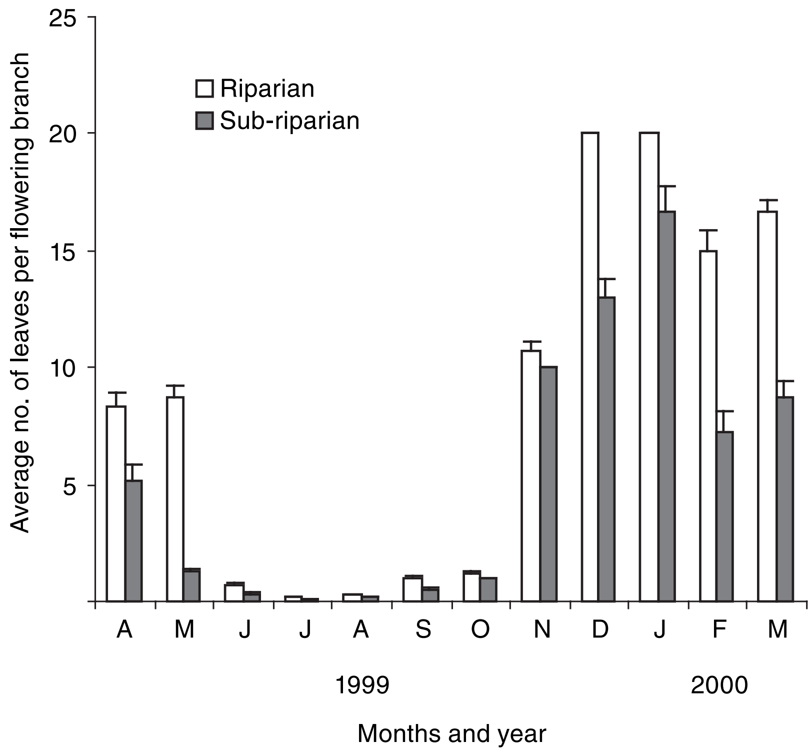

Figure 9. Monthly leaf density of bellyache bush (1999–2000) associated with light density beneath and above (control) the canopy of bellyache bush. Vertical bars indicate the s.e. of the mean. From Bebawi *et al*. (2005b).

the lowest density (20 plants m^{-2}) plants flowered 55 days after germination. In contrast, only 6.3% of plants within the highest density (320 plants m^{-2}) had flowered 42 months after germination (Bebawi *et al*. 2005c). In a pot trial, the percentage of bellyache bush plants that flowered decreased exponentially with increased density (Bebawi *et al*. 2005c).

Once bellyache bush plants reach reproductive maturity, they have a definite pattern of flowering within inflorescences. More female than male flowers mature on the first day, with female flowering showing a declining trend thereafter over a five day period (Reddi and Reddi 1983). In contrast, the number of male flowers gradually increases so that they dominate by the twelfth day, after which their frequency gradually declines. In effect, the inflorescence is protogynous (Reddi and Reddi 1983). Dehgan and Webster (1979) showed that there was a lag of 24–48 h in anthesis of male flowers after opening of female flowers.

The ratio of male to female flowers is on average 11:1 (Reddi and Reddi 1983, Wild 2003). Dehgan (1983) found that short days result in production of more male flowers, while long days caused either a drastic increase in or total change to female flowers. Consequently, the ratio of male to female flowers and therefore seed production may be influenced by latitude and season.

Female flowers produce nearly 1.6 times more nectar than male flowers (Reddi and Reddi 1983). A positive association has been detected between temperature and nectar concentration and an inverse one between relative humidity and nectar concentration (Reddi and Reddi 1983).

Bellyache bush nectar consists of glucose, sucrose and fructose, amino acids and proteins (Reddi and Reddi 1983). The nectar is attractive to insects, which are essential for normal seed set (Reddi and Reddi 1983, Wild 2003). Pollination may occur through selfing, because the flowers are self-compatible, or through outcrossing (Dehgan and Webster 1979). The former mechanism ensures perpetuation of the species and the latter maintains species heterozygosity (Dehgan and Webster 1979).

Many insect species have been observed foraging on nectar of bellyache bush in Queensland (Appendix 1). Most of the insects listed in Appendix 1 are beneficial to bellyache bush because they perform vital roles such as pollination, defence and dispersal. For example, meat ants (*Iridomyrmex spadius* Schattuck), honey bees (*Apis mellifera* Lepeltier) and oleander butterflies (*Euploa core-corinna* Craemer) visit flowers and perhaps pollinate bellyache bush. Hives of the stingless bee *Trigona carbonaria* Smith were successfully used to pollinate bellyache bush grown in glasshouses.

Seed production and dispersal

Seed production of bellyache bush is generally prolific, but many factors such as environmental conditions, plant biotype, plant density and location can influence the quantity of seeds produced.

Adult plants growing in Queensland have been found to produce between 2000 and 12 000 seeds $plant^{-1}y^{-1}$ (Bebawi and Campbell 2002a), which corresponds to around 170 kg ha^{-1}. In Western Australia bellyache bush is reported to produce between 1800 and 2400 seeds $plant^{-1}y^{-1}$ (APB Infonote 1994). Annual seed production of bellyache bush in the Indian sub-continent was estimated at 500 kg ha^{-1} (Raina and Gaikwad 1987).

Dense infestations of bellyache bush growing in a relatively dry location in North Queensland produced four seeds m^{-2} during the 2003–2004 wet season (288 mm rainfall), in comparison to 343 seeds m^{-2} for plants growing in a wetter location (506 mm rainfall) (Vogler and Keir 2005).

Plants produce fewer seeds at high density. Above 40 plants m^{-2}, seed production per plant began to decline. At very high densities (in excess of 300 plants m^{-2}), there was very little seed production (Bebawi *et al*. 2005c).

A preliminary pot trial showed that Queensland bronze biotype plants produced 102 seeds $plant^{-1}$ $month^{-1}$ compared with 62 seeds $plant^{-1}$ $month^{-1}$ for the Katherine green biotype (F.F Bebawi unpublished results).

Seed dispersal occurs initially via dehiscent capsules that are capable of catapulting seeds as far as 13 m (Bebawi and Campbell 2002a), although in dense infestations most seeds fall close to the parent plant.

Once on the ground, some ants (particularly native meat ants (*I. spadius*)) disperse bellyache bush seeds (Figure 10) (Bebawi and Campbell 2002a). In one study, an average of 12 330 seeds were retrieved from the middens (refuse piles) of individual meat ant nests over 12 months, with highest numbers recorded between February and June (Bebawi and Campbell 2004). Meat ants appear to feed on the caruncle and exotegmen of bellyache bush seeds and when finished discard the seed in their middens. The middens provide an improved environment (e.g. high nutrient status and absence of fire) for germination and survival of seedlings.

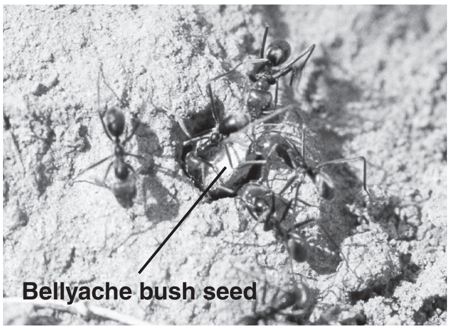

Figure 10. Meat ants (*Iridomyrmex spadius*) dispersing bellyache bush seed into nest entrance.

Water, humans and other animals, particularly the great bowerbird (*Chlamydera nuchalis* Jardine & Selby) are identified as potential long-distance dispersers of bellyache bush seeds (APB Infonote 1994, Ashley 1995, Smith 1995, F.F. Bebawi personal observations). Of these, floodwater is considered most important within catchments and humans are recognized as the main dispersers of bellyache bush at a national and global scale (Csurhes 1999).

Germination

Fresh bellyache bush seeds exhibit high viability, but low germinability (Bebawi and Campbell 2004). For example, fresh intact seed collected in North Queensland was 88% viable but only 10% of these were readily germinable (Bebawi and Campbell 2004). Similarly, germination of seeds from Puerto Rico averaged just 4% (Liogier 1990). Innate (primary) dormancy has been reported for other Euphorbiaceae (Ellis *et al*. 1985).

Seed type, seed weight, geographical location, temperature, control technique, and ants affect germination of bellyache bush seed (Liogier 1990, Bebawi and Campbell 2002a, 2002d, 2004). Seeds commence germination with the start of the wet season (Ashley 1995) but will germinate at other times of the year if environmental conditions are favourable. For example, in North Queensland germination will often occur throughout the year on rainfall events that exceed 25 mm (F.F Bebawi unpublished results).

Ants promote the germination of bellyache bush seeds (Bebawi and Campbell 2004). In a laboratory study 98% of ant-discarded seeds were viable and readily germinable (100%). Viability of intact seeds that had the caruncle manually removed was on average 10% lower than that of ant-discarded seeds, and only 8% of fresh viable intact seeds were germinable (Bebawi and Campbell 2004). Removal of caruncles imitates the effect of meat ants on germination but not to the same extent as in ant-discarded seeds (Bebawi and Campbell 2004). Additional scarification by ants on external seed structures may also promote germination.

Optimal germination temperatures for intact bellyache bush seeds occur between 24 and 31°C. Germination generally commences five days after the imposition of favourable environmental conditions and reaches a maximum between days 11 and 12 (F.F Bebawi unpublished results).

Burial depth and litter cover also affect germination and viability following fire (Bebawi and Campbell 2002d).

Germination and viability were negatively correlated with peak fire temperature, which was affected by litter cover. No viable seeds remained under litter cover, but >80% of seeds placed on bare ground or 2 cm below ground remained viable (Bebawi and Campbell 2002d). Fire reduced germination and viability of seeds within capsules by 31% and 35% respectively when compared with unburnt seeds (Bebawi and Campbell 2002d).

Seed longevity
In a seed burial trial comparing germination and viability of intact and ant dispersed seeds exposed to either nil (rainfall excluded) or natural rainfall, no intact seeds exhumed after four years remained viable under natural rainfall conditions, whereas some ant-discarded seeds were still viable (3%). However, both intact and ant-discarded seeds exhumed after four years were 20% viable when rain was excluded (F.F. Bebawi unpublished results).

In a seed bank depletion trial, seedling emergence was still occurring after 51 months at a rocky site away from a river, whereas emergence had finished earlier (37 months) at a heavy clay soil site within the same period (F.F. Bebawi unpublished results). Differences in seed bank depletion were attributed to differences in soil moisture conditions between the two sites.

Seedling establishment
Seedling densities can be very high under favourable environmental conditions. Averages of 247, 126, and 90 seedlings m^{-2} were measured within rocky, sub-riparian and riparian infestation of bellyache bush, respectively (F.F. Bebawi unpublished results). Higher seedling densities (300–400 seedlings m^{-2}) were recently recorded under dense canopies of bellyache bush (Vogler and Keir 2005).

Treatment of bellyache bush infestations can result in massive recruitment of seedlings (Bebawi and Campbell 2002c, Vitelli and Madigan 2002, Bebawi *et al*. 2004). For example, bellyache bush increased in density from five plants m^{-2} prior to aerial application of foliar herbicides to 400 plants m^{-2} post treatment (Vitelli and Madigan 2002). Similarly, for every plant killed by foliar spraying, slashing, stickraking and burning as part of an integrated research trial, 20, 97, 74 and 69 seedlings emerged respectively (Bebawi *et al*. 2004). Treatments that caused the greatest soil disturbance appeared most conducive for seedling recruitment.

High seedling mortality generally occurs, particularly if rainfall is limited and/or there is strong intra- or interspecific competition (Bebawi and Campbell 2002c, Vitelli and Madigan 2002). For example, seedling density in burnt plots reached a peak of 390 seedlings m^{-2} in December 1999 and crashed to 30 seedlings m^{-2} one year later. In unburnt plots, seedlings peaked at 200 m^{-2} before crashing to 5 m^{-2} during the same period (Bebawi and Campbell 2002c). A field trial that compared the impact of a range of four bellyache bush seedling densities on seedling survival showed that 12 months after seedling emergence, seedling density was reduced by 75, 89, 98 and 99% at 25, 125, 250 and 500 seedlings m^{-2} respectively (F.F. Bebawi unpublished results).

Even if high mortality of seedlings occurs under relatively dry conditions, sufficient recruitment for re-infestation of treated sites and expansion of infestations occurs in the absence of followup control activities. Observations by the authors suggest that once seedlings reach about 20 cm in size they are very hardy and will generally tolerate extreme environmental conditions.

Vegetative reproduction
Bellyache bush can readily regenerate from stem cuttings (e.g. dumped garden plant material) (Pitt and Miller 1991, Parsons and Cuthbertson 2001) and whole plants that may be removed during control activities or flood events. The shallow root system of bellyache bush allows seedlings and mature plants to be easily dislodged (Pitt and Miller 1991).

Several landholders have found bellyache bush plants reshooting several months after they were pulled and left lying on the ground. Similarly, during a simulated slashing trial most off-cuts of bellyache bush (particularly those cut during the dry season) flowered and produced capsules with viable seed up to 12 months after being cut (Bebawi and Campbell 2002b), although a few of these had grown some new roots which were connecting them to the ground.

Importance
Bellyache bush is considered to be one of the more poisonous and aggressive weeds growing in the dry tropics of northern Australia (Csurhes 1999, Parsons and Cuthbertson 2001). While it is in the relatively early stages of invasion, Lazarides and Hince (1993) indicated that bellyache bush has the potential to spread over 75% of the Australian continent (including the Northern Territory, Western Australia, and Queensland), where it would cause significant environmental, economic and social impacts. Bellyache bush was ranked number 21 of all widespread weeds in Australia (Thorp and Lynch 2000). It ranked number three for North Queensland (Bebawi *et al*. 2002), and four for South Queensland (Walton and Elliot 2003) in weed research priority exercises. It is also listed as a priority weed in Western Australia (Pitt *et al*. 1990, Pitt 1999) and in the Katherine and Darwin regions of the Northern Territory (draft regional plan www.katherineweeds.nt.gov.au).

Lantana (*Lantana camara* L.) was once the main shrub weed around Palu in Central Sulawesi, but it has now been replaced by Siam weed (*Chromolaena odorata* L.), which is currently being overtaken by bellyache bush (Partridge 2001).

Detrimental
Economic impact The economic impact of bellyache bush on the livestock industry has been reported in Australia (Tothill et al. 1982), particularly in North Queensland, where direct losses to the pastoral industry occurred during drought due to poisoning of cattle, horses and goats (Csurhes 1999). All cases of poisoning occurred in the dry season when pasture quality and quantity was at its lowest. Two landholders alone have spent approximately $56 240 on control of bellyache bush in the Burdekin Catchment, North Queensland (Csurhes 1999). A property owner within the Burdekin Catchment spent more than $50 000 over 10 years in an attempt to prevent bellyache bush spreading along 17 km of river frontage (Bowen Independent 1996).

In the Northern Territory, bellyache bush has spread into pastoral land, forming dense thickets with little or no grass underneath, and making land unsuitable for grazing (Miller 1982). In Papua New Guinea, sown pastures have become non-viable due to encroachment of several weeds including bellyache bush (Chandhokar 1978).

Environmental impact Bellyache bush invasion results in a loss of biodiversity, wildlife habitat, changed fire regimes, increased soil erosion and destabilization of creek and river banks. Monospecific stands of bellyache bush inhibit establishment of native plants (Csurhes 1999). For example, in North Queensland, there was no black speargrass (*Heteropogon contortus* L.) remaining under the canopy of bellyache bush after two years (F.F. Bebawi unpublished results).

An aqueous extract of bellyache bush latex is known to kill freshwater fish (Singh and Singh 2002). The methanol and n-butanol extracts of unripened seeds of bellyache bush have also killed two species of freshwater snails (*Lymnaea luteola* L. and *Indoplanorbis exustus* Deshayes) overseas (Amin *et al*. 1972, Adewunmi and Marquis 1980, Singh and Agarwal 1988, Sukumaran *et al*. 1995).

Social impacts Detrimental effects on human health include seed poisoning (Kingsbury 1964), dermatitis (Souder 1963) and sneezing (Irvine 1961). Although numerous cases of severe poisoning have been reported from the plant's native range, no human deaths were recorded (Begg and

Gaskin 1994). However, if bellyache bush infestations become more widespread in northern Australia, particularly around schools, parks and other public amenity areas, risks to human health may become more serious.

All parts of bellyache bush are considered toxic but the seeds are especially so (Gardner and Bennetts 1956, Oakes and Butcher 1962, Kingsbury 1964, Marcano-Fondeur 1992, Wheeler 1992, IPCS INCHEM 2004). Main toxins include purgative oil and curcin, which is found mainly in the seeds and also in the fruit and sap (Chopra and Badhwar 1940, Simonsen 1945, Gardner and Bennetts 1956, Morton 1981, Joubert et al. 1984, Marcano-Fondeur 1992, Burkill 1994, Parsons and Cuthbertson 2001, IPCS INCHEM 2004). Curcin is similar to ricin, the toxic protein of castor oil plant (*Ricinus communis* L.). Bellyache bush seeds have been used criminally in America (Irvine 1961).

Clinical symptoms of bellyache bush poisoning are largely associated with gastro-intestinal irritation (IPCS INCHEM 2004, Biehl and Hecker 1986, Adolf *et al*. 1984, Burkhill 1994, Parrota 2001). In humans there is acute abdominal pain and a burning sensation in the throat about half an hour after ingesting seeds, followed by nausea, vomiting, and diarrhoea (Kingsbury 1964, Watt and Breyer-Brandwijk 1962, Burkhill 1994, Parrota 2001). The vomitus and faeces may contain blood. In severe intoxications, dehydration and haemorrhagic gastroenteritis can occur, as well as central nervous system and cardiovascular depression and collapse. Children are more susceptible (IPCS INCHEM 2004, Kingsbury 1964, Watt and Breyer-Brandwijk 1962), particularly as the fruit and seeds of bellyache bush are attractive to children. Three seeds can kill a child (Gardner and Bennetts 1956, Oakes and Butcher 1962, Watt and Breyer-Brandwijk 1962, Kingsbury 1964, Begg and Gaskin 1994). Bellyache bush sap or latex can also cause acute dermatitis on contact (Souder 1963).

For Aboriginal people of Australia, bellyache bush can reduce the availability of 'bush tucker' and other resources by displacing native plants and animals (King and Wirf 2005). Bellyache bush can also disrupt spiritual and physical connections to the country, for example by restricting access to sacred sites (Gardner 2005, King and Wirf 2005). Impenetrable infestations of bellyache bush restrict hunting, camping and bushwalking activities and the general physical movement of people (Gardner 2005, King and Wirf 2005). Bellyache bush is unpleasant to touch because it is sticky and leaves permanent reddish-brown stains on garments.

Beneficial

Medicinal The major benefits of bellyache bush are associated with its medicinal attributes. Various parts have been studied as sources of novel pharmaceuticals, including potential anticancer drugs (Biehl and Hecker 1985, de Padua *et al*. 1999). Roots, stems, leaves, seeds, and fruits have been widely used in traditional folk medicine in many parts of western Africa (de Padua *et al*. 1999, IPCS INCHEM 2004). Extracts from the plant have been used to treat a number of human ailments, ranging from anaemia, vertigo, worms, leprosy, leukaemia, dysphonia, urinary complaints, ulcers, itches, conjunctivitis, dermatitis, gout, snakebite and venereal diseases (Irvine 1961, Kupchan *et al.* 1976, Morton 1981, Liogier 1990, Das and Das 1994, Horsten *et al.* 1996, de Padua *et al*. 1999).

In Peru the leaves and latex are used to treat abscesses, tonsillitis, asthma, diarrhoea, toothache, fever, gingivitis, fungal skin infections, inflammations, burns and cough (Pinedo *et al*. 1997).

In certain African countries, people are accustomed to chewing seeds of bellyache bush when in need of a laxative (IPCS INCHEM 2004). The seeds are oily, purgative and emetic (Irvine 1961). Tea made from bark is used in Nigeria to cure intestinal worms (Irvine 1961). The leaves are boiled up and used as a bath for fever and the leaves are used as a purgative in Jamaica (Irvine 1961, de Padua *et al*. 1999). Roots of bellyache bush have been used for treatment of leprosy (Das and Das 1994, Baxter 2000).

Plant parts used for healthcare in India include the young stem, root, bark and latex (Das and Das 1994). These parts are used either alone or with other components for the treatment of abdominal discomfort, bone fracture, toothache, conjunctivitis, open wounds, diarrhoea, dysentery, haemorrhoids, intra-uterine death, muscular pain, rheumatism, tongue sores and infections around fingernails and toenails (Banerji *et al*. 1993, de Padua *et al*. 1999). Crude hot water extract of bellyache bush exhibited antimalarial properties. It was capable of 100% inhibition of the malaria agent *Plasmodium falciparum* (Gbeassor *et al*. 1989).

Extracts of bellyache bush have a reputation as a cancer cure (Biswanth and Ratna 1995, Biswanth *et al*. 1996, Morton 1981, Morton 1982, Taylor *et al.* 1983). For example, on the island of Aruba, people believe that a decoction of the stems from bellyache bush cures throat cancer (Morton 1982). Derivatives of the diterpene jatrophone were also isolated from roots of bellyache bush and shown to have antitumour properties in vitro (Taylor *et al*. 1983).

Other benefits Other potential benefits of bellyache bush include its use as a source of oil for energy (Forni-Martins and Cruz 1985, Burkill 1994), a source of plant food for human and animal consumption, an additive for plastic formulations (Ogbobe and Akano 1993) and a source of insecticides (Prasad *et al*. 1993, Chatterjee *et al*. 1980). In Asia, bellyache bush is used for dye (Smith 1995) and for production of biogas when used as pressed mud cake (Abubacker *et al*. 1999). Oil extracted from bellyache bush seeds is also used as an illuminant in Africa (Burkill 1994). It is possibly still sold in some nurseries in Australia (Calvert 1999) and elsewhere as an ornamental due to its colourful bronze leaves (Howard 1989, Parsons and Cuthbertson 2001).

In drier regions of West Africa, bellyache bush is used as a hedge around villages to protect them against bush fires (Irvine1961, Ogbobe and Akano 1993). Some West Africans also believe that bellyache bush has magical powers that protect against snakes, lightning, and violence (Burkill 1994).

Legislation

Bellyache bush is a Class 2 pest plant targeted for control under the *Queensland Land Protection (Pest and Stock Route Management) Act 2002* (Queensland Government 2003). This imposes a legal responsibility for control on all landowners for land under their management and it is an offence to keep or sell bellyache bush without a permit. In the Northern Territory, bellyache bush is a declared weed under the *Weeds Management Act 2001* and is categorized as Class B (growth and spread to be controlled) and Class C (not to be introduced into the Northern Territory) (Parsons and Cuthbertson 2001). In Western Australia, bellyache bush is a declared plant under the *Agriculture and Related Resources Protection Act 1976* as a P1 (introduction into and movement within the area is prohibited) and P3 (the numbers or distribution or both should be reduced) for the municipal districts of Derby-West Kimberly and Broome (Parsons and Cuthbertson 2001).

Weed management

Individual bellyache bush plants are easy to kill with conventional control techniques such as herbicides, machinery and fire (Bebawi and Campbell 2002b,c,d, Bebawi *et al.* 2004). However, large-scale seedling recruitment generally occurs following the initiation of control activities. This highlights the need for a long term management strategy to treat seedlings that may emerge while ever a viable seed bank remains. A key priority should be the establishment of a healthy pasture that will compete with bellyache bush seedlings and reduce the opportunities for establishment (Ashley 1995, Csurhes 1999).

Herbicides

Herbicides can cause high mortality of bellyache bush when applied using hand-help equipment to treat scattered to medium infestations (Chadhokar 1978, Pitt and Miller 1991, Vitelli *et al.* 1988). Plants within dense bellyache bush infestations have also been successfully treated by aerial application of herbicides (Vitelli and Madigan 2002). However, irrespective of the application technique, considerable recruitment often occurs subsequently (Vitelli and Madigan 2002).

In Papua New Guinea, foliar application of 2,4-D or 2,4,5-T (5–10 g L^{-1}) in water was not effective against bellyache bush (Chadhokar 1978). Field studies undertaken in North Queensland showed that the addition of a 0.2% v/v wetting agent (poly dimethyl siloxane) increased the activity of 2,4-D acid (10 g L^{-1}), 2,4-D amine (5 g L^{-1}), and 2,4-D ethyl ester (5 g L^{-1}), resulting in mortality rates of 90, 100 and 90%, respectively (Vitelli *et al.* 1988). In the same trial, amitrole (4 g L^{-1}), 2,4-DP (24 g L^{-1}), 2,4-D/picloram (4.8/1.2 g L^{-1}), fluroxypyr (4 g L^{-1}), glyphosate (2.8 g L^{-1}), metsulfuron (0.12 g L^{-1}) and triclopyr/picloram (4.5/1.5 g L^{-1}) killed 50, 73, 97, 100, 100, 100 and 100% of the treated plants, respectively (Vitelli *et al*. 1988). Similar results occurred for metsulfuron (98% mortality) in trials in the Northern Territory, but fluroxypyr (0.3, 0.6 and 0.9 kg ha^{-1}) and glyphosate (0.45, 0.9 and 1.35 kg ha^{-1}) controlled less than 10% of the treated plants (Pitt and Miller 1991). The addition of wetting agents will significantly increase the effectiveness of herbicides when applied as foliar sprays (Csurhes 1999, Pitt and Miller 1991).

In North Queensland, the aerial application of herbicides was tested as a potential method for treating large areas of dense infestations of bellyache bush growing in non-timbered areas (Vitelli and Madigan 2002). Using a carrier spray volume of 200 litres per hectare, five foliar herbicides (triclopyr/picloram at 450/150 g ha^{-1}, glyphosate at 2.16 kg ha^{-1}, fluroxypyr at 400 g ha^{-1}, metsulfuron at 72 g ha^{-1}, and metsulfuron plus glyphosate at 72 + 867 g ha^{-1}) killed between 92 to 100% of bellyache bush plants (Vitelli and Madigan 2002). 2,4-D ester at 4 kg ha^{-1} performed poorly, killing only 63% (Vitelli and Madigan 2002). Efficacy dropped from 98 to 42% when bellyache bush growing in timbered country was aerially treated using triclopyr plus picloram (Vitelli and Madigan 2002). In trials undertaken by the Northern Territory government, three rates of metsulfuron (50, 75 and 100 g ha^{-1}) and three rates of glyphosate mixed with simazine (1.5 + 2.0, 1.5 + 4.0 and 3.0 + 4.0 kg ha^{-1}) were aerially applied with carrier spray volumes of 60 L ha^{-1} to dense stands of mature bellyache bush. Twelve months after application, there were no visible effects from herbicide application (Pitt and Miller 1991).

Cut stump and basal bark techniques can produce good kills of bellyache bush. In Papua New Guinea, a complete kill was obtained when 2,4,5-T (5–10 g L^{-1}) in diesel was applied to stumps cut at ground level (Chadhokar 1978). Similarly, cut stump applications of picloram/2,4,5-T (2.5/10 g L^{-1}) in water and basal bark applications of picloram/2,4,5-T (2/8 g L^{-1}) in diesel killed 100% of plants (Pitt and Miller 1991). Cut stump trials in North Queensland also found 2,4-D (1.5, 3 and 30 g L^{-1} water), 2,4-D/picloram (0.5/2, 1/4, and 2/8 g L^{-1} diesel), fluroxypyr (3, 6 and 12 g L^{-1} diesel), triclopyr (4.8, 9.6 and 19.2 g L^{-1} diesel) and neat diesel killed 90 to 100% of the treated bellyache bush plants (Vitelli *et al.* 1988). To be effective the cut stump method requires both treatment of the stump and disposal of the cut plant, as cut sections can produce seed.

The use of residual herbicides to reduce seedling recruitment has been tested. In the Northern Territory, high mortality of mature plants and control of seedlings for up to two years was achieved with hexazinone and tebuthiuron (Table 1) (Pitt and Miller 1991). In a North Queensland trial, metsulfuron applied between 36 and 1162 g ha^{-1} and tebuthiuron (500, 1000 and 1500 g ha^{-1}) were applied to pots containing 50 bellyache bush seeds. One hundred and eighty days post application, seedling mortality plus seed mortality was recorded at greater than 80% for each treatment, compared to control pots with 35% mortality (J.S. Vitelli unpublished results).

In Queensland, permits are required under the *Vegetation Management Act 1999* when controlling weeds if off-target damage may result in the death of native plants, particularly in riparian areas (www.legislation.qld.gov.au/LEGISLTN/CURRENT/V/VegetManA99.pdf). The use of gel-applied herbicides such as picloram potassium salt placed onto freshly cut stumps of scattered bellyache bush plants may present a safe option when using herbicides in riparian zones (M. Ferguson unpublished results). Only two chemicals (metsulfuron and fluroxypyr) are currently registered for the control of bellyache bush in Australia (Table 2).

Table 1. Suppression of mature and seedling bellyache bush compared to untreated areas 24 months after the application of residual herbicides on a property in the Northern Territory (adapted from Pitt and Miller 1991).

Herbicide	Rate (kg a.i. ha^{-1})	Plant suppression (%)	
		Seedlings	Mature (>50 cm)
Hexazinone	5.0	78	69
	10	93	91
	15	94	93
Tebuthiuron	1.0	58	52
	1.5	93	89
	2.0	96	94

Table 2. Herbicides registered for control of bellyache bush in Australia (adapted from Infopest Nov 2005, Biosecurity, Department of Primary Industries and Fisheries, Brisbane).

Situation	Active ingredient	Application rate	States registered in Australia[A]
Agricultural land – non-crop	fluroxypyr as mhe (200 g L^{-1})	0.5 L 100 L^{-1}	NSW, Q, WA
Forests – timber Production	fluroxypyr as mhe (200 g L^{-1})	0.5 L 100 L^{-1}	NSW, Q, WA
Land – commercial/industrial	fluroxypyr as mhe (200 g L^{-1})	0.5 L 100 L^{-1}	NSW, Q, WA
Land – commercial/industrial	metsulfuron-methyl (600 g kg^{-1})	10 g 100 L^{-1}+ penetrant	NSW, NT, Q, SA, T, V, WA
Pastures	fluroxypyr as mhe (200 g L^{-1})	0.5 L 100 L^{-1}	NSW, Q, WA
Pastures	metsulfuron-methyl (600 g kg^{-1})	10 g 100 L^{-1}+ penetrant	Q, WA
Pastures – native	metsulfuron-methyl (600 g kg^{-1})	10 g 100 L^{-1}+ penetrant	NSW, NT, Q, SA, T, V, WA
Rights of way	fluroxypyr as mhe (200 g L^{-1})	0.5 L 100 L^{-1}	NSW, Q, WA
Rights of way	metsulfuron-methyl (600 g kg^{-1})	10 g 100 L^{-1}+ penetrant	NSW, NT, Q, SA, T, V, WA

[A] States where registered: NSW = New South Wales, NT = Northern Territory, Q = Queensland, SA = South Australia, T = Tasmania, V = Victoria and WA = Western Australia.

Fire

Burning is an effective control technique against bellyache bush where there is sufficient fuel to carry a fire (Bebawi and Campbell 2002a,b,c). In the Charters Towers region, 76% mortality occurred following burning of a riparian infestation in September 1999. A second burn a year later (October 2000) increased the mortality rate to 92% (Bebawi and Campbell 2002c), with temperatures of up to 640°C recorded at ground level (Bebawi and Campbell 2002c). Exposure of bellyache bush to such high temperatures caused them to ooze caramelized latex and blister profusely due to the high sugar concentration of the latex (Bebawi and Campbell 2002b). Despite the average fuel load being relatively high, there was significant variation across the site and mortality tended to vary accordingly. Nevertheless, juvenile plants were more susceptible to fire than mature plants, with old plants being the most tolerant (Bebawi and Campbell 2002c).

A large portion of the seed bank is able to survive fire, resulting in large scale recruitment (Bebawi and Campbell 2002c). For example, 540 seedlings m^{-2} emerged from burnt plots compared with 190 seedlings m^{-2} in unburnt plots in a North Queensland trial. Seedling density in burnt plots averaged 37 seedlings m^{-2} after two years, compared with four seedlings m^{-2} in the unburnt controls (Bebawi and Campbell 2002c). Fire could therefore exacerbate the bellyache bush problem if followup control is not implemented.

Fire can only be used when there is a sufficient fuel load (Vitelli 2000). In drier areas, burns may only occur following several years of above average rainfall. There are also substantial costs in using fire, particularly as stock must be excluded before and after a burn, fire cannot always be used in fire sensitive areas (Vitelli 2000) and pasture may be lost.

Flame throwers have been tested for treatment of bellyache bush where chemical and mechanical control is inappropriate or ineffective (Vitelli and Madigan 2004). Flaming for 10 seconds around the entire circumference of the base of individual bellyache bush plants (5 cm above ground level) at a maximum temperature of 820°C killed 92% of the treated plants at a cost of 7.5 cents per plant (Vitelli and Madigan 2004). This practice would be most appropriate for treating small and/or scattered infestations.

Mechanical control

Since bellyache bush has a shallow root system it can be fairly easily removed by hand, especially if the soil is moist (Csurhes 1999). A number of landholders with small patches in the Burdekin region prefer to use this practice. By physically removing the plants they are confident that plants have been killed. Landholders also often put the removed material in stacks and burn it, so as to kill any reproductive material and reduce the risk of plants reattaching to the soil and growing (S.D. Campbell unpublished observations).

Cutting bellyache bush close to ground level can also be effective (Bebawi and Campbell 2002b). No plants cut off at ground level regrew, whereas those cut above ground level reacted differently depending on the season. The majority of plants cut at 10, 20, and 40 cm height in the dry season regrew, whereas only those cut at 20 and 40 cm in the wet season regrew. In general, plants were more susceptible when cut in the wet season (Bebawi and Campbell 2002b).

The use of tractor-mounted slashers has provided similar results in areas of suitable terrain. In one field trial 100% of plants were killed, irrespective of whether they were juvenile, mature or adult plants (Bebawi *et al.* 2004). There are, however, instances in other areas where not all plants have been killed after being cut off at ground level, with re-shooting sometimes occurring (Chadhokar 1978, Pitt and Miller 1991).

The use of heavy machinery such as bulldozers can be effective for directly killing plants, as well as for cleaning up infested areas so that other forms of control can be implemented. In one trial, a stick rake on the front of a bulldozer caused greater than 90% mortality of plants within a dense infestation. Those that survived were generally smaller plants that escaped being ripped out (Bebawi *et al.* 2004). For mechanical control of woody weeds such as bellyache bush, efficacy is generally highest for treatments that completely remove the whole plant or sever the root system underground (20–30 cm). Season of application, soil texture, soil moisture and weed density also influence survival and regrowth (Vitelli 2000).

Physical disturbance that occurs when using mechanical control will generally result in massive recruitment of seedlings (Bebawi *et al*. 2004). This can be a means of depleting the seed bank more quickly, provided regrowth is controlled before it reaches reproductive maturity (Campbell and Grice 2000).

There are some legislative restrictions that may influence whether mechanical techniques can be used in certain situations. For example, in Queensland, it is a requirement to obtain a permit under the *Vegetation Management Act 1999* to use machinery in riparian areas (Vitelli 2000).

Pasture management

Preliminary results from a field trial investigating the impact of five simulated grazing regimes on four bellyache bush population densities suggest that bellyache bush grows best in areas void of pasture. Where there is grass cover, seedling recruitment is reduced and plants grow more slowly (F.F Bebawi unpublished results). As for most tropical weeds, there are very few data on how bellyache bush can be managed using grazing or pasture management.

Natural enemies

Jatropha spp. generally have few phytophagous insects or pathogens in their native range (Dehgan 1982). In India, bellyache bush was reported completely free of any visible fungal or insect damage (Raina and Gaikwad 1987). However, in Australia, the leaf-mining moth, *Epicephala* sp. (Wilson 1997) and the castor oil looper, *Achaea janata* L. cause minor defoliation of bellyache bush. The tenebrionids beetles, *Lyphia australis* Blackburn and *Platycotylus nitidulus* Macleay, and the nitidulid beetles, *Carpophilus marginellus* Motschulsky and *C. obsoletus* Erichson, have also been observed attacking the stems in the Northern Territory (F.F Bebawi unpublished results).

A soil borne fungus *Scytalidium dimidiatum* (Penz.) Sutton & Dyko has been observed to cause canker and wilt of bellyache bush stems in North Queensland. *S. dimidiatum* (formerly *Torula dimidiata*) is the synanamorph of *Nattrassia mangiferae* (Syd. & P.Syd.) Sutton & Dyko (syn. *Hendersonula toruloidea*). It is a very common soil-borne fungus associated with a wide range of hosts, including crop species (such as mangoes in Queensland) and eucalypts, and causing stem end rot (Tomley 2003).

Bellyache bush has been a target for biological control in Australia since 1996 (Heard and Chan 2002). A total of 170 locations in nine countries (Mexico, Venezuela, Dominican Republic, Puerto Rico, Nicaragua, Netherlands Antilles, Guatemala, Trinidad and Cuba) have been investigated for potential agents against *Jatropha*. Over 1000 specimens were collected and sent for identification.

Of the insects investigated, *Pachycoris klugii* Burmeister (Scutelleridae) was the most damaging herbivore of plantations of *J. curcas* in Nicaragua, but unfortunately failed to develop on *J. gossypiifolia*. *Cylindrocopturus jatrophae* Fall (Curculionidae), a stem-boring weevil, *Colaspis* sp. (Chrysomelidae) and *Styloleptus* sp. and *Parmenonta* sp. (Cerambycidae) were imported into quarantine but could not be reared. While *Lagocheirus* sp. (Cerambycidae) established in quarantine, host testing revealed it fed on cassava and was rejected. Preliminary studies on the rust fungus, *Phakopsora jatrophicola* Cummins ex Cummins (Uridenales) are promising, but limited funds have prevented further host testing.

To date, the seed feeding jewel bug, *Agonosoma trilineatum* Fabricius (Scutelleridae) is the only agent approved for release in

Australia against bellyache bush (Figure 11). The jewel bug was first released in the Northern Territory in March 2003 at Willeroo Station and in North Queensland in June 2004 at Barkla Station (Heard 2003, Bebawi 2004).

The potential impact of jewel bugs on bellyache bush has been quantified in a greenhouse experiment (Bebawi *et al*. 2005a). Potted bellyache bush plants were exposed to 0, 6 or 24 jewel bugs per plant. Jewel bugs significantly increased the level of abortion of both immature and mature capsules, particularly at the higher density of insects. Immature capsules were the most susceptible, averaging 80% capsule abortion, compared with only 21% for more mature capsules (Bebawi *et al*. 2005a). After 30 days exposure to the jewel bug, seed production was reduced by 22% and 75% respectively at low and high jewel bug density (Bebawi *et al*. 2005a). Furthermore, nearly 60% and 83% of the seeds produced at low- and high jewel bug density were damaged (Bebawi *et al*. 2005a). In the laboratory, feeding by adult jewel bugs completely destroyed seeds of bellyache bush (Heard and Chan 2002).

To date, there have been limited signs of *A. trilineatum* establishment at three of the nine release sites in Queensland. The most promising signs of establishment were seen in early 2005, when nymphs were observed near one release site and in early 2006, when both adults and nymphs were seen at a further two release sites. Evidence of feeding damage on seed capsules was also noted. It is uncertain yet whether the insect will persist at these sites (C.J. Lockett unpublished data).

Figure 11. Male (left) and female (right) jewel bug (*Agonosoma trilineatum*) mating on a bellyache bush capsule.

Table 3. Recruitment of bellyache bush seedlings as affected by singular (initial treatment, 2003), first follow-up (2004) and second follow-up (2005) control techniques at Almora Cattle Station, north Queensland.

Control technique	Singular (initial treatment 2003)	1st followup (2004)	2nd followup (2005)
	Seedling recruitment for every plant killed		
Foliar spray	20	6	3
Burn	69	12	9
Slash	97	19	11
Stick-rake	74	19	11

Integrated control

No single control method provides effective management of bellyache bush at a reasonable cost (Vitelli 2000). Results from a trial of integrated control methods have shown that high kill rates of bellyache bush can be obtained with a single application of techniques such as foliar spraying, slashing, fire and stickraking (Bebawi *et al*. 2004). However, followup control will generally be needed for several years to control remaining plants and seedling regrowth. Selective foliar spraying appears to be one of the most effective options for followup as it allows the maintenance of a grass cover to compete with seedlings that emerge afterwards. In the integrated control trial, for every plant killed by a single foliar spray treatment, 20 plants were recruited from the seed bank, much less than in slashing, mechanical and fire treatments which averaged 97, 74 and 69 plants, respectively (Bebawi *et al*. 2004). Furthermore, followup foliar treatments implemented one and two years later resulted in only six and three new plants being recruited respectively, for every plant killed (Table 3) (F.F. Bebawi unpublished results). This means that with two followups, seedling recruitment can be reduced up to 85%, making control in subsequent years much easier (F.F. Bebawi unpublished results).

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References

Abubacker, M.N., Rao, G.R. and Kumaresan, A. (1999). Sugarcane press mud cake: accelerator of biogas production in various weed biomass. *Advances in Plant Sciences* 12, 73-8.

Adewunmi, C.O. and Marquis, V.O. (1980). Molluscicidal evaluation of some *Jatropha* species grown in Nigeria. *Quarterly Journal of Crude Drug Research* 18, 141-5.

Adolf, W., Opferkuch, H.J. and Hecker, E. (1984). Irritant phorbol derivatives from four *Jatropha* species. *Phytochemistry* 23, 129-32.

Amin, M.A., Daffala, A.A. and El Moneim, O.A. (1972). Preliminary report of the molluscicidal properties of Habat El-Mollok, *Jatropha* sp. *Transactions of the Royal Society of Tropical Medicine Hygiene* 66, 805-6.

Anon. (1888). List of useful plants grown in the Government Botanical Garden at Port Darwin. Government Resident's Report on Northern Territory for the Year 1887, pp. 33-40.

Anon (2005). Draft 'Weed management plan for bellyache bush (*Jatropha gossypiifolia*) in the Northern Territory (2005–2008)'. (Department of Infrastructure, Planning and Environment, Northern Territory, Australia).

APB Infonote (1994). Agriculture Protection Board of Western Australia. Infonote 11/94 AGDEX 647.

Ashley, M. (1995). The biology and management of *Jatropha gossypiifolia*. Technical Bulletin No. 234. (Department of Primary Industry and Fisheries, Northern Territory).

Backer, C.A. and Bakhuizen van den Brink, R.C. (1963). 'Flora of Java. Volume 1'. (N.V.P. Noordhoff-Groningen, The Netherlands).

Bailey, F.M. (1912). 'Comprehensive catalogue of Queensland plants – both indigenous and naturalized', p. 478. (Queensland Government, Brisbane).

Banerji, J., Das, B., Bose, P., Chakrabarti, R. and Chatterjee, A. (1993). 'Traditional medicine', ed. B. Mukherjee, p. 352. (Oxford and IBH Publishing, New Delhi, India).

Barron, F. (2004). Bellyache bush on the Palmer and Walsh Rivers. Bellyache bush Workshop Proceedings, Tropical Weeds Research Centre, Department of Natural Resources and Mines, Charters Towers, Queensland.

Baxter, P. (2000). Deadly weeds on Leper Island. *Northern Territory News*, November 8, p. 19.

Bebawi, F.F. (2004). Ecology and agronomy. Bellyache bush Workshop Proceedings, Tropical Weeds Research Centre, Queensland Department of Natural Resources and Mines, Charters Towers, Queensland.

Bebawi, F.F. and Campbell, S.D. (2002a). Seed dispersal of a myrmecochorous weed, bellyache bush (*Jatropha gossypiifolia*) in riparian landscapes of northern Queensland. Proceedings of the Royal Society of Queensland, Landscape Health in Queensland symposium, eds A.J. Franks, J. Playford, A. Shapcott, pp. 98-102. (The Royal Society of Queensland, Brisbane, Queensland).

Bebawi, F.F. and Campbell, S.D. (2002b). The response of bellyache bush (*Jatropha gossypiifolia*) plants cut off at different heights and seasonal times. *Tropical Grasslands* 36, 65-8.

Bebawi, F.F. and Campbell, S.D. (2002c). Impact of fire on bellyache bush (*Jatropha gossypiifolia*) plant mortality and seedling recruitment. *Tropical Grasslands* 36. 129-37.

Bebawi, F.F. and Campbell, S.D. (2002d). Effects of fire on germination and viability of bellyache bush (*Jatropha gossypiifolia*) seeds. *Australian Journal of Experimental Agriculture* 42, 1063-9.

Bebawi, F.F. and Campbell, S.D. (2004). Interactions between meat ants (*Iridomyrmex spadius*) and bellyache bush (*Jatropha gossypiifolia*). *Australian Journal of Experimental Agriculture* 44, 1157-64.

Bebawi, F.F., Campbell, S.D. and Stanley, T.D. (2002). Priority lists for weed research in the wet- and dry-tropics of north Queensland. *Plant Protection Quarterly* 17, 67-73.

Bebawi, F.F., Davis, K. and Lockett, C. (2005a). Bellyache bush (*Jatropha gossypiifolia*) biocontrol potential – preliminary results. Proceedings of the 8th Queensland Weed Symposium, Weed Management – Making a Difference, ed. W.D. Vogler, pp. 78. (Weed Society of Queensland, Brisbane, Queensland).

Bebawi, F.F., Mayer, R.J. and Campbell, S.D. (2005b). Phenology of bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland. *Plant Protection Quarterly* 20, 46-51.

Bebawi, F.F., Mayer, R.J. and Campbell, S.D. (2005c). Flowering and capsule production of bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland. *Plant Protection Quarterly* 20, 129-32.

Bebawi, F., Vitelli, J., Campbell, S. and Madigan, M. (2004). Integrated control methods for bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland: preliminary results. Proceedings of the 14th Australian Weed Conference, eds B.M. Sindel and S.B. Johnson, pp. 150-2. (Weed Society of New South Wales, Sydney).

Begg, J. and Gaskin, T. (1994). *Jatropha gossypiifolia* – poisons information. Monograph 643. http://www.inchem.org/documents/pims/plant/jgossyp.htm. IPCS INCHEM, Ontario. Accessed 2005.

Berg, R. (1975). Myrmecochorous plants in Australia and their dispersal by ants. *Australian Journal of Botany* 23, 475-508.

Biehl, J. and Hecker, E. (1985). On the isolation of macrocyclic diterpenes from roots of *Jatropha gossypiifolia* Euphorbiaceae. *Acta Agronomica Academiae Scientiarum Hungaricae* 34, 78.

Biehl, J. and Hecker, E. (1986). Irritant and antineoplastic principles of some species of the genus *Jatropha* Euphorbiaceae. *Planta Medica* 5, 430.

Biswanth D., Rao, S.P. and Srinivas, K.V. (1996). Isolation of isogadain from *Jatropha gossypiifolia*. *Planta Medica* 62, 90.

Biswanth, D. and Ratna, D. (1995). Gossypifan, a lignan from *Jatropha gossypiifolia*. *Phytochemistry* 40, 931-2.

BoDD (2004). Euphorbiaceae. Botanical Dermatology Database, http://bodd.cf.ac.uk.

Bowen Independent (1996). Field day warns of bellyache bush danger. Bowen Independent Newspaper Report, 18 October 1996, p. 7.

Brundu, G. and Camarda, I. (2004). The exotic flora of Chad: A first contribution. *Weed Technology* 18, 1226-31.

Burkill, H.M. (1994). 'The useful plants of West Tropical Africa. Volume 2', p. 636. (Royal Botanic Gardens, Kew, UK).

Calvert, G. (1999). Weeds–the silent invaders. Society for Growing Australian Plants' Queensland Region Conference, Townsville 28 June–5 July, ed. Brian Walters, Australian Plants online, Association of Societies for Growing Australian Plants (ASGAP), http://farrer.riv.csu.edu.au.

Campbell, S.D. and Grice, A.C. (2000). Weed biology: a foundation for weed management. *Tropical Grasslands* 34, 271-9.

Chadhokar, P.A. (1978). Weed problems of grazing lands and control of some problem weeds in the Markham Valley of Paua New Guinea. *PANS* 24, 63-6.

Chatterjee, A., Das, B., Adityachaudhury, N. and Debkirtaniya, S. (1980). Note on the insecticidal properties of the seeds of *Jatropha gossypiifolia* Linn. *Indian Journal of Agricultural Science* 8, 637-8.

Chopra, R.N. and Badhwar, R.L. (1940). Poisonous plants of India. *Indian Journal of Agricultural Science* 10, 1-44.

Csurhes, S.M. (1999). Bellyache bush (*Jatropha gossypiifolia*) in Queensland. Pest Status Review Series – Land Protection. (Queensland Department of Natural Resources, Brisbane).

CSIRO (1998). Biological control of Northern Territory weeds. (Unpublished Annual Report).

Das, B. and Das, R. (1994). Medicinal properties and chemical constituents of *Jatropha gossypiifolia* Linn. *Indian Drugs* 31, 562-7.

Datta, N. (1967). In IOPB chromosome number reports XII. *Taxon* 16, 341-50.

Dehgan, B. (1982). Novel Jatrophas for Florida landscapes. *Proceedings Florida State Horticultural Society* 95, 277-80.

Dehgan, B. (1983). Propagation and growth of Cycads. A Conservation Strategy. *Proceedings Florida State Horticultural Society* 96, 137-9.

Dehgan, B. and Webster, G.L. (1979). Morphology and infragenic relationships of the genus *Jatropha* (Euphorbiaceae). *Botany* 74, 1-73.

de Padua, L.S., Bunyapraphatsara, N. and Lemmens, R.H.M.J. (1999). 'Plant Resources of South-East Asia No 12 (1). Medicinal and Poisonous Plants 1', 711 pp. (Backhuys, Leiden, The Netherlands).

Ellis, R.H., Hong, T.D. and Roberts, E.H. (1985). Handbooks for Genebanks No. 3. Handbook of Seed Technology for Genebanks, Volume II. Compendium of Specific Germination Information and Test Recommendations. International Board for Plant Genetic Resources, Rome.

Everist, S.L. (1974). Poisonous plants of Australia. (Angus Robertson, Sydney).

Fernandez, M.D., Pieters, A., Azkue, M., Rengifo, E., Tezara, W., Woodward, F.I., and Herrera, A. (1999). Photosynthesis in plants of four tropical species growing under elevated CO_2. *Photosynthetica* 37, 587-99.

Forni-Martins, E.R. and Cruz, N.D. (1985). Research in progress with physic nut at the Instituto Agronomico. *Agronomico* 37, 109-13.

Francis, J.K. (2005). *Jatropha gossypiifolia* L. *In* Wildland shrubs of the United States and its territories', www.fs.fed.us/global/iitf/wildland-shrubs.htm.

Gardner, C.A. and Bennetts, H.W. (1956). 'The toxic plants of Western Australia'. (West Australian Newspapers Ltd., Perth).

Gardner, M. (2005). Towards more strategic management of weeds on Top End Aboriginal Lands. Tropical Savannas CRC, James Cook University, Townsville, Queensland, Australia.

Gbeassor, M., Kossou, Y., Amegbo, K., Souza, C. and Koumaglo, K. (1989). Antimalarial effects of eight African medicinal plants. *Journal of Ethnopharmacology* 25, 115-8.

Govaerts, R., Frodin, D.G. and Radcliffe-Smith, A. (2000). 'World checklist and bibliography of Euphorbiaceae'. (Royal Botanic Garden, Kew, England).

Heard, T. (2003). 'A study of the biology of selected agents for biological control of *Jatropha gossypiifolia* using CSIRO quarantine facility in Brisbane'. Fifth Annual Report 2002–2003, CSIRO Entomology, Indooroopilly, Brisbane, Australia.

Heard, T.A. and Chan, R.R. (2002). Application to release *Agonosoma trilineatum* (Heteroptera: Scutelleridae) a biological control agent of the weed bellyache bush *Jatropha gossypiifolia* (Euphorbiaceae). (CSIRO Entomology, Indooroopilly, Queensland).

Heard, T.A., Chan, R.R., and Segura, R. (2002). Prospects for the biological control of bellyache bush, *Jatropha gossypiifolia*. Proceedings of the 13th Australian Weed Conference, eds H. Spafford Jacob, J. Dodd and J.H. Moore, pp. 366-9. (Plant Protection Society of Western Australia, Perth).

Heller, J. (1996). 'Physic nut. *Jatropha curcas* L. Promoting the conservation and use of underutilized and neglected crops'. (Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy).

Hemming, C.F. and Radcliffe-Smith, A. (1987). A revision of the Somali species of *Jatropha* (Euphorbiaceae). *Kew Bulletin* 42, 103-22.

HERBRECS (1998, 2004). HERBRECS specimen data base list for *Jatropha* – adhoc updating retrieval. (Queensland Herbarium, Environmental Protection Agency, Indooroopilly, Queensland).

Hickman, J.C. (1974). Pollination by ants: a low energy system. *Science* 184, 1290-2.

Holm, L., Pancho, J.V., Herberger, J.P. and Plucknet, D.L. (1979). 'A geographical atlas of world weeds'. (John Wiley and Sons, New York).

Horsten, S., Berg, A., Kettenes-van den Bosch, J., Leeflang, B. and Labadie, R. (1996). Cyclogossine A: a novel cyclic heptapeptide isolated from the latex of *Jatropha gossypiifolia*. *Planta Medica* 62, 46-50.

Howard, R.A. (1989). 'Flora of the Lesser Antilles, Leeward and Windward Islands. Volume 5', 604 p. (Arnold Arboretum, Harvard University, Jamaica Plain, MA, USA).

IPCS INCHEM (2004). *Jatropha gossypiifolia*. www.inchem.org/documents/pims/plant/jgossyp.htm.

Irvine, F.R. (1961). 'Woody plants of Ghana with special reference to their uses'. (Oxford University Press, London).

Joubert, P.H., Brown, J.M.M., Hay, I.T. and Sebata, P.D.B. (1984). Acute poisoning with *Jatropha curcas* purging nut tree in children. *South African Medical Journal* 65, 729-30.

King, S. and Wirf, L. (2005). Draft 'Weed management plan for bellyache bush (*Jatropha gossypiifolia*) in the Northern Territory (2005–2008). Northern Territory Department of Infrastructure, Environment, and the Arts, Palmerston, Northern Territory Government, NT.

Kingsbury, J.M. (1964). 'Poisonous plants in the United States and Canada'. (Prentice-Hall Inc., NJ, USA).

Kleinschmidt, H.E. and Johnson, R.W. (1987). 'Weeds of Queensland'. (Queensland Department of Primary Industries, Brisbane).

Klotzsch, J.F. (1853). *Jatropha elegans* (Pohl) Klotzsch, in Seeman. *Botanical Voyage Herald* 102.

Kupchan, S.M., Sigel, C.W., Matz, M.J., Gilmore, C.J. and Bryan, R.F. (1976). Structure and stereochemistry of jatrophone a novel macrocyclic diterpenoid tumour inhibitor. *Journal of the American Chemical Society* 98, 2295-300.

Lazarides, M. and Hince, B. (1993). 'CSIRO handbook of economic plants of Australia'. (CSIRO Publishing, Melbourne, Victoria).

Liogier, H.A. (1990). Descriptive flora of Puerto Rico and adjacent islands. *Spermatophyta* 2, p. 481.

Marcano-Fondeur, E. de J. (1992). Las plantas venenosas en la medicina popular. Naturaleza Dominicana. http://marcano.freeservers.com/nature/conference/venen.html, 6 p.

Miller, I.L. (1982). Weeds in the Northern Territory: current situation and future directions. (Northern Territory Department of Primary Production, Division of Agriculture and Stock, Darwin).

Miller, I.L. and Pitt, J.L. (1990). Is *Jatropha gossypiifolia* the next *Mimosa pigra*? *Australian Weeds Research Newsletter* 39, 1-6.

Miller, P. (1754). 'The gardener's dictionary, 4th edition'. (British Museum Publications, London).

Morton, J.F. (1981). 'Atlas of medicinal plants of Middle America. Bahamas to Yucatan'. (C.C. Thomas, Springfield, IL, USA).

Morton, J.J. (1982). 'Plants poisonous to people in Florida and other warm areas'. (Southeastern Printing Co., Inc. Stuart, Florida, USA)

Nanda, P.C. (1962). Chromosome number of some trees and shrubs. *Journal Indian Botanical Society* 41, 266-8.

Oakes, A.J. and Butcher, J.O. (1962). Poisonous and injurious plants of the US Virgin Islands. Miscellaneous Publication 882, United States Department of Agriculture, Agricultural Research Service, Washington DC.

Ogbobe, O. and Akano, V. (1993). The physico-chemical properties of the seed and seed oil of *Jatropha gossypiifolia*. *Plant Foods for Human Nutrition* 43, 197-200.

Parrotta, J.A. (2001). Healing plants of Peninsular India. (CABI Publishing, Wallingford, UK).

Parsons, W.T. and Cuthbertson, E.G. (2001). 'Noxious weeds of Australia', 2nd edition, pp. 429-30. (CSIRO Publishing, Collingwood, Victoria).

Partridge, I. (2001). Grasslands of Indonesia. In TGS news and views about pasture development in the tropics and subtropics – Tropical Grassland Society of Australia, Newsletter 17(3), 4-6.

Perry, L.M. (1980). 'Medicinal plants of east and southeast Asia: attributed properties and uses'. (MIT Press, Cambridge).

Pinedo, M. Rengifo, E. and Cerruti, T. (1997). 'Plantas medicinalis de la Amazonia Peruana'. (Instituto de Investigaciones de la Amazonia Peruana, Iquitos).

Pitt, J.L. (1997). Bellyache bush (*Jatropha gossypiifolia*). Northern Territory Department of Primary Industry and Fisheries, Darwin.

Pitt, J.L. (1999). Bellyache bush. Agnote No. 480, Northern Territory of Australia, Darwin.

Pitt, J.L. and Miller, I.L. (1991). The pest status and chemical control of *Jatropha gossypiifolia* L. in the Northern Territory, Australia. Proceedings of the 13th Asian-Pacific Weed Science Society, Jakarta).

Pitt, J.L., Smith, R.A. and Crothers, M. (1990). *Jatropha gossypiifolia* in the Northern Territory. Proceedings of the 9th Australian Weeds Conference, Adelaide, South Australia, p. 414.

Pohl, J.E. (1827). Plantarum Brasiliae Icones et Descriptiones. *Vindobonae* 1, 12.

Prasad, Y.R., Alankararao, G.S. and Baby, P. (1993). Constituents of the seeds of *Jatropha gossypiifolia*. *Fitoterapia* 64, 376.

Queensland Government (2003). Land protection (pest and stock route management) Act 2002 – Subordinate Legislation 2003 No. 117. (Queensland Government – Department of Natural Resources and Mines, Brisbane).

Raina, A.K. and Gaikwad, B.R. (1987). Chemobotany of *Jatropha* species in India and further characterisation of 'curcas oil'. *Journal of the Oil Technologists Association of India* 19, 81-5.

Rao, A.R. and Malaviya, M. (1964). On the latex-cells and latex of *Jatropha*. *Proceedings of the Indian Academy of Sciences* 60B, 95-106.

Rao, E.S. and Raju, V.S. (1994). The genus *Jatropha* in Andhra Pradesh, India. *Journal of Economic and Taxonomic Botany* 18, 585-9.

Reddi, E.U.B, and Reddi, C.S. (1983). Pollination ecology of *Jatropha gossypiifolia* (Euphorbiaceae). *Proceedings Indian Academy of Sciences (Plant Sciences)* 92, 215-31.

Rengifo, O, Urich, R. and Herrera, A. (2002). Water relations and leaf anatomy of the tropical species, *Jatropha gossypiifolia* and *Alternanthera crucis*, grown under an elevated CO_2 concentration. *Photosynthetica* 40, 397-403.

Simonsen, J.L. (1945). 'List of indigenous plants of the colonial empire of possible scientific and technical interest'. (Mimeo.) (Imperial Institute, London).

Singh, A. and Agarwal, R.A. (1988). Possibility of using latex of Euphorbiales for snail control. *Science of the Total Environment* 77, 231-6.

Singh, D. and Singh, A. (2002). Biochemical alteration in freshwater fish *Channa puntatus* due to latices of *Euphorbia royleana* and *Jatropha gossypiifolia*. *Environmental Toxicology and Pharmacology* 12, 129 – 36.

Singh, R.P. (1970). Structure and development of seeds in Euphorbiaceae: *Jatropha* species. *Beitr. Biol. Pflanzen* 47, 79-90.

Smith, N.M. (1995). 'Weeds of natural ecosystems: a field guide to environmental weeds of the Northern Territory'. (Environment Centre, Darwin).

Souder, P. (1963). Poisonous plants on Guam. *In* 'Venomous and poisonous animals and noxious plants of the Pacific region', eds H.L. Keegan and W.V. Macfarlane, pp. 15-29. (Pergamon Press, New York, USA).

Sreenivasa Rao, E. and Raju, V.S. (1994). On the occurrence of two varieties of *Jatropha gossypiifolia* L. in India. *Journal of the Indian Botanical Society* 73, 361.

Sukumaran, D., Parashar, B.D. and Rao, K.M. (1995). Toxicity of *Jatropha gossypiifolia* and *Vaccaria pyramidata* against freshwater snails vectors of animal schistosomiasis. *Fitoterapia* 66, 393-8.

Taylor, M.D., Smith, A.B., Furst, G.T., Gunasekara, S.P., Bevelle, C.A., Cordell, G.A., Farnsworth, N.R., Kupchan, S.M., Uchida, H., Branfman, A.R., Dailey, R.G. and Sneden, A.T. (1983). New anti leukemic derivatives from *Jatropha gossypiifolia*: structural and stereochemical assignment through nuclear magnetic resonance spectroscopy. *Journal of the American Chemical Society* 105, 3177-83.

Tezara, W., Fernandez, M.D., Donoso, C. and Herrera, A. (1998). Seasonal changes in photosynthesis and stomatal conductance of five plant species from a semiarid ecosystem. *Photosynthetica* 35, 399-410.

Thorp, J.R. and Lynch, R. (2000). The Determination of Weeds of National Significance. National Weeds Strategy Executive Committee, Launceston, Tasmania.

Tomley, A. (2003). Bellyache bush *Jatropha gossypiifolia* infection by *Scytalidium dimidiatum.* Queensland Department of Natural Resources and Mines Office Memo.

Tothill, J.C., Mott, J.J. and Gillard, P. (1982). Pasture weeds of the tropics and subtropics with special reference to Australia. *In* 'Biology and ecology of weeds', eds W. Holzner and N. Numata, pp. 403-22. (Dr. W. Junk Publishers, The Hague).

Vitelli, J.S. (2000). Options for effective weed management. *Tropical Grasslands* 34, 280-94.

Vitelli, J.S. and Madigan, B.A. (2002). Is aerial control of bellyache bush effective? Proceedings of the 13th Australian Weed Conference, eds H. Spafford Jacob, J. Dodd and J.H. Moore, pp. 169-172. (Plant Protection Society of Western Australia, Perth).

Vitelli, J.S. and Madigan, B.A. (2004). Evaluation of a hand-held burner for the control of woody weeds by flaming. *Australian Journal of Experimental Agriculture* 44, 75-81.

Vitelli, J.S., Shaw, R., Dorney, W., van Haaren, P., Jeffrey, P., Brown, A., Pettit, B., Schuhmann, A. and Cowan, D. (1988). *Jatropha gossypiifolia* rate screening trials. Biological Branch Annual Report 1987–1988, p. 16-19. Queensland Department of Lands, Brisbane.

Vogler, W. and Keir, A. (2005). The rate of spread of bellyache bush (*Jatropha gossypiifolia*) in North Queensland. Proceedings of the 8th Queensland Symposium, ed. W.D. Vogler, p. 102. (Weed Society of Queensland, Townsville).

Walton, C. and Elliot, H. (2003). Weeds of southern Queensland: research priorities. Department of Natural Resources and Mines, Brisbane, Queensland.

Watt, J.M. and Breyer-Brandwijk, M.G. (1962). 'The medicinal and poisonous plants of southern and eastern Africa, 2nd edition'. (E. and S. Livingstone, Ltd., London).

Wheeler, J.R. (1992). 'Flora of the Kimberley Region'. (Department of Conservation and Land Management, Como, Western Australia).

Wild, K.L. (2003). Understanding the flowering and seeding behaviour of bellyache bush (*Jatropha gossypiifolia*). A report submitted as a requirement for the degree of Bachelor of Agricultural Science (Rural Technology) in the University of Queensland, Gatton, Queensland).

Wilson, C.G. (1997). Phytophagous insect fauna of two weeds, *Hyptis suaveolens* (L.) Poit. and *Jatropha gossypiifolia* L., in Australia's Northern Territory. *Australian Entomologist* 24, 55-60.

Appendix 1. Summary of insects, vertebrates, and fungi associated with *Jatropha gossypiifolia* and locations where collected. All Australian collections were made in Queensland. Source of overseas insects was obtained from Reddi and Reddi (1983) and CSIRO (1998). Source of Queensland insects was identified by Mr. Geoff Monteith, Curator Entomology, Queensland Museum, Brisbane.

Family	Scientific Name	Common name	Country
Insects			
Acrididae	*Austracris* sp.	Spur-throated locust	Australia
	Acrida conica Fabricius	Giant green slantface grasshopper	Australia
	Chortoicetes terminifera Walker	Australian plague locust	Australia
	Phaulacridium vittatum Sjostedt	Wingless grasshopper	Australia
Alydidae	*Daclera rufescens* Stal.	Bug	Australia
	Melanacanthus sp.	Brown bean bug	Australia
Apidae	*Apis cerana indica* Fabricius	Asian honey bee	India
	Apis florae Fabricius	Dwarf honey bee	India
	Apis mellifera Lepeltier	Honey bee	
	Trigona carbonaria Smith	Native bee	
	Trigona sp.		India
Bombyliidae	*Eucahrimia* sp.		India
	Geron sp.	Bee flies	India
Bruchidae	*Algarobius bottimeri* Kingsolver	Mesquite bruchid beetle	Australia
Buprestidae	*Chalcophorotaenia australasiae* Saunders	Jewel beetle	Australia
	Conognatha sp.		Australia
Calliphoridae	*Rhyncomya viridaurea* Wiedemann	Fly	India
Cerambycidae	*Lagocheirus araneiformis* Linnaeus	Stem boring beetle	Venezuela
	Lagocheirus sp.	Stem boring beetle	Mexico, Venezuela
	Leptostylus sp.		Venezuela
	Lepturges sp.		Venezuela
	Ozineus sp.	Beetle	Venezuela
	Parmenonta sp.		Mexico
	Styloleptus laticollis Drury	Broad-necked root borer	Dominican Republic
	Trachyderes mandibularis Audinet-Serville	Long-horned beetle	Mexico
Chrysomelidae	*Altica* sp.	Metallic green flea beetle	Mexico
	Colaspis sp.	Leaf beetle	Venezuela
	Cryptocephalus sp.	Cylindrical leaf beetle	Venezuela
	Desmogramma sp.	Beetle	Venezuela
	Monomacra sp.	Orange beetle	Mexico
	Monoxia sp.		Venezuela
	Paria sp.	Sap feeding beetle	Venezuela
	Synbrotica sp.		Mexico
Coccinellidae	*Coccinella transversalis* Fabricius	Transverse ladybird	Australia
	Coccinellidae sp.		Mexico
Coenagrionidae	*Pseudagrion aureofrons* Tillyard	Goldfront sprite damselfly	Australia
Coreidae	*Amorbus alternatus* Dallas	Squash bug	Australia
	Amorbus obscuricornis Westwood	Gumtree bug	Australia
	Mictis profana Fabricius	Crusader bug	Australia
Cosmopterygida	*Cosmopterygidae* sp.	Leaf miner	Venezuela
Eumenidae	*Rhynchium metallicum* Saussure	Wasp	India
Flatidae	*Siphantha acuta* Walker	Green plant hopper	Australia
Formicidae	*Calomyrmex similis* Mayr	Beauty ants	Australia
	Camponotus novaehollandiae	Northern sugar ants	Australia
	Camponotus sp.	Sugar ants	Australia
	Crematogaster sp.	Cocktail ants	India
	Iridomyrmex anceps Roger	Tropical tyrant ants	Australia
	Iridomyrmex spadius Schattuck	Meat ant	Australia
	Iridomyrmex sp.	Tyrant ants	Australia
	Paratrechina sp.	Parrot ants	Australia

continued/…

Family	Scientific Name	Common name	Country
Insects continued/…			
Geometridae	*Geometridae* sp.	Moth	Venezuela
Gracillariidae	*Epicephala gracillariidae*	Leaf miner, moth	Australia
	Epicephala sp.	Moth	Australia
Halictidae	*Pseudapis oxybeloides* Smith	Bee	India
Hemiptera	*Auchenorrhyncha* sp.	Leaf hopper	Mexico
Histeridae	*Histeridae* sp.	Clown beetles, Hister beetles	Mexico
Lampyridae	*Lampyridae* sp.	Fire flies	Mexico
Lepidoptera	*Gelechioidea* sp.	Moth	Mexico
	Papilionoidae sp.		Venezuela
Libellulidae	*Diplacodes haematodes* Burmeister	Common percher dragonfly	Australia
	Orthetrum caledonicum Brauer	Blue skimmer dragonfly	Australia
Lycaenidae	*Nacaduba biocellata* Felder & Felder	Two-spotted line blue butterfly	Australia
Lycarnidae	*Zizina labradus* Godart	Common grass blue butterfly	Australia
Mantidae	*Austrovates* sp.	Blackbarrel mantid	Australia
	Tenodera australasiae Leach	Purple-winged mantid	Australia
Meloidae	*Meloidae* sp.	Blister beetles	Mexico
Milichidae	*Milichiella* sp.	Fly	India
Myrmicinae	*Myrmecia pilosula* Smith	Jumping jacks	Australia
Nitidulidae	*Carpophilus marginellus* Motschulsky		Australia
	Carpophilus obsoletus Erichson		Australia
Noctuidae	*Achaea janata* Linnaeus	Castor oil looper	Australia
	Bulia confirmans Walker		Venezuela
	Chrysodeixis argentifera Guenee	Tobacco looper butterfly	Australia
	Ischyja neocherina Butler	Sugarcane moth looper	Australia
	Metaponpneumata rogenhoferi Moschler		Venezuela
	Ponometia exigua Fabricius	Moth	Venezuela
	Spodoptera latifascia Walker	Moth	Mexico
Nyphalidae	*Euploea core-corinna* Cramer	Common crow butterfly	Australia
Pieridae	*Belonis java* Linnaeus	Caper white butterfly	Australia
	Catopsilia crocale Cramer	Butterfly	India
	Catopsilia pomona Fabricius	Lemon migrant butterfly	Australia
	Eurema hecabe Linnaeus	Common grass yellow butterfly	Australia
Pompilidae	*Ctenostegus* sp.	Spider wasp	Australia
Ponerinae	*Odontomachus turneri* Forel	Giant snappy ants	Australia
	Rhytidoponera convexa Mayr	Convex pony ants	Australia
	Rhytidoponera metallica Smith	Metallic pony ants	Australia
Pyralidae	*Herpetogramma licarsisalis* Walker	Grass webworm butterfly	Australia
Reduviidae	*Apiomerus vexillarius* Champion		Venezuela
	Gminatus Australia Stal	Orange assassin bug	Australia
	Poccilobdallus formosus Stal	Assassin bug	Australia
	Poecilosphadrus sp.	Assassin bug	Australia
	Pristhesancus plagipennis Walker	Common assassin bug	Australia
Sarcophagidae	*Sarcophaga orchidea* Asahina	Housefly	India
	Sarcophaga sp.		India
Scarabaeidae	*Glycyphana* sp.	Harvest beetle	Australia
	Protaetia sp.	Beetle	Australia
Scoliidae	*Campsomeris radula* Fabricius	Wasp	Australia
	Scolia cruenta Klug	Wasp	India
	Scolia sp.	Wasp	Australia
Scutelleridae	*Agonosoma trilineatum* Fabricius	Jewel bug, sucking bug	Venezuela
	Agonosoma sp.		Venezuela
	Coleotichus artensis Montroonzier	Bug	Australia
	Coleotichus costatus Fabricius	Shield bug	Australia
	Lampromicra senator Fabricius		Australia

continued/…

Family	Scientific Name	Common name	Country
Insects continued/…			
Sphecidae	*Sphex cognatus* Smith	Sand wasp	Australia
Sphingidae	*Hyles lineata* Fabricius	White-lined sphinx moth	Australia
Stratiomyidae	*Exaireta spinigera* Weidemann	Garden soldier fly	Australia
Tenebrionidae	*Blapstinus* sp.	Darkling beetle	Venezuela
	Branchus opatroides Champion		Mexico
	Epitragus sp.	Defoliator	Venezuela
	Hylocrinus sp.		Mexico
	Lyphia australis Blackburn		Australia
	Phegoneus sp.		Mexico
	Platycotylus nitidus Macleay		Australia
	Xystropus sp.		Venezuela
Tephritidae	*Dacus tryoni* Froggatt	Queensland fruitfly	Australia
Teragnathidae	*Nephila edulis* Koch	Golden orb web spider	Australia
Theridiidae	*Latrodectus hasseltii* Thorell	Redback spider	Australia
Thyreocoridae	*Galgupha* sp.		Venezuela
Tineidae	*Tineidae* sp.	Moth	Venezuela
	Xylesthia sp.	Stem mining moth	Mexico, Venezuela
Tortricidae	*Amorbia* sp.	Totricid moth	Mexico
	Platynota rostrana Walker	Peel-feeding totricid caterpillar	Mexico
	Platynota sp.	Leafrollers caterpillars	Mexico
Vespidae	*Epiodynerus nigrocinctus* Saussure	Potter wasp	Australia
	Ropalidia romandi Le Guillon	Australian paper wasp	Australia
	Ropalidia spatulate Van der Vecht	Wasp	India
Xylocopidae	*Xylocopa latipes* Drury	Carpenter bee	India
Fungi			
Uredinales	*Phakopsora jatrophicola* Cummins	Rust fungus	Mexico
	Scytalidium dimidiatum Sutton & Dyko	Soil-borne fungus	Australia