Australian Government
Department of Health
Office of the Gene Technology Regulator

The Biology of *Musa* L. (banana)

[Photo credit: Janet Gorst]

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This document provides an overview of baseline biological information relevant to risk assessment of genetically modified forms of the species that may be released into the Australian environment.

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ABBREVIATIONS

ABARES	Australian Bureau of Agricutural and Resource Economics and Sciences
ABGC	Australian Banana Growers Council
ABS	Australian Bureau of Statistics
APVMA	Australian Pesticides and Veterinary Medicines Authority
BAC	Bacterial Artificial Chromosome
BBTV	Banana Bunchy Top Virus
BQ	Biosecurity Queensland
BSV	Black Sigatoka Virus
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
CIRAD-FHLOR	CIRAD Departements Productions Frutières et Horticoles
DAFF	Department of Agriculture, Fisheries and Forestry (see QDAF)
DAFWA	Department of Agriculture and Food Western Australia
DPIF	Department of Primary Indsutries and Fisheries Northern Territory
EMBRAPA	Empresa Brasiliera de pesquisa Agropecuaria
FAO	Food and Agriculture Organisation of the United Nations
FHIA	Fundación Hondureña de Investigación Agrícola
Foc	*Fusarium oxysporum* f. sp. *cubense*
Foc Tr4	*Fusarium oxysporum* f. sp. *cubense* Tropical race 4
GM	Genetically modified
GMGC	Global Musa Genomics Consortium
HAL	Horticulture Australia Limited (now Horticulture Innovation Australia Limited)
INIBAP	International Network for the Improvement of Banana and Plantain
IPGRI	International Plant Genetic Resources Institute
LGA	Local Government Area
LMO	Living Modified Organism
MGIS	Musa Germplasm Information System
NSW	New South Wales
NSW DPI	New South Wales Department of Primary Industries
NT	Northern Territory
Qld	Queensland
QBAN	Queensland Banana Accredited Nursery
QDAF	Queensland Department of Agriculture and Fisheries (formerly QDPI and DAFF)
QDPI	Queensland Department of Primary Industries
PHA	Plant Health Australia
PRP	Pathogenesis Related Protein
TBRI	Tropical Banana Research Institute
Vic.	Victoria
WA	Western Australia
WCMC	World Conservation Monitoring Centre
WCSP	World Checklist of Selected Plant families (Kew)

PREAMBLE

This document describes the biology of *Musa* L. with particular reference to the Australian environment, cultivation and use. Information included relates to the taxonomy and origins of cultivated *Musa* spp., general descriptions of their morphology, reproductive biology, biochemistry, and biotic and abiotic interactions. This document also addresses the potential for gene transfer to occur to closely related species. The purpose of this document is to provide baseline information about the parent organism for use in risk assessments of genetically modified (GM) *Musa* spp. that may be released into the Australian environment.

In this document, the general term 'banana' is used to encompass cultivated varieties of the genus *Musa* that fall into one of two sub-groups, the sweet or dessert banana which makes up approximately 43% of world production and the cooking banana which makes up approximately 57%. The general term 'plantain; is applied to a specific subgroup of cooking bananas (Valmayor et al. 2000). The yellow sweet banana cultivars most commonly found in western greengrocers are the focus of this Biology document. Sweet bananas in general, however, show enormous diversity in terms of plant stature and fruit size, and fruit colour extends from yellow and green to red and orange (Ploetz et al. 2007).

Bananas are a major food crop globally and are grown and consumed in more than 100 countries throughout the tropics and sub-tropics (International Network for the Improvement of Banana and Plantain - INIBAP 2000). In developing countries they are the fourth most important food crop after rice, wheat and maize (INIBAP 2000). Worldwide, over 1,000 banana cultivars or landraces are recognised (Heslop-Harrison & Schwarzacher 2007). The banana plant is a tall tree-like plant with a false stem (pseudostem) consisting of leaf sheaths and an underground true stem (corm) that is able to produce suckers by which the plant can reproduce. Each pseudostem produces a single flowerhead. The female flowers of the flowerhead give rise (either with or without fertilisation) to the banana fruits.

SECTION 1 TAXONOMY

The genus name *Musa* is thought to be derived from the Arabic name for the plant (*mouz*) which, in turn, may have been applied in honour of Antonius Musa (63 – 14 BC), physician to Octavius Augustus, first emperor of Rome (Hyam & Pankhurst 1995). The name 'banana' is derived from the Arabic *banan* = finger (Boning 2006) and was thought to be used in Guinea (West Africa) concomitant with the introduction of the fruit by the Portuguese. The name then spread to the New World (Cheesman 1948).

The genus *Musa* is a member of the family Musaceae, which includes at least one other genus (*Ensete*) and, depending upon the affiliations of the taxonomist, may also include the monotypic genus *Musella* (Constantine & Rossel 2001). All genera are monocotyledons and, as such, are technically defined as 'herbs' even though some species can grow up to 15 m tall (see Section 3.1).

The unresolved taxonomy at the family level continues down to the genus level and there are inconsistencies in the number of sections and number of species proposed for inclusion in the genus *Musa.* This has largely been brought about by the domestication of the fruit-bearing cultivars and the subsequent temporal and genetic separation from the original species, as well as the widespread vegetative reproduction in the genus and natural occurrence of many hybrids (Heslop-Harrison & Schwarzacher 2007). Assigning Linnean binomials[1] to cultivated *Musa* is, in the opinion of some, meaningless and has resulted in such binomials being assigned to taxa that are now known to be

[1] The eighteenth century Swedish naturalist Carl Linnaeus devised a binomial system, still used today, for naming organisms; the name is formed by the combination of two 'Latinised' words: a) the genus name and b) the descriptive specific epithet (e.g. *Musa acuminata*).

well-defined hybrid groups or even cultivars (Constantine & Rossel 2008). For example, the sweet banana was assigned the binomial *Musa sapientum* by Linnaeus but it was shown later that the 'type' plant was, in fact, a cultivar of a complex hybrid (Cheesman 1948). A genome nomenclature was proposed in 1955 (Simmonds & Shepherd 1955) and later revised in 1987 (Silayoi & Chomchalow 1995). This system basically assigns a score for selected morphological features but also requires chromosome counts in order to assign plants to a genome group (Pillay et al. 2004). More recent revisions of classification have been based on molecular phylogenetic studies of the genus. The following discussion will provide a summary of the development in classification and provide the most recent information regarding species and cultivar naming where possible.

The number of sections[2] within *Musa* is between two and six. The World Checklist of Selected Plant Families (WCSP, website accessed 24/08/2016) lists 88 species (accepted names), some of which contain a number of subspecies and/or varieties. Cheesman (1947) first proposed the grouping of the genus *Musa* into four sections, with grouping based on morphological characteristics. *Eumusa* (now *Musa*, Wong et al. 2002) and *Rhodochlamys* sections containg species with 2n = 2x = 22. *Callimusa* and *Australimusa* sections contain species with 2n = 2x = 20.

One species, *M. ingens* from Papua New Guinea, with an 'anomalous' chromosome number (2n = 2x = 14) has been the subject of debate over its placement and has historically been placed in *Ingentimusa* Argent (1976). Debate has continued (Simmonds & Weatherup 1990; Daniells et al. 2001) and more recent studies have placed it in *Callimusa* (Häkkinen 2013). Constantine and Rossel (2008) list six sections: *Australimusa*, *Callimusa*, *Ingentimusa*, *Eumusa* (*Musa*) *1*, *Eumusa* (*Musa*) *2* and *Rhodochlamys*, but also suggest that this number of sections should be reduced if results of newer work are confirmed.

Using the results of amplified fragment length polymorphism (AFLP), an examination of the relationships among the sections *Musa*, *Rhodochlamys*, *Callimusa* and *Australimusa,* two sections, *Callimusa* and *Musa*, were proposed, based solely on chromosome number (Wong et al. 2002). In 2013, Hakkinen reviewed the classification of *Musa* species into two sections, based on the results of a number of molecular phylogenetic studies. The first includes species with chromosome numbers n = x = 11 from the (previous) *Musa* and *Rhodochlamys* sections, designated *Musa*. The second contains species with chromosome numbers n = x = 10/9/7 from the (previous) *Callimusa*, *Australimusa* and *Igentimusa* sections, designated *Callimusa* (Häkkinen 2013). That paper also provides a summary of *Musa* taxonomy.

A listing of species that may be considered as part of the *Musa* genus is given in Table 1. As there is still debate about the naming of some species and about the use of sections and/or 'minor' sections, species are grouped in the table by Section and 'Minor' section where this has been specified in the literature. This allows comparison of the species listed in the table with the discussion in the text. For species included in the WCSP list and not in the other references for this table, species are listed as "Not Specified" in the "Section" column.

Table 1. Indicative listing of the species in *Musa*[a].

Chromosome number	Section	'Minor' Section	Species	Main Distribution
2n=2x=14	*Callimusa*	*Ingentimusa*	*M. ingens*	Papua New Guinea
2n=2x=20	*Callimusa*	*Callimusa*	*M. azizii*	Borneo
			M. barioensis	Borneo
			M. bauensis	Borneo
			M. borneënsis[b]	Borneo
			M. campestris[b]	Indonesia, Borneo
			M. coccinea	China, Indonesia, Vietnam

[2] According to the International Code of Botanical Nomenclature, the term 'section' is a secondary rank that is applied below the genus level and above the species level.

Chromosome number	Section	'Minor' Section	Species	Main Distribution
			M. exotica	Vietnam
			M. gracilis	Malaysia
			M. lawitiensis[b]	Borneo
			M. paracoccinea	China, Vietnam
			M. sakiana	Borneo
			M. salaccensis	Indonesia
			M. splendida	Vietnam
			M. violascens	Malaysia
		Australimusa	*M. alinsanaya*	Philippines
			M. beccarii[b]	Borneo
			M. boman	Papua New Guinea
			M. bukensis	Papua New Guinea
			M. fitzalaniia	Australia
			M. hirta	Indonesia, Borneo
			M. insularimontana	Taiwan
			M. jackeyi	Australia
			M. johnsii	Papua New Guinea
			M. lolodensis	Papua New Guinea
			M. maclayi[c]	Papua New Guinea
			M. monticola	Borneo
			M. muluensis	Borneo
			M. peekelii[d]	Papua New Guinea, Philippines
			M. textilis	Philippines, Brunei, Moluccas
			M. tuberculata	Borneo
			M. troglodytarum[b]	New Guinea
			M. viridis	Vietnam
			M. voonii	Borneo
		Not specified[e]	*M. arfakiana*	New Guinea
			M. haekkinenii	Vietnam
			M. juwiniana	Borneo
			M. lokok	Borneo
			M. lutea	Vietnam
			M. viridis	Vietnam
2n=2x=22	*Musa*	*Musa*	*M. acuminata*[c]	India, Indonesia, Malaysia, Philippines Sri Lanka, Thailand, Vietnam, Australia
			M. balbisiana[b]	Philippines, Bhutan, China, India, Vietnam, Papua New Guinea, Sri Lanka
			M. banksii	Australia, PNG, Samoa
			M. basjoo[b]	Japan, China
			M. cheesmanii	India
			M. flaviflora	Bangladesh, Bhutan, India
			M.griesonii	Bhutan
			M. itinerans[b]	China, India, Thailand, Vietnam
			M. nagensium	China, India, Thailand
			M. x paradisiaca	Widespread
			M. ochracea	India
			M. schizocarpa	Indonesia, Papua New Guinea
			M. sikkimensis	Bangladesh, Bhutan, India, Thailand
		Rhodochlamys	*M. aurantiaca*[b]	India
			M. laterita	India, Burma, Thailand
			M. mannii[b]	India

Chromosome number	Section	'Minor' Section	Species	Main Distribution
			M. ornata	Bangladesh, Burma, India, Borneo
			M. rosea	Bangladesh, Burma
			M. rubra	Burma, India
			M sanguinea	Northern India, Burma, China
			M. thomsonii	India
			M. velutina[d]	Northern India
			M. viridis	Vietnam
		Not specified[e]	*M. celebica*	Indonesia
			M. chunii	China
			M. insularimontana	Taiwan
			M. kattuvazhana	India
			M. lanceolata	Indonesia
			M. rubinaea	China
			M. shankarii	India
			M. siamensis	Thailand
			M. tonkinensis	Vietnam
			M. yamiensis	Taiwan
			M. yunnanensis[b]	China
			M. zaifui	China
Not specified[f]			*M. argentii*	India
			M. arunachalensis	India
			M. corneri	Malaysia
			M. cylindrical	India
			M. inandamanensis	Andaman Islands
			M. kamengensis	India
			M. markuii	India
			M. nagalandiana	India
			M. nanensis	Thailand
			M. puspanjaliae	India
			M. rubida	Malaysia
			M. ruiliensis	China
			M. sabuana	Andaman Islands
			M. serpentina	Thailand

[a] Species included in the list are those specified as 'accepted names' in the WCSP database (Govaerts 2016). Further information is included from (Simmonds & Weatherup 1990; INIBAP 2000; Sharrock 2000a; Häkkinen & Sharrock 2001; Pollefeys et al. 2004; Ploetz et al. 2007; Constantine & Rossel 2008; Häkkinen 2013).
[b] These species are listed in WCSP as containing a number of distinct varieties
[c] These species are listed in WCSP as containing a number of subspecies and distinct varieties
[d] These species are listed in WCSP as containing a number of subspecies
[e] Species listed in Häkkinen (2013) as section *Callimusa* or *Musa*, with no 'minor' sections
[f] Species listed in WCSP. No section is listed when the search is performed. If required this information may be sought from original refrences for each species

There are two species native to Australia (see Section 8) - *M. acuminata* subsp. *banksii*[3] and *M. jackeyi* - with a third species, *M. fitzalanii* thought to exist only as a herbarium specimen (Ross 1987; Pollefeys et al. 2004). The Australian bush food commonly known as 'Bush Banana' (*Leichardtia australis*) is not related to *Musa*.

Sections *Callimusa* and *Rhodochlamys* consist of non-parthenocarpic species that have no nutritionally valuable fruits and are important only as ornamentals (Pillay & Tripathi 2007; Constantine & Rossel 2008). *Australimusa* species are noted as useful for fibre and fruit, *Eumusa* (*Musa*) 1 and *Eumusa* (*Musa*) 2 as fruit, vegetable, wrapping and ornamental (Constantine & Rossel 2008). Most of the cultivated sweet bananas and plantains belong to the Section *Musa* and are

[3] Identified more recently as *M. banksii* (Govaerts 2016)and included in Table 1 under this name.

triploid varieties that evolved from two wild diploid species, *M. acuminata*, given the genome designation 'AA', and *M. balbisiana*, given the genome designation 'BB' (Simmonds & Shepherd 1955).

The formation of homogenomic triploid (2n=3x) hybrids with the AAA genotype occurred within *M. acuminata* (see Section 2.1) leading to the development of cultivars that mostly comprise the sweet bananas (Daniells et al. 2001). Examination of chloroplast DNA of *Musa* spp. has suggested that the origin of the edible banana cultivars is linked particularly to two sub-species of *M. acuminata*, namely *M. acuminata* subsp. *banksii* (*M. banksii*) and *M. acuminata* subsp. *errans* (Horry et al. 1997).

Crosses of the diploid and triploid types of *M. acuminata* with *M. balbisiana* led to the formation of heterogenomic triploid hybrids that are mostly plantains (AAB genotype) and other cooking bananas (ABB genotype). Tetraploid (2n=4x) and other diploid combinations also exist (Pillay et al. 2004). Hybrids of *M. acuminata* and *M. balbisiana* can be referred to as *Musa x paradisiaca*[4] (Espino et al. 1992; Appendix 1, Aticle H2 in IAPT 2012). The use of isozymes and molecular markers has confirmed the multi-specific origin of edible bananas (Visser 2000). Studies using restriction polymorphisms of the chloroplast and mitochondrial DNA suggest that species of the section *Rhodochlamys* may constitute a secondary genepool for the improvement of cultivated bananas (Nwakanma et al. 2003).

Simmonds and Shepherd (1955) suggested that genome nomenclature was more appropriate for naming taxa and proposed that the generic name be followed by a letter combination indicating the ploidy and the genome sets, followed by the cultivar/cultivar group[5] name (Table 2). The reference from which the table is derived focusses on Pacific Island cultivars (Ploetz et al. 2007). The cultivars in each subgroup show little genetic diversity and are derived from each other through somatic mutations (Horry et al. 1997). Genome group AAB subgroup Pome represents the cultivar that makes up about 4% of Australian production. Dwarf Cavendish is the most widely distributed clone of edible banana worldwide (Ploetz et al. 2007).

[4] The prefix 'x' in front of the epithet indicates the hybrid nature of the species

[5] The word 'cultivar' is a contraction of 'cultivated variety' and describes a group of cultivated plants within a species that are significant in agriculture, forestry or horticulture and have clearly distinguished, heritable characteristics. 'Cultivar' is synonymous with the term 'variety'. However it is not analogous with the category 'botanical variety' that is used to refer to naturally occurring variants within a species (Hartmann & Kester 1975). Cultivars/varieties mentioned in this document are indicated in quotation marks eg. 'Cavendish'.

Table 2. Examples of genome nomenclature for common edible banana cultivars[a]

Genome Group	Subgroup (Cultivar)[b]	Clone Set[b,c]	Examples of other common cultivar names[b]
AA	Inarnibal	Inarnibal	Pisang Lemak
	Lakatan	Lakatan	Pisang Berangan, Phayan
	Pisang Lilin	Pisang Lilin	Lidi, Pisang Lidi
	Sucrier	Sucrier	Lady's Finger, Amas, Caramelo
AB	Kamarangasenge	Sukari Ndizi	Sukali Ndizi, Kamarangasenge
	Ney Poovan	Ney Poovan	Lady's Finger
AAA	**Cavendish**	**Giant Cavendish**	**Williams, Mons Mari, Tall Mons Mari, Williams Hybrid**
		Dwarf Cavendish	**Dwarf Cavendish**
		Extra Dwarf Cavendish	**Dwarf Parfitt**
		Pisang Masak Hijau	Hamakua', Bungulan, Lacatan
		Grande Naine	Umalong, Pisang Ambon Jepang
		Double	Dwarf Chinese
	Gros Michel	Gros Michel	Bluefields, Jainabalavau
		Cocos/Highgate	Cocos/Highgate
		Lowgate	Lowgate
		Ibota	Yangambi Km5
		Mutika/Lujugira	Beer, Musakala
	Red	**Red**	**Red Dacca**
		Red Green	**Green Dacca, Red Raja**
AAB	Iholena	Fa'I Mamae	Fa'I Mamae, Mama'e Ulu'
		Iholena Iholena	Iholena Iholena, Iholena Ha'a H'a'
		Iholena Kāpua	Puapuanui
		Iholena Lele	Iholena Lele
	Maoli-Pōpōulu[d]	**Pacific Plantain**[e]	**Pacific Plantain**, Comino, Pompo
	Mysore		**Mysore**, Misisluki, Pisang Keling
	Pisang raja	Pisang Raja	Pisang Raja, Larip, Houdir
	Plantain	French	Obino l'Ewai', Njock Kon
		French Horn	Mbang Okon
		False Horn	Agbagba, Ordishele
		Horn	Ishitim, Pisang Tandok
	Pome	**Pome**	**Lady's Finger, Improved lady's Finger**
		Prata Aña	Dwarf Apple, Dwarf Brazilian
		Pacovan, Pacha Naadan	**Improved Lady Finger**
	Silk	Silk	Sugar, Amarosa, Manzano
ABB	**Bluggoe**	**Bluggoe**	**Square Cooker**, **Mondolpin**
		Dwarf Bluggoe	Chamaluco Enano, Cachaco Enano
		Silver Bluggoe	Katsila, Silver Moko
	Monthan	Nalla Bontha Bathees	
		Monthan	Maduranga, Pisang Abu Bujal
		Sambrani Monthan	
		Pacha Montha Bathees	
	Klue Teparod	Kluai Tiparod	Pisang Abu Siam, Kluai Teparod
	Ney Mannan	**Ney Mannan**	**Blue Lubin**, **Blue Java**
	Pelpita	Pelpia	Pilipia
	Pisang Awak	**Pisang Awak**	**Ducasse**, Kluai Namwa, Choui Tay
	Saba	Benedetta	Benedetta, Inabaniko
		Cardaba	Cardaba
		Saba	Saba, Pisang Kepok
AAAB		FHIA[f]	FHIA-01d (Goldfinger); FHIA-18 (Bananza)

[a] Information adapted from (Ploetz et al. 2007) and from ProMusa website, Banana Cultivar Checklist. Cultivars grown in Australia are highlighted in **bold**

[b] Subgroups are names given to a group of commonly grown cultivars. Those included are the cultivars listed by the author as the more important cultivars of the genome. Clone set (terminology from Promusa varieties list – see text below) is the main name listed for a cultivar, examples of common names include a selection of (often regional) alternative cultivar names. Where appropriate, Australian cultivar names are given. For full lists see Ploetz et al 2007.
[c] Main cultivar names, examples are members of this cultivar with regional specific names
[d] Contains Maoli and Pōpōulu subdivisions, each with many cultivars with many common names; see Ploetz 2007 for full list.
[e] In the Maoli subdivision
[f] FHIA = varieties bred at the Fundación Hondureña de Investigación Agrícola in Honduras

Naming of cultivars can be confusing, for example the name 'Lady ('s) Finger' has been used to name several distinct AA, AB and AAB clones. The Banana Cultivar checklist (Promusa sourced 26/08/2016) lists 6966 entries, which are classified by local name (common cultivar name), cultivar, clone set-cluster and subgroup. This list is designed to show synonyms (different names for the same clone) and homonyms (similar names referring to different clones) to assist in clarifying a complex taxonomy (PROMUSA 2016a).

The complexity of the composition of genomic groups meant that an estimate of the genome size of *Musa* was given as a range. Pillay et al. (2004) suggested this range lies between 550 and 612 Mbp[6], a relatively small size. An analysis of the organisation of the banana genome was performed through sequencing of bacterial artificial chromosome (BAC) clones (Aert et al. 2004; Cheung & Town 2007). BACs can accommodate large quantities of inserted DNA cloned from an organism and a physical map of overlapping BAC clones can span an entire chromosome. A comprehensive discussion of *Musa* genomics can be found in Heslop-Harrison & Schwarzacher (2007). More recent work has sequenced the genome of DH-Pahang, a doubled-haploid *M. acuminata* genotype of subsp. *malaccensis.* This work has produced a draft sequence for the 523 Mbp genome (D'Hont et al. 2012).

SECTION 2 ORIGIN AND CULTIVATION

2.1 Centre of diversity and domestication

The precise origin of edible bananas is not known but the generally accepted theory is that Malesia, a biogeographical region including the Malay Peninsula, Indonesia, the Philippines and New Guinea, was the primary centre and India was a secondary centre (Simmonds & Shepherd 1955). It is likely that dispersal out of Asia was linked entirely to human movement (Daniells et al. 2001).

The modern day edible bananas are a mix of wild and cultivated, species and hybrids associated with *M. acuminata* and *M. balbisiana*. *M. acuminata* is the most widespread of the species in section *Musa* (Daniells et al. 2001) and the centre of diversity is thought to be either Malaysia (Simmonds 1962) or Indonesia (Horry et al. 1997). Some of the primitive edible seeded diploids of this genus evolved through the development of sterility, parthenocarpy and fleshy seedless fruits (Simmonds 1959a). The genetic basis of parthenocarpy in *M. acuminata* has not been characterised (Heslop-Harrison & Schwarzacher 2007). Clones of the diploids were cultivated in wetter parts of Southeast Asia (Valmayor et al. 2000) and the development of vigorous seedless triploid cultivars was the result of chromosome restitution (Raboin et al. 2005) and/or crosses between edible diploids and wild *M. acuminata* (Daniells et al. 2001).

Edible diploids of *M. balbisiana* underwent a parallel evolution in drier parts of Asia (India, Myanmar, Thailand, Philippines) but there was some geographical overlap with *M. acuminata* (perhaps resulting from human movement of cultivars) and hybrids of the seeded types were produced (Valmayor et al. 2000; Daniells et al. 2001). The Indian subcontinent was a major centre for hybridisation (Daniells et al. 2001). The result of the parallel evolution and subsequent hybridisation of the two species was the occurrence of the range of genotypes described in Section 1

[6] The amount of DNA in the nucleus of a eukaryotic cell is expressed as the total number of base pairs (bp) in a haploid (1C) chromosome complement.

(i.e. homogenomic and heterogenomic diploids, triploids and tetraploids). The genomes of the two species contributed different traits, with *M. acuminata* largely contributing parthenocarpy and sterility (Simmonds & Shepherd 1955) and *M. balbisiana* contributing hardiness, drought tolerance, disease resistance and starchiness (Pillay et al. 2002). Most of the cultivars of the edible bananas derive from collections of spontaneous mutants in wild plants that were then brought into cultivation and multiplied vegetatively. The hybridisation events and mutations have occurred many hundreds of times over (Heslop-Harrison & Schwarzacher 2007).

East Africa and West Africa represent two main secondary centres of *Musa* diversity as a result of a long history of cultivation in these regions (De Langhe 1995). There are approximately 60 cultivars of African Highland bananas unique to East Africa but it is not known whether these derived from traded plants (maybe 2,000 years ago) or from indigenous edible diploids (De Langhe 1995; Daniells et al. 2001). These Highland bananas have the AAA genotype (Karamura 1998). It is thought that plantains reached West Africa 3,000 years ago and that they may have initially been propagated for their starchy corms and/or fibres rather than for their fruit. Vegetative propagation eventually led to the evolution of fleshy, seedless fruits that were edible (De Langhe 1995).

Another secondary centre of diversity is Polynesia to where the 'Maia Maoli/Popoulu' cultivars (thought to be AAB hybrids) were carried from the Philippines more than 4,000 years ago (De Langhe 1995).

A brief history of the domestication of banana is given by De Langhe (1995). It is claimed that there was written (Sanskrit) reference to bananas as early as 500 BC (De Langhe 1995). It is thought that traders from Arabia, Persia, India and Indonesia distributed banana suckers around coastal regions (except in Australia) of the Indian Ocean between the 5th and 15th centuries. From the 16th to 19th centuries, suckers were traded by the Portuguese and Spanish in tropical America. Further world trade saw the establishment of bananas in Latin America and the Caribbean. Today the cultivation of bananas occurs throughout the tropics and sub-tropics of Asia, America, Africa and Australia.

The most widely distributed banana cultivar is 'Dwarf Cavendish' (Ploetz et al. 2007). It is likely that this was not derived from a single plant but is a group of clones derived by mutation from tall members of the Cavendish subgroup (Constantine & Rossel 2001). Dwarfism is a commonly occurring mutation of Cavendish (see Section 2.3.1). With regard to the 'Dwarf Cavendish' cultivar, which was brought to Australia (see Section 2.3) and became the basis of the Australian industry (see Section 2.3.2), it is thought that the original plants were first obtained in approximately 1826 from southern China by Charles Telfair and taken to Mauritius (Marin et al. 1998). From here, some plants were then taken to England and, several years later, derivatives from these were sold to the Duke of Devonshire (Lord Cavendish) who continued to propagate them in his glasshouses. In 1836, the resulting plants were formally given the varietal name 'Cavendish'. John Williams, a missionary, took suckers from England to Samoa in 1838 and from here the cultivar was spread to Tonga and Fiji in the 1840s (Marin et al. 1998). Plants were probably taken from the Pacific Islands to the eastern coast of Australia in the 1850s (see Section 2.3).

2.2 Commercial uses

The fruit is the main product of the banana plant and bananas are the developing world's fourth most important food crop after rice, wheat and maize (INIBAP 2000). Millions of small-scale farmers in Africa, South Asia and Northern Latin America grow the fruit for household consumption and/or local markets. Uganda is the second largest producer of bananas, with 75 % of farmers growing bananas, the staple food. Daily consumption of bananas in Uganda is estimated at close to 1 kg, mainly cooking bananas (PROMUSA 2016b). The majority of bananas grown in Uganda are East African Highland cultivars used for cooking and brewing (Karamura 1998).

Total world production of bananas in 2013 was 107.4 million tonnes and 37.9 million tonnes of plantains (FAO 2016). Bananas and plantains are produced in approximately 135 countries, with less

than 15 % of the total (bananas and plantains combined) producton exported (PROMUSA 2016j). The two major sweet banana producing countries are India and China, but neither of these exports significant quantities (see Table 3). By comparison Ecuador, the fifth largest producer, exported approximately 87% of its bananas in 2013 (Table 3) and is the largest supplier of sweet bananas to world trade (Table 4). The major importers of sweet bananas are the European Community and the USA (Table 5).

Table 3. Major sweet banana producing countries in 2013[a]

Country	Production in 2006 (x1,000 tonnes)	% of bananas exported
India	27,575.0	0.1%
China (mainland)	12,075.2	<0.1%
Philippines	8,645.8	38%
Brazil	6,892.6	0.1%
Ecuador	5,995.5	87%

[a] Data source: FAOStat, accessed 08/08/2016(FAO 2016)

Table 4. Major sweet banana exporting countries in 2013[a]

Country	Export (x 1,000 tonnes)
Ecuador	5,352.0
Philippines	3,267.6
Guatemala	1,950.5
Costa Rica	1,928.1
Colombia	1,549.3

[a] Data source: FAOStat, accessed 08/08/2016 (FAO 2016)

Table 5. Major sweet banana importing countries in 2013[a]

Country	Import (x1,000 tonnes)
USA	4547.9
Germany	1344.1
Russian Federation	1339.1
Belgium	1275.3
UK	1140.0

[a] Data: FAOStat, accessed 08/08/2016 (FAO 2016)

In the early 20th century, the principal sweet banana traded was the cultivar 'Gros Michel' (INIBAP 2000). A Panama Disease outbreak (caused by the fungus *Fusarium oxysporum* f. sp. *cubense* (Foc) – see Section 7.2) that occurred in commercial plantations around the world in the early 1940s caused this highly susceptible cultivar to be gradually replaced from 1960 by more disease-resistant cultivars of the Cavendish sub-group (INIBAP 2000). Today these cultivars represent approximately 40 - 50% of the bananas that are grown worldwide and almost all of bananas traded on the world market (Arias et al. 2003). However, a new race of the *Fusarium* fungus (named Tropical Race 4 – abbreviated to FocTR4) to which the Cavendish sub-group is susceptible has now evolved. This has affected plantations in a number of countries (PROMUSA 2016f) and will be discussed in more detail in Section 7.2.2. It is possible that Cavendish cultivars will eventually lose dominance of world trade if resistant varieties from outside the Cavendish subgroup can be found.

The banana fruit can be eaten raw or cooked (e.g. deep fried, dehydrated, baked in the skin, steamed), can be processed into flour and can be fermented for the production of beverages such as banana juice, beer (e.g. *mbege* brewed by the Chagga people in the Kilimanjaro region of Tanzania), vinegar and wine (Morton 1987; Pillay et al. 2002; Nelson et al. 2006; Edmeades et al. 2006; Pillay & Tripathi 2007). The nutritional characteristics of the fruit are discussed in Section 5. Other parts of the banana plant are also eaten (Espino et al. 1992). For example, the flower is eaten raw or cooked in Southeast Asia; the core of the pseudostem (trunk) is used for cooking in Burma and Bengal; leaf

buds are eaten as a vegetable (Nelson et al. 2006). The corm is a source of starch and has been eaten in times of famine in Africa and Asia (De Langhe 1995). All parts of sweet banana/plantain plants, but particularly the fruits, have also been used to feed livestock in those parts of the world where there is excess production (Babatunde 1992). Ashes obtained from burning banana leaves are used as flavouring for curries and a salt substitute in India (Nelson et al. 2006).

Banana leaves have a variety of practical uses including wrapping for food, plates for serving food, polishing floors, thatching (Espino et al. 1992; Nelson et al. 2006). Fibres obtained from the pseudostem are used for making cloth (Espino et al. 1992; Nelson et al. 2006) and leaf fibres are utilised in string, cordage and rope (Nelson et al. 2006). Plants in the section *Australimusa* are an important source of fibres, particularly Abaca/Manila hemp (from *M. textilis*) (Horry et al. 1997). Manila hemp, until the advent of the first synthetic fibres, was used in the manufacture of marine ropes because of its strength, lightness and water-resistance. Today it is used mainly in the paper making industry where its long staple length, strength and cellulose content, make it useful in specialised papers including tea and coffee bags, sausage casing paper, currency notes, cigarette filter papers, medical/ disposal papers and some high-quality writing paper (Wigglesworth 2007).

The sap of banana plants, particularly the Fe'i cultivars that have a distinctive reddish-violet sap (Sharrock 2000b), has been used as a dye and ink (Nelson et al. 2006; Pillay & Tripathi 2007). Various parts of the plant are also used, particularly in Pacific cultures, for medicinal purposes. Root sap can be used to treat mouth thrush in children and skin warts. Banana peel has been found to have antibiotic properties (Nelson et al. 2006).

2.3 Cultivation in Australia

The earliest record of bananas being grown in Australia was in the early to mid 1800's near Carnarvon in Western Australia (ABGC 2016c). The plants were thought to have been brought from China by migrants. Bananas had been growing in China since approximately 200 AD (Simmonds 1959a) and the 'Dwarf Cavendish' cultivar that has become the major banana traded globally came from Southern China via Mauritius, England and Fiji (see Section 2.1). It is likely that introduction of 'Dwarf Cavendish' to Queensland (Qld) occurred with the drafting of cane cutters from Fiji and other Pacific islands in the 1870's as well as through Chinese migrants (ABGC 2016c). 'Lady Finger' and 'Sugar' bananas were also introduced from the Pacific islands (Daniells 1986). These accessions were initially made for ornamental purposes only and the first sweet banana fruits traded commercially were actually imported from Fiji to Sydney. The early Australian banana trade was dominated by Chinese merchants many of whom owned plantations in Fiji (Couchman 2005). When tariffs on imported bananas were raised, these same Chinese merchants promoted the further establishment of banana plantations in northern NSW and by 1919 they owned or managed some 500 acres around the Mullimbimby area (Pearson et al. 2002). This area had originally been planted commercially with bananas after 1891 when Herman Reich introduced the 'Dwarf Cavendish' cultivar to Kororo and the Coffs Harbour area. The growing region was subsequently expanded north to Woolgoolga and the Clarence, Richmond, Brunswick, and Tweed River regions in northern NSW (ABGC 2016c). By the 1960s, when NSW was producing 80 per cent of the nation's bananas, the industry in this region had reached its peak (Coffs Harbour City Council 2003). Since then it has declined as major plantings have been developed in northern Qld (see Section 2.3.2).

Other areas of eastern Australia also became centres for banana production at various times. In the 1880s in northern Qld, Chinese workers from the Palmer River goldfields established fruit-growing industries, including bananas, around Cooktown, Port Douglas, Cairns and Geraldton (later Innisfail) (Pearson et al. 2002). The Widgee Shire (around Gympie in Qld) was the largest banana producing area in Australia between 1918 and the early 1930's but then declined with the infestation of rust thrip and the increased commercial competition from other regions, particularly in northern NSW (Cooloola Shire Library Service 2001).

Somatic mutations occur relatively frequently in bananas (see Section 2.3.1) and two cultivars now widely grown in Australia were thought to arise in this way (Daniells 1986). 'Williams', a giant form of the 'Dwarf Cavendish', is thought to have appeared as a mutation in a 'Dwarf Cavendish' plantation in the Clarence Valley of northern New South Wales (NSW) in the early 1900s. 'Mons Mari' arose as a mutation in a 'Dwarf Cavendish' plantation called Mons Mari (Mountain by the Sea) near Buderim in south east Qld in about 1910. The two cultivars were traded between NSW and Qld but, as there is very little difference between them, it has been suggested that the cultivar name is only of academic interest (Daniells 1986). Over the years a number of somatic mutations within 'Williams'/'Mons Mari' and 'Lady Finger' have led to further selections within these cultivars with characters such as pseudostem colour and height, and finger shape being altered (Daniells 1986).

Temperature is an important factor in successful commercial banana production, with the optimum temperature being approximately 27^{o} C and poor fruit production occurring if the temperature drops below 15^{o} C (Espino et al. 1992). A banana crop requires 20 – 60 mm of rainfall (or irrigation) per week at bunching, with water requirements varying due to environmental conditions, growth stage and irrigation efficiency (QDAF 2012d). Today, commercial banana plantations are found in the same areas as commercial papaya plantations (OGTR 2008) and Qld accounts for most of Australia's production – approximately 97% based on 2014/15 data (ABS 2016). Approximately 95% of banana production in Australia is in districts around Cairns and north in areas near Cooktown. Other production areas are south eastern Qld, northern NSW, WA and the Northern Territory (NT - Figure 1) (ABGC 2016b). Home gardeners as far south as Melbourne can grow fruit-bearing plants under sheltered conditions (Baxter 1997).

[Source: Biosecurity Australia (2007)]

Figure 1. Commercial banana growing areas in Australia as defined by Local Government Areas

2.3.1 Commercial propagation

Most sweet banana cultivars are effectively sterile and hence are propagated vegetatively from sections of the corm (called 'bits') containing unopened buds (or 'eyes'), or from suckers that are

young shoots (Morton 1987; Espino et al. 1992). For a detailed description of the morphology of the banana plant see Section 3.

Two tissue culture techniques have been used to propagate banana plants:

- Micropropagation is used worldwide and more bananas are micropropagated than any other fruit crop (Smith et al. 2005). However, the cost of micropropagated plants is relatively high and often prohibitive to growers in developing countries (Escalant & Jain 2004). The procedures used for micropropagation of bananas have been extensively reviewed (Vuylsteke 1989; Israeli et al. 1995; Smith et al. 2005). In Australia, in the mid 1990s, the Qld Department of Primary Industries and Fisheries (QDPI&F – now QDAF) established a banana clean planting scheme based on virus indexed tissue cultured plants. This tissue culture facility at Nambour (on the Qld Sunshine Coast) is one of only three globally recognised banana virus-indexing centres.
- Somatic embryogenesis in cell suspension cultures has now been scaled up to bioreactor stage for some cultivars (Kosky et al. 2002; Kosky et al. 2006). See Section 2.4.2 for further details about somatic embryogenesis.

Bits are usually obtained from plants growing in a designated planting material nursery (Broadley et al. 2004; QDAF 2012a) that has been established in clean ground (ideally, virgin land) from clean planting material (ideally, micropropagated plants). A number of pests and diseases (see Section 7.2) are easily transmitted via infected vegetatively propagated material and planting material nurseries can reduce or eliminate such transmission. In Australia strict controls on the movement and planting of banana plants are imposed to prevent the spread of banana diseases.

The nursery is ready for 'digging' just before plants reach fruiting and hence when there are high carbohydrate reserves in the corm (Morton 1987; Broadley et al. 2004). The pseudostems are removed at approximately 20 cm above ground and the 'butt' (entire corm) is then uprooted. A number of bits, each containing a bud on a cube of corm, are cut out of each butt, formed suckers down to 250 g may also be removed. These parts can then be transported to the plantation 'blocks' for planting. Bits grow slowly at first but eventually catch up to plants grown from suckers (Morton 1987). Preparation of bits and suckers is labour-intensive and also requires specialist skills (Broadley et al. 2004).

In Australia it is common for planting material to be sourced directly from hardened-off micropropagated plants rather than using bits or suckers. Virus-indexed micropropagated plants produce high plant yields and uniform crops, and can improve plantation cycle management (Smith et al. 2005). Their use as the preferred planting material is recommended (Broadley et al. 2004; Smith et al. 2005). However, there have been problems with somaclonal variation[7] occurring in micropropagated banana plants with off-type frequencies as high as 100% being reported in tissue culture plantings of 'Lady Finger' (Genome type AAB, Pome subgroup) in north Qld in 1991 and 1992 (Smith et al. 1999). Most of the off-types in the Cavendish subgroup manifest as either 'dwarf' or 'giant' (Khayat et al. 2004). Dwarfism is the most common off-type (Bairu et al. 2006) and plants not only have short stature but also manifest problems with the fruit including choking (where the bunch fails to emerge fully from the plant), closely packed hands and short finger length (Smith & Drew 1990). In the Australian 'Lady Finger' cultivar the most common off-type has slow growth, poor bunch size and unmarketable fruit (Smith et al. 1999). There is evidence that the rate of somaclonal variation is related to length of time spent in tissue culture and high multiplication rates associated with the use of high concentrations of the cytokinin benzylamino purine in the culture medium (Damasco et al. 1998; Sahijram et al. 2003; Bairu et al. 2006). As a result, there have been recommendations that the number of subculture cycles be limited to eight or that the number of

[7] Somaclonal variation is a term coined (Larkin & Scowcroft 1981) to describe phenotypic variation in tissue cultured plants that would normally not be expected to show any variation. It can be genetic or epigenetic in origin (Sahijram et al. 2003). It is more usually associated with plants regenerated from callus and cell culture than with plants derived from micropropagation (Smith 1988).

plants produced from a primary explant be limited to less than 1,000 (Sahijram et al. 2003). A number of other factors (e.g. genotype, primary explant source, ploidy level, karyotype changes, post-transcriptional events, transposable elements) may also contribute to the rate at which somaclonal variation occurs but the precise mechanism leading to its occurrence in bananas is unknown (Smith 1988; Damasco et al. 1998; Sahijram et al. 2003). Both morphological and molecular screening techniques have been successfully used to identify somaclonal variants at an early stage (Smith & Hamill 1993; Damasco et al. 1996; Smith et al. 1999; Sahijram et al. 2003; Ramage et al. 2004). A major problem with molecular screening has been that off-types are detected by the absence rather than presence of a band; this problem has been overcome by the development of a PCR test containing a positive internal control (Ramage et al. 2004).

Little information is available on the occurrence of somaclonal variation in banana plants derived through somatic embryogenesis although one study suggests that the rate for the cultivar FHIA-18 is very low (Kosky et al. 2006).

Both Qld and NSW have adopted the Queensland Banana Accredited Nursery (QBAN) system that provides both vegetative and tissue cultured planting material. The QBAN scheme includes monitoring and recording of all aspects of the propagation process to ensure 'traceable clean planting material that is free of targeted pests' (PHA & Queensland DEEDI 2009). There are legal resitrictions on the movement of banana material and banana pest carriers (such as soil and equipment used in banana production) in the states and territories. These are important in the control of banana pests and diseases and more information is provided in Section 7.2 of this document.

2.3.2 Scale of cultivation

The majority of bananas grown in Australia are produced for local consumption with over five million bananas consumed daily (ABGC 2016b). Approximately 95% of Australian production is Cavendish varieties, with the remainder including Lady('s) Finger, Goldfinger, Ducasse, Red Dacca, Sucrier and Pacific Plantain (HAL 2014), with Cavendish making up 90% of Qld production and Lady Finger 4% (Queensland Government 2015). .

North Qld, which now provides most of Australia's bananas, is prone to natural disasters such as cyclones and floods, which greatly influence continuity of supply. On 20 March 2006, Cyclone Larry crossed the north coast of Qld near Innisfail causing major damage (approximately 80% of the banana crop was destroyed) in the area between Cairns in the north and Cardwell in the south. This area is where 70% of Australia's commercial banana crop is grown (QDAF 2014). The result was the loss of harvestable fruit for approximately 9 months and the potential for an unwanted degree of synchonisation of the crop cycle as plantations came back into production. Staggered plantings partially overcame this. It is estimated that when Tropical Cyclone Yasi crossed the Qld coast near Mission Beach (between Cardwell and Innisfail) in February 2011, approximately 75 % of Australian production was affected and shortages continued until late 2011 (HAL 2014). Banana production declined from 265,570 tonnes in 2004/05 to 187,384 tonnes in 2005/06 following Cyclone Larry, and then increased in the following years to a peak of 302,173 tonnes in 2009/10. Following Cyclone Yasi, production declined in 2010/11 to 202,751 tonnes before increasing again in the following years (Source: ABS Agricultural Commodities 7121.0, reports from 2006-2016).

The Australian Bureau of Statistics (ABS) Agricultural Commodities data for 2014/15 provides data for the production area, production volume and number of producers for the Australian banana industry (Table 6).

Table 6. Banana production data for Australia 2014/15[a]

Production Area	Production (t)	Area (ha)[b]	Average Yield (t/ha)	Number of properties[c]
Australia	252,024	11,788	23.0	595
Qld	243,823	10,101	25.8	253
NSW	1,119	5,769	5.4	274
NT	7	155	-	4
WA	2,425	7.5	63	63
Victoria[d]	n/a	9	n/a	n/a

[a] Data source: Australian Bureau of Statistics (ABS 2016)
[b] Total area, includes area with crops of bearing age and areas with crops of non-bearing age
[c] Total number of properties, not all properties have crops of bearing age (ie. no production)
[d] Small experimental planting areas, not of bearing age
- Data unreliable (ABS)

In 2005, prior to Cyclone Larry, Australia had approximately 1,850 banana growers (ABGC 2007). Current data indicates there are approximately 600 properties in the Australian banana industry (ABS 2016), as shown in Table 6. A summary of the major production areas is given in Table 7.

Table 7. Banana production areas in Australia in 2005[a]

Area	*Climatic type*[b]	*Predominant soil types*	*Topography*	*Irrigation*
North Qld (Babinda to Cardwell)	Tropical rainforest	Light to medium alluvial clays	Floodplains	Under canopy in dry season
		Basaltic krasnozems	Undulating slopes	
South-east Qld (Bundaberg to Qld border)	Sub-tropical (no dry season)	Podsolic clays or shales	Wind protected, frost-free slopes	May irrigate in drier periods
Northern NSW (Qld border to Coffs Harbour)	Sub-tropical (no dry season)	Basaltic krasnozems	Plateau	May irrigate in drier periods
Humpty Doo (near Darwin, NT)	Tropical rainforest	Sandy loams	Tops and slopes of plateaus	May irrigate in drier periods
Kununurra (north-eastern WA)	Grassland (winter drought)	Sandy loams	Plains and higher land of sandstone ridges	May irrigate in drier periods
		Cracking clays	River banks and levies	
Carnarvon (mid west coast of WA)	Desert (summer drought)	Sandy loams	Alluvial floodplain	Year round irrigation is essential

[a] Information compiled from Biosecurity Australia (2007)
[b] Koeppen Classification system taken from Australian Government Bureau of Meteorology website (Climate classifications)

2.3.3 Cultivation practices

Practices vary widely across Australia's commercial plantations depending on the climatic conditions, environmental conditions, cultivar and scale of production. Basically the grower has the choice, each season, of replanting from virus indexed material (see Section 2.3.1) or allowing each plant to 'ratoon' - whereby the pseudostem that has just borne fruit is cut down and is replaced by a sucker from the corm (see Section 4.5). Windbreaks are recommended in wind prone areas. Generally slopes of less than 15% are preferred; this reduces the chance of soil erosion and trapping of cold air, improves flexibility in the plantation layout and facilitates mechanisation (Broadley et al. 2004) (see Section 6 for a more detailed discussion of abiotic considerations in the growth of commercial plantations).

Considerable detail about cultivation practices in Australia is covered in a publication available from Queensland Department of Agriculture and Fisheries (QDAF - Broadley et al. 2004). A Best Management Practice manual was produced in 2013 which provides further information on industry practices (King 2013). The more important points are considered below.

Plantations in the tropical north of Australia tend to be cut down and replanted every two to three years whereas in more southerly areas it is not uncommon for plantations to be ratooned for up to 15 years, with an average of five to seven ratoon cycles (Broadley et al. 2004). A number of factors contribute to the decision on how many ratoons to use, including the extent that mechanisation can be utilised (Robinson 1995). In north Qld, most plantations are on flat land and hence mechanisation is high. As ratoon numbers increase, the spatial arrangement of plants becomes less ordered so that machine access can be hampered (Robinson 1995). Continued use of machinery over the same parts of a block can also lead to undesirable soil compaction that can adversely affect yield (Robinson 1995). More southerly plantations have a high frequency of sloped blocks (Broadley et al. 2004) that are too steep to allow machine access and therefore problems of plant spacing and soil compaction caused by machinery are not relevant considerations; the lack of mechanisation is an incentive to replant less frequently (Broadley et al. 2004). Other factors that affect the decision about whether to replant or ratoon include the issue of yield decline resulting from a build up of soil nematodes and/or a reduction of soil pH; and marketing issues associated with control over harvest time as maturity of pseudostems developing from suckers tends to become less synchronous (Robinson 1995).

In the Australian tropics, bananas are best planted between June and November (Lindsay et al. 1998). This allows the plant crop and the first one or two ratoon crops to be produced during the winter-spring period when better market prices can be obtained. Also, land preparation and plantation management are easier when plantings are undertaken during these drier months; hot and wet conditions can promote soil erosion and lead to rotting of planting material.

South of Maryborough the planting season can extend from August to the end of January, with planting occurring in September in southern Qld and usually from October to November in northern NSW (Broadley et al. 2004).

Selection of suckers for producing the next crop depends on a number of considerations. These include the evenness of the crop (especially at harvest), selection of early or late suckers, position of the follower in relation to the row direction and in relation to the bunch on the parent plant (QDAF 2012e). Nurse suckers can be selected and managed in order to assist in scheduling of harvest, to rejuvenate old plantations or to recover from damage, such as cyclone damage by skipping a ratoon cycle and thus delaying the next crop (QDAF 2012f). In tropical regions, single rows, with a single sucker, are commonly 5 m apart, with plant spacings of 1.2 m. When these are converted to double rows in the first ratoon, with two following suckers, the plant spacings are increased to 2.2 m, with row spacings of 5.5 m. In double rows the plant spacings are 1.7 m, with the centres of double rows spaced 6.5 to 7.0 m apart. The inter-row distance is set on the basis of machinery access (Broadley et al. 2004). Suggested spacings for varieties in the sub-tropics are given in Table 8.

Table 8. Plant spacings of commonly grown varieties in the sub-tropics[a]

Variety	Spacing between plants (m)	Spacing between rows (m)	Plants per ha
Cavendish	1.8-2.1	3-3.5	1362-1852
Ladyfinger	3-4	3.2-4	625-1041
Goldfinger	2.5-3	3	1111-1333

[a] Adapted from Broadley et al. (2004)

In some situations wider plant spacings may be beneficial. For example, in the tropics this would allow for air movement between the rows thus reducing the susceptibility to diseases, while in relatively dry, non-irrigated areas wide plant spacings would reduce the competition for water (Broadley et al. 2004).

The banana growth cycle has seven recognised growth stages used by growers to implement farm management practices such as fertilisation and irrigation requirements (Broadley et al. 2004). These stages follow planting or ratooning and can be summarised as follows:

i. 15 leaf stage
ii. 25 leaf stage
iii. bunch emergence
iv. bract fall
v. ½ maturity
vi. mature bunch
vii. postharvest

Weed control is important as weeds can compete vigorously with banana plants as well as harbouring pests. The presence of weeds also makes disease detection in the banana plantation difficult (see Section 7.1 for further discussion).

Management of pests and diseases is also important and it is recommended that an Integrated Pest Management approach be used (Broadley et al. 2004; King 2013) incorporating physical, cultural, biological and chemical controls to manage pests (King 2013).). Insecticides can be applied as sprays, dusts or injections into plants parts (the 'bell' and pseudostem. Information regarding chemical controls for banana pests and diseases is available from the APVMA website. Pests and diseases are discussed in more detail in Section 7.2.

Banana plants have high nitrogen and potassium requirements in order to produce good fruit yields (Broadley et al. 2004). A number of important considerations are outlined for making decisions about fertiliser applications to banana crops including not only crop requirements, soil ans climatic conditions, costs of fertilisers, but also environmental impacts of fertiliser applications in the broader environment. In general, older blocks and rattoons in tropical regions require 20 – 30 kg nitrogen, 60 – 70 kg potassium and 4 – 7 kg phosphorus *per* hectare *per* month (King 2013). The 'Lady Finger' banana requires 10% more nitrogen and potassium than the 'Cavendish' banana (QDAF 2012c).

The irrigation requirements for bananas depend on a number of factors including climatic conditions, soil types, planting densities and crop stage. Irrigation of bananas varies substantially between growing regions, with Carnarvon in WA relying almost entirely on irrigation, while production in eastern subtropical regions is generally rainfed and tropical regions may rely on irrigation during dry periods (King 2013). In many instances, fertigation (irrigation of plants with water containing fertilizer) may be an efficient way of applying nutrients to the crop (Broadley et al. 2004; King 2013). While water is important for crop growth, overwatering can also cause problems (King 2013).

Routine desuckering of banana stools is undertaken at least every 4 months in order to remove suckers (Figure 2) that may compete with the pseudostem for water and nutrients (Broadley et al. 2004). If suckers develop well ahead of fruiting of the pseudostem, they should be removed. However, as the pseudostem matures, one sucker will be left to become the replacement plant.

[Photo credit: Janet Gorst]

Figure 2. Banana plant showing the main pseudostem (P) with two suckers.

In most commercial operations, the banana bunches are covered in plastic or cloth bags to prevent blemishes from mechanical and bird/flying fox/sugar glider damage (Figure 3). This operation also enhances the effectiveness of insecticides that have been applied to the developing bunch and aids fruit development through provision of a warm environment (Broadley et al. 2004). The cover should not be applied until about 21 days after shooting so that the fingers are firm enough to resist frictional damage (Morton 1987). The use of tubular polyvinyl chloride (PVC) and polyethylene was first trialled in Qld in the late 1950s and became standard practice worldwide (Morton 1987). Other tasks performed on developing bunches include bunch trimming, insecticide treatment and removal of the 'male bud' (debelling) at the end of the inflorescence so as to redirect sugars to the developing fruits (Morton 1987; Broadley et al. 2004). Pseudostems of some cultivars, particularly those in the Cavendish subgroup, usually require propping to prevent their falling over as the developing bunches become heavier (Figure 3); the props are applied as soon as possible after bunch emergence (Broadley et al. 2004).

Figure 3. Two types of plastic bunch covers.

Bananas in Australia are harvested year-round. Bunches from new plantings are usually harvested about 16 to 18 months after planting, but this may be as early as 12 months. Subsequent (ratoon) crops are harvested 6 -12 months after sucker set (Morton 1987). For both the plant crop and ratoon crop this is 3 - 5 months after the bunches appear at the top of the plant, or 90 – 120 days after flowers have opened (Rieger 2006). Commercially, harvesting takes place when the fruits on the upper hands are just changing to light green (Figure 4). The fruits are generally ripened artificially in storage rooms held at 14.5 – 30^{o} C and with initial high humidity (90 – 95%) that is reduced to 85%. Ethylene gas is pumped in at a rate that provides the desired speed of ripening (Morton 1987).

[Photo credit: Janet Gorst]

Figure 4. Packing shed in a small commercial facility showing cool room (A), harvested bunches hanging on a conveyor system, and turntable (left foreground) for washing individual hands removed from the bunches.

Transportation of banana fruit should occur between 13.5°C and 15°C, as lower temperatures can permanently halt the ripening process, and the fruit will develop necrotic flecking and eventually turn grey (Nelson et al. 2006). Fruit ripening is particularly affected by the ripening temperatures – see Section 6.1.2.

Many factors determine yield from a banana plantation including environmental conditions, agronomic practices, the cultivar and ratooning management (Morton 1987). Indicative yields for cultivars grown in Australia are given in Table 9. Cavendish production ranges from 500 to 3000 cartons per hectare per year for non-irrigated crops, with bunches of 10 – 30 kg (one to three cartons), with irrigated yields approximately 50 % higher. Lady Finger yields an average of 500 to 750 cartons per hectare per year with bunch sizes of approxuimately 12 kg (QDAF 2010).

Table 9. Growth and production of commonly grown varieties[a]

Variety	Number of hands in bunch	kg/bunch
Giant Cavendish (e.g. Williams)	7-14	20-60 kg[b] (average 22kg)
Ladyfinger	7-10	10-30 kg[c] (average 13kg)
Bonanza and Goldfinger	7-15	25-50 kg
Ducasse	9-12	25-35 kg
Pacific Plantain	10-15	25-40 kg
Red Dacca	5-7	20-35 kg

[a] Adapted from Broadley et al. (2004)
[b] Equivalent to 1.5-2 cartons
[c] Equivalent to 1 carton

Following bunch harvest, the practices that are followed are dependent on whether blocks are to be replanted or ratooned. An important aspect of management in commercial plantations that are ratooned is choosing the optimal following sucker (see Section 4.5) to produce the next crop. Sucker development passes through three distinct stages (Pillay & Tripathi 2007):

- *i) Peeper* – where the young sucker possesses scale leaves only
- *ii) Sword sucker* – where the sucker has sword leaves only
- *iii) Maiden sucker* – where the sucker/ratoon has normal foliage leaves but has not reached the fruiting stage (Figure 5).

[Photo credit: Janet Gorst]

Figure 5. Maiden sucker developing after the pseudostem (P) has been cut back. Note the circular arrangement of leaf sheaths in the transverse section of the pseudostem (see discussion in Section 3.1).

For optimal growth a single, vigorous, sword sucker should be chosen which originates from a deep-seated bud (QDAF 2012e); this will become the maiden sucker and form the next pseudostem. Additionally, one or more 'peepers' may also be allowed to exist to serve as future replacement plants. All other suckers should be killed to prevent competition with the developing pseudostem. Properly carried out, this practice will lead to higher yields of better quality fruit. It also permits the scheduling of production to coincide with periods of higher prices and increases the evenness of the crop. Choosing uniform healthy followers and maintaining row alignment can extend the life of the plantation (Morton 1987; Broadley et al. 2004).

If delay of production is desired and the grower is prepared to sacrifice bunch weight, the process of nurse suckering can be done. This method actually misses a ratoon cycle (Broadley et al. 2004). It involves allowing a sucker (referred to as the 'nurse sucker') to reach a height of approximately 1.5 m at bunch harvest. The growing point of the sucker is then cut out after bunch harvest and this causes a flush of new suckers to develop from the nurse. From these new suckers a single sucker is allowed to develop into a pseudostem. This technique adds a further 3 months to the harvest time normally expected from a ratoon crop (Broadley et al. 2004).

In blocks that are to be replanted there is usually a 6 – 24 month fallow period (Broadley et al. 2004). The old crop is removed, corms are destroyed and a green manure crop, ideally with a high resistance to burrowing nematode reproduction, is planted. Suitable crops include Bonar rape (*Brassica napus* cv Bonar), Indian mustard (*Brassica juncea*), canola (*Brassica napus*), highland swede (*Brassica napus*), *Paspalum wettsteinii* and rye grass (*Lolium perenne*) (Broadley et al. 2004). The fallow allows an improvement in soil structure, aeration and water holding capacity as well as helping to control nematodes (Robinson 1995; Broadley et al. 2004).

2.4 Crop Improvement

Banana improvement is an expensive, slow and complicated process. There are three major emphases in genetic improvement: conventional breeding, mutation breeding and genetic

modification (Vuylsteke 2000; Escalant et al. 2002; Escalant & Jain 2004) but *in vitro* mutation breeding has, so far, delivered the most promising results (Smith et al. 2005). Globally, the problem of banana improvement is tackled through ProMusa (2007), which was established in 1997 through the efforts of the International Network for the Improvement of Banana and Plantain (now amalgamated in Bioversity International) to foster international cooperation. In 2001, the Global *Musa* Genomics Consortium (GMGC) was established to apply new technologies to the sustainable improvement of banana (Frison et al. 2004). ProMusa aims to develop a range of new banana hybrids suitable for production by banana growers worldwide. The programme uses all three approaches for improvement, and research activities are managed within PROMUSA working groups. Pest and disease problems are the main focus of improvement programmes (Pillay et al. 2002).

In addition to the Genomics Consortium, the *Musa* Germplasm Information System (MGIS) was also established in 1997 as a system for the exchange of germplasm data between curators of *ex situ* *Musa* collections. MGIS is a database containing detailed and standardised information on the accessions stored in different *Musa* genebanks around the world. In September 2016, there were 3679 accessions managed by 12 participating institutions as shown in Table 10. MGIS provides a valuable resource for researchers who can use it to identify the most appropriate germplasm to be used in trials.

Table 10. List of institutions participating in the *Musa* Germplasm Information System (MGIS website)[a]

Country	Institute name	Acronym	Institute code	Number of accessions
Australia	Department of Agriculture, Fisheries and Forestry, Queensland Government	DAFF[b] South Johnstone	AUS043	42
Belgium	International Transit Centre, Bioversity International	ITC	BEL084	1509
Cameroon	Centre Africain de recherche sur bananes et plantains	CARBAP	CMR004	365
China	Institute of Fruit Tree Research (IFTR), Guangdong Academy of Agricultural Sciences (GDAAS)	IFTR/GDAAS	CHN153	217
Costa Rica	Corporación Bananera Nacional S.A.	CORBANA	CRI026	108
Democratic Republic of Congo	Institut National pour l'Etude et la Recherche Agronomiques	INERA	COD018	57
Guadeloupe (France)	Centre de Ressources Biologiques	CRB	GLP005	354
Indonesia	Indonesian Tropical Fruit Research Institute	ITFRI	IDN150	306
Ivory Coast	Centre National de Recherches Agronomiques	CNRA	CIV063	65
Papua New Guinea	National Agricultural Research Institute	NARI	PNG004	62
Uganda	National Agricultural Research Organization	NARO	UGA003	442
United States	United State Depart. Of Agriculture, Tropical Agriculture Research Station	USDA-TARS	USA108	152

[a] Sourced 31 August 2016.
[b] Queensland Department of Agriculture, Fisheries and Forestry (DAFF); Now Queensland Department of Agriculture and Fisheries (QDAF).

Since 1988, QDAF (formerly QDPI&F and DAFF) at its facility in Nambour, has maintained one of the world's largest *in vitro* repositories of banana germplasm. This facility is able to conserve, multiply and distribute pathogen-free germplasm for planting and breeding programmes. The cultures are maintained at approximately 16^{o} C in low light (approximately 13 - 25 µmol m^{-2} s-1) and therefore require infrequent subculturing (once every 6 – 12 months) in comparison with cultures maintained for production that are grown at 26 – 30^{o} C and 40 – 100 µmol m^{-2} s-1 (Vuylsteke 1989). There is,

however, a requirement for the occasional re-initiation of cultures as they can deteriorate with prolonged time in tissue culture. As of September 2012, this collection housed 417 tissue culture and *in vitro* accessions and 200 field accessions (MUSANet 2012; MUSANet 2016).The QDAF field collection, at South Johnstone, listed in Table 9, is a subset (42 accessions) of the *in vitro* accessions and provides a valuable source of material for the re-initiation of *in vitro* cultures.

It was suggested that one of the main problems hampering genetic improvement in *Musa* has been a lack of basic knowledge about the diversity and taxonomic relatedness within the genus (De Langhe 2000). The tools of genomics research such as genetic mapping, identification of quantitative trait loci, marker assisted-breeding/aided introgression, and identification and cloning of (resistance) genes are helping to resolve diversity questions and open up new areas for more efficient breeding of *Musa* (Pillay et al. 2002; Kahl 2004; Frison et al. 2004; Smith et al. 2005; Pillay & Tripathi 2007; Heslop-Harrison & Schwarzacher 2007).

A genome sequencing project was undertaken by the GMGC and, in 2012, one of the main objectives of the consortium was achieved (PROMUSA 2016g) when the *Musa* genome was sequenced (D'Hont et al. 2012). In late 2015, GMGC was integrated into MusaNet, the global *Musa* genetics resources network and at that stage included 70 scientists from 24 countries (PROMUSA 2016g).

There are a number of networks that are involved in collaborative research and discussion to ensure the availablility of banana genetic material and information for research. These include INIBAP and International Plant Genetic Resources Institute (IPGRI) which have now jointly adopted the name Bioversity International which curates and coordinates banana genetic information as part of its focus on agricultural biodiversity and research for development. Likewise, MusaNet is a global network with a focus on conserving and using *Musa* genetic resources and is also coordinated by Bioversity International. Details of these and other organisations can be found on the ProMusa Organizations page.

2.4.1 Breeding

Conventional breeding

The strategy in banana breeding is to incorporate the desired traits often present in wild and cultivated diploids to existing cultivars (Pillay & Tripathi 2007). A major problem with breeding of sweet bananas is that the creation of triploids or tetraploids, rather than diploids, is necessary to maintain the production of parthenocarpic fruits for the commercial sweet banana trade; seedlessness is essential for edibility as seeds are large and hard. Since parthenocarpy is closely linked to male sterility (see Section 4.1.2) this presents a conundrum for the breeder since there is low availability of both female and male parents. Members of the Cavendish subgroup of AAA cultivars, which currently dominate world trade of sweet bananas, set seed so rarely that they can be regarded as female sterile (Shepherd 1987). Members of the Gros Michel subgroup (also AAA genome type) produce an average of 2 seeds per bunch when hand pollinated with diploids (Simmonds 1966). Other banana genome types show a range of seed fertility, which can be influenced by climatic conditions (Ortiz & Vuylsteke 1995).

Notionally, triploids can be produced as a result of crosses of either diploid with diploid (with recombination only from the male parent) or of tetraploid with diploid (with both parents segregating) (Shepherd 1987) where the female parent is the tetraploid, so as to avoid problems associated with pollen derived from a tetraploid (see Section 4.1.2). Both artificial and open pollination are able to generate viable triploid seed (Ortiz & Crouch 1997) and selection for fertility can increase the efficiency of pollination (Ortiz & Vuylsteke 1995).

There are logistical reasons why breeding in *Musa* is less than ideal: the seed-to-seed crop cycle takes about 2 years to complete; and physically, each plant occupies approximately 6 m^2 in the field, thus requiring a large investment in space (Ortiz et al. 1995).

Australia does not have any conventional breeding programmes for banana. However, there are a number of centres worldwide where conventional breeding of *Musa* is undertaken (Vuylsteke 2000; Escalant et al. 2002). The major breeding strategy was developed at the Fundación Hondureña de Investigación Agrícola (FHIA) in Honduras and is based on the development of improved diploids that are then used as male parents in crosses with female-fertile triploids to produce tetraploids (Escalant et al. 2002). While a number of improved tetraploids have been produced and subsequently distributed, progress has been very slow because of the low fertility of the triploid female parents (Escalant et al. 2002). More recent work has produced Cavendish hybrids with resistance to black sigatoka and Panama disease race 1 (see section 7.3 for more information on banana diseases), which now need to be tested in areas with Panama disease tropical race 4. However, a continuous program is required to develop improved male and female plants to overcome new pest and disease threats (Aguilar Morán 2013).

Tetraploid banana plants often show premature senescence, leaf drop, fruit drop, short fruit shelf life, weak pseudostems and undesirable seed production (Shepherd 1987; Ude et al. 2002). The QDPI&F (now QDAF) has introduced several FHIA cultivars into Australia and, together with counterparts in NSW and the NT, evaluated them for agronomic performance and pest and disease (especially FocTR4) resistance in a range of environments. The most successful of the sweet banana cultivars obtained to date have been FHIA-01 ('Goldfinger') and FHIA-18 ('Bananza') from the AAAB genome group. 'Goldfinger' is resistant to Panama Disease, highly resistant to Black Sigatoka, tolerant to the burrowing nematode, is cold tolerant and does not lodge (PROMUSA 2016e). It also has good fruit quality and postharvest performance (Seberry & Harris 1998).

Other major centres of banana breeding are located in France and Guadeloupe (Centre de Coopération Internationale en Recherche Agronomique pour le Développement Departements Productions Frutières et Horticoles – CIRAD-FLHOR); Nigeria and Uganda (International Institute of Tropical Agriculture); Cameroon (Centre de Recherches Régionales sur Bananier et Plantain - CARBAP) and Brazil (Empresa Brasiliera de pesquisa Agropecuaria - EMBRAPA). Because of the lack of effective strategies to control Panama Disease, the development of FocTR4-resistant cultivars has been the major priority in genetic improvement programs (Moore et al. 2001). Other priorities also relate to pest and disease resistance (Persley & DeLanghe 1986; Horry et al. 1997; Pillay & Tripathi 2007) but commercial attributes such as yield, water use efficiency, fruit dimensions, fruit flavour and ripening characteristics could also benefit from improvement (Pillay & Tripathi 2007; Heslop-Harrison & Schwarzacher 2007). An extensive discussion of banana breeding can be found in Pillay and Tripathi (2007).

A different approach to conventional breeding has been developed by CIRAD-FLHOR and CARBAP and involves the creation of tetraploids from desirable diploids through colchicine doubling; the tetraploids are then used in crosses with superior diploids to produce horticulturally desirable triploids (Hamill et al. 1992; Escalant et al. 2002).

Banana Streak Viruses (BSV) are currently a major constraint to *Musa* genetic improvement and mass propagation. Interspecific hybrids containing the B genome contain integrated sequences for Banana Streak Virus that are readily activated. While a number of promising hybrids have been produced, those containing a B genome have been found positive for the virus and hence cannot be distributed to growers (Escalant & Jain 2004).

Mutation breeding

Mutation breeding programmes broadly encompass two approaches, namely gamma irradiation and somaclonal variation. However, chemical mutagenesis using ethyl methyl sulphonate (EMS), sodium azide and diethylsulphate has also been used (Smith et al. 2005). The parameters for successful gamma irradiation of shoot tips of *in vitro*-derived plantlets were established in the 1990s and plants of the Gros Michel cultivar 'Highgate', tolerant to *Fusarium oxysporum,* were obtained (Bhagwat & Duncan 1998). In Australia, *in vitro* gamma irradiation of the Cavendish cultivar 'Dwarf Parfitt'

yielded a number of putative mutants one of which (DPM25) had good agronomic characteristics as well as field resistance to subtropical race 4 *Foc* although this resistance was not as high as that in the 'Dwarf Parfitt' parent (Smith et al. 2006). Trials were conducted in the NT to evaluate DPM25 resistance to FocTR4 (Walduck et al. 2006), a much more virulent race than subtropical race 4.

Somaclonal variation, while presenting a concern to commercial growers (see Section 2.3.1) is a tool that has been used to improve banana germplasm via novel sources of variability (Sahijram et al. 2003). The major centre for development of banana cultivars through somaclonal variation is the Taiwan Banana Research Institute (TBRI) which, in 1984, established a Cavendish breeding programme based on field screening somaclonal variants for resistance to FocTR4 (Tang 2005). Micropropagated banana plantlets are distributed to growers who then screen the plants for superior somaclones. The programme has produced a number of resistant clones although none of these is regarded as a suitable replacement for the existing 'Giant Cavendish' cultivars traded worldwide. In Australia, two somaclone lines (GCTV-119 and GCTV-Formosana) from TBRI are being tested in the NT but results to date suggest that they are varyingly susceptible to FocTR4 (Walduck et al. 2006).

Somaclonal variation is regarded as a convenient strategy for banana improvement for a number of reasons (Vuylsteke 2000): i) a wide range of banana cultivars are already in tissue culture; ii) it is a comparatively cheap strategy that does not involve biosafety issues or regulatory approval; iii) it is not necessary to have undertaken molecular analysis of desirable traits. A problem with the strategy is that the outcome is not predictable and cannot be targetted and, in reality, there have been few commercially useful variants produced (Tang 2005).

Further information about a number of organisations involved in breeding and propagating banana plant material for distribution can be found on the ProMusa "Organizations" portal (PROMUSA 2016h). In addition, a number of collaborative networks for banana research, including banana breeding can be foundon this page.

2.4.2 Genetic modification

Early experiments with banana established plant tissue culture regeneration systems, a necessary precursor to successful transformation. The main pathway of regeneration is via somatic embryogenesis. As somatic embryos may be of unicellular origin (Escalant et al. 1994), the likelihood of chimeric plants being produced is very low and this therefore makes embryogenic suspension cultures ideal transformation targets (Becker et al. 2000).

Although embryogenic suspension cultures have been induced from various explant types (including the bases of leaf sheaths or rhizome fragments of plants produced *in vitro*; thin sections of highly proliferating bud cultures placed in liquid medium; and zygotic embryos) the most successful explants are immature male flowers (Cirad 2003). However, a rapid decline in the embryogenic response soon after harvest as well as a seasonal dependence mean that cultures must be induced quickly from harvested flowers (Escalant et al. 1994). There is also the added problem that not all banana cultivars, especially plantains, produce male flowers. The use of other methods for producing embryogenic suspension cultures such as the 'scalp' method can be labour-intensive and protracted (Strosse et al. 2004). Embryogenic suspension cultures have been induced from a wide range of genotypes (Smith et al. 2005).

Transformation protocols involving *Agrobacterium tumefaciens* – mediated transformation (May et al. 1995; Acereto-Escoffie et al. 2005), microprojectile bombardment (Becker et al. 2000; Houllou-Kido et al. 2005) and electroporation of protoplasts (Sagi et al. 1995; Sagi et al. 2000) have been developed. Initially, genetic modification involved the expression of marker genes but as procedures have become more robust the emphasis has shifted to engineering for pest and disease resistance (Atkinson et al. 2003). For a review of the transformation of bananas see Smith et al. (2005).

Promoters from both banana and other species have been isolated for use in transformation systems (Smith et al. 2005). In Australia, promoter regions from Banana Bunchy Top Virus (BBTV) satellites S1 and S2 and from the banana vegetative actin gene (*ACT1*) have been used successfully to drive introduced genes in transgenic banana plants (Kahl 2004). Hermann et al. (2001) cloned the ACT1 gene, which shows strong constitutive expression in the pseudostem, leaves and roots.

Transgenic research on resistance to fungal diseases has centred on *Fusarium oxysporum* f. sp. *cubense* (Panama Disease) and *Microsphaerella fijiensis* (Black Sigatoka) (see discussion of these in Section 7.2) with emphasis on the expression of various genes encoding defensin-type antimicrobial peptides and non-specific lipid-transfer proteins (Sagi 2003). There are also several groups worldwide involved in the development of transgenic virus resistance against Banana Bunchy Top Babuvirus, Banana Streak Badnavirus, and Banana Bract Mosaic Potyvirus (Dale & Harding 2003). More recently, promising results have been obtained from bioassays of GM banana (Gros Michel) tissue containing one of two rice chitinase genes for resistance to *M. fijiensis* (Kovács et al. 2013).

In the mid 1990s the idea of using transgenic plants as edible vaccine-producing systems, especially in underdeveloped countries, saw proposals to genetically modify banana fruit to express antigens of a number of viruses and bacteria such as hepatitis B and cholera (Mason & Arntzen 1995). Despite considerable research, this vision has still not been realised (Arntzen 2005).

Field trials of GM banana have previously been approved in Australia for disease resistance or enhanced nutrition (see OGTR website for details). To date no GM bananas have been approved for release overseas. A review of GM banana literature suggests that, despite being an apparently ideal species for improvement via GM, a number of technical, practical and financial considerations have limited the widespread application of GM solutions for banana improvement (Remy et al. 2013).

SECTION 3 MORPHOLOGY

3.1 Plant morphology

Detailed morphological descriptions of the banana plant can be found in numerous publications (Simmonds 1959a; Barker & Steward 1962; Purseglove 1972; Morton 1987; Ross 1987; Simmonds & Weatherup 1990; Espino et al. 1992; Karamura & Karamura 1995; Rieger 2006; Pillay & Tripathi 2007). Here the description of the morphology of the banana plant is dealt with in more general terms.

The cultivated banana plant is a tall (two to nine metres) perennial monocotyledon and therefore classed as an arborescent herb. The wild species *M. ingens* may grow up to 15 m and have a circumference of 2.5 m (INIBAP 2000). The above ground 'trunk' is called a pseudostem and consists of concentric layers of leaf sheaths rolled into a cylinder 20 – 50 cm in diameter (see Figure 5). Variation in pseudostem morphology exists between cultivars, especially its length, disposition and coloration. The pseudostems of Highland and sweet bananas are predominantly green to dark green with black blotches while those of plantains are yellowish green with brown blotches (Pillay & Tripathi 2007). The true stem is a large underground corm (also called a butt) and the meristem of the apical bud initially gives rise to the leaves before it elongates up through the pseudostem and emerges some 10 – 15 months after planting as a large terminal inflorescence (i.e. each pseudostem produces only one inflorescence) (see Figure 7).

The leaves of *Musa* plants emerge, tightly rolled (Figure 6), from the centre of the pseudostem in an anti clockwise spiral manner (Barker & Steward 1962). The leaf sheaths taper on both sides to form the petiole, which can vary in colour between cultivars and even within plants derived from the same corm. The leaf is more or less vertical when it emerges becoming horizontal and eventually drooping. The size of emerging leaves increases until just before flowering and then decreases until the emergence of the last leaf (the flag leaf) immediately before the emergence of the inflorescence. At its maximum size, the leaf of a banana plant is the largest of any plant in the world and the blade

(lamina) can grow to 4 m long and 100 cm wide. Each blade has a pronounced midrib and well-marked, pinnately-arranged parallel veins. The leaf margins tear along the veins in windy conditions giving the blades a tattered appearance.

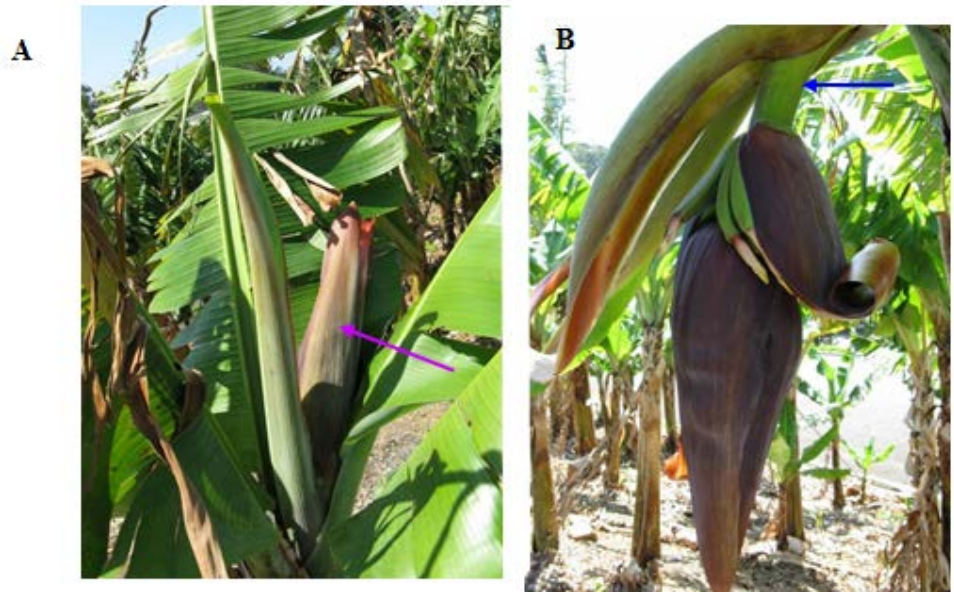
The root system, like that of all monocotyledons, is adventitious spreading out laterally as far as 5.5 m and forming a dense mat mainly in the top 15 cm of soil.

[Photo credit: Janet Gorst]

Figure 6. Emergence of a rolled leaf (arrowed) from the top of the pseudostem. The older leaves have unrolled as they have developed and show the characteristic predominant midrib, parallel venation and blade tearing

3.2 Reproductive morphology

The shoot meristem transforms into an inflorescence at about the time when the eleventh-last leaf has been produced. There is no evidence of a photoperiodic requirement for flowering (Purseglove 1972). Once it begins to elongate the inflorescence may grow an average of 8 cm per day finally emerging (Figure 7A) after about a month (Simmonds 1959a). The inflorescence is classed as a compound spike and the peduncle (inflorescence stalk) emerges upwards through the centre of the pseudostem before bending down under the weight of the developing spike (Figure 7B).



[Photo credit: Janet Gorst]

Figure 7. **A) Inflorescence** (purple arrow) emerging through the top of the pseudostem; **B) Developing inflorescence**, which has bent down, showing the bell shape, peduncle (blue arrow) purple bracts, and fruits developing on the female flowers inside the bract at the proximal end of the inflorescence (see Figure 8 for a close-up).

The immature inflorescence is encased inside purple bracts (Figure 7B) that give the appearance of a large bud; it is often referred to as the 'bell'. Inside the bracts are five to fifteen double whorls of floral parts comprising female flowers at the proximal end (closest to the base of the peduncle), male flowers at the distal end (closest to the tip of the peduncle), and neuter or hermaphrodite flowers sometimes present in between. Each node is covered by a purple bract. These bracts open in sequence (one per day) from base to tip, becoming reflexed before being shed. As the hands of fruits start to develop from the female flowers (Figure 8A), the male flowers are usually shed leaving the peduncle bare except for the very tip, which consists of a 'male bud' (also referred to as the bell) containing the last-formed of the male bracts and flowers (Figure 8B). In some cultivars, this male part is shed quickly, and this character may be a useful distinguishing characteristic.

[Photo credit: Janet Gorst]

Figure 8. **A) Close-up of female flowers** showing the remains of the white, tubular tepals (arrows) and the fruits (*) developing from the ovaries in a hand; **B) Maturing inflorescence** showing the fruits developing from the female flowers and starting to reflex (turn upwards), and the 'bell' containing the male flowers.

The tepals are white, tubular and toothed (Figure 8A). In flowers such as those of banana where there may not be a clear distinction between sepals and petals, the resulting structures may be referred to as 'tepals' (Simmonds 1959a). Other authors (Ross 1987) consider that there is a distinction between petals and sepals but refer to these collectively as the 'perianth'. The flowers secrete nectar at the tip of the ovary and this then collects at the base of the tepals. They are negatively geotropic and turn upwards as they develop (Figure 8B). Male and female flowers are morphologically indistinguishable until the inflorescence is about 12 cm long; at this point the ovary in the male flower fails to develop any further (Simmonds 1959a). Flowers have a three-lobed stigma and style and an inferior ovary fused from 3 loculi. Each loculus of a female flower contains two rows of ovules embedded in a strip of mucilage (Simmonds 1953). There are five stamens in male flowers; these are reduced to staminodes in female flowers. Pollen, if produced, is sticky (Simmonds 1959a).

Each fruit is a berry and is known as a 'finger'. Each cluster of fruits at a node is known as a 'hand' and the entire collection of hands is known as a 'bunch'. The number of hands varies with species and cultivar. The outer protective layer of each fruit, known as the 'skin' or 'peel', is a fusion of the hypanthium (floral receptacle) and outer layer (exocarp) of the pericarp (fruit wall derived from the ovary wall). This peel is easily removed from the fleshy pulp that originates mainly from the endocarp (innermost layer of the pericarp) (Simmonds 1953). During the development of the fruit from the ovary, the tepals, style and staminodes abscise leaving a characteristic calloused scar at the tip of the fruit. Colour, size, texture and flavour of common cultivated *Musa* fruits vary with cultivar. Edible *Musa* cultivars have fleshy, seedless fruits while wild bananas may have little flesh and be filled with black seeds 3 – 16 mm wide (Morton 1987). The seeds have linear embryos, large amounts of endosperm and a thick, hard testa (Ellis et al. 1985).

SECTION 4 DEVELOPMENT

4.1 Reproduction

4.1.1 Asexual reproduction

All *Musa* spp. can propagate asexually; in the triploid sweet bananas this is, effectively, the only form of reproduction. Information on asexual reproduction in commercial plantings and unmanaged plantings is contained in Section 2.3.1 and Section 4.5, respectively.

4.1.2 Sexual reproduction

Pollen viability and total pollen counts vary between cultivars but, generally, diploid *Musa* species produce more viable pollen than tetraploids which, in turn produce more viable pollen than triploids. In one study the pollen of the diploid cultivars had 88% viability, the pollen of tetraploids had 29% viability and the pollen of triploids had less than 10% viability (Fortescue & Turner 2004). Viability is, however, only measured in terms of the presence of vital features such as an intact plasma membrane or positive esterase activity (Fortescue & Turner 2004). This does not take into account the fact that while the pollen produced by tetraploids may be viable, it is essentially 'impotent' because it is diploid (Shepherd 1987). The germination of such pollen *in vivo* if it occurs is very slow; however, it is possible to achieve fertilisation by using pollen from tetraploid plants (Ortiz 2000).

The sweet banana cultivars traded globally are regarded as inherently female sterile and seed set is low (Simmonds 1959a; Ortiz & Vuylsteke 1995). A more recent report indicates that male Cavendish bananas have intermediate fertility and that while female fertility is very low, female plants of these cultivars should not be classified as sterile (Aguilar Morán 2013). Male sterility and parthenocarpy are closely linked although the reasons for their occurrence may be different (Fortescue & Turner 2005). While the occurrence of male sterility in edible triploid banana cultivars is caused mainly by chromosome irregularities at meiosis, the female sterility that also occurs is widespread across all ploidy levels and is often due more to morphological defects such as multiple archesporia, failure of embryo sac development, failure of fertilisation and derangement of post-fertilisation events (Simmonds 1962). Triploid females without such functional abnormalities can successfully produce diploid progeny when crossed with diploid pollen (Fortescue & Turner 2004). One study suggested that the ovules of both triploid and diploid plants contain embryo sacs but that in triploids the embryo sacs are often incorrectly positioned and this may be a significant contributor to the sterility of triploids (Fortescue & Turner 2005). It has also been determined that the presence of the *M. balbisiana* B genome increases the likelihood of embryo sacs being correctly positioned and that this may be a reason for the increased fertility of triploid cultivars containing the B genome (e.g. AAB and ABB) over those with the AAA genome (Fortescue & Turner 2005).

Evidence suggests that wild bananas are moderately outbred (though self-pollination may be a frequent event) and that they tolerate an occasional generation of inbreeding without suffering significant inbreeding depression (Simmonds 1962).

4.2 Pollination and pollen dispersal

As already discussed, pollination is not a common occurrence in cultivated sweet bananas and there are few seeded cultivars in Australia (see Section 8 and Section 9 for further consideration of opportunities for crossing of cultivated with wild species in Australia). Pollination is essential for fruit development in the seeded cultivars (Simmonds 1959a).

Both male and female flowers are nectiferous. The abundant nectar and sticky pollen suggest animal pollination in the wild species. While a variety of insects have been observed visiting flowers, the characteristics of the inflorescences of many banana types suggest adaptation to bat pollination. These characteristics include nocturnal opening of flowers, characteristic odour, strong, often

pendent inflorescences, accessible nectar, dull flower colour, and flowers exposed freely below the foliage (Simmonds 1962; Nur 1976; Liu et al. 2002). The pollen of flowers visited by bats is also high in protein and the nectar-feeders are able to supplement their nitrogen intake by also feeding on the pollen (Howell 1974). In commercial bananas that do not produce pollen the flowers would not present a complete food source (Law 2001).

The Database of Neotropical Bat/Plant Intercations (Geiselman et al. 2002) lists a number of species of new world tropical bats pollinating *Musa* spp. (see Appendix 1a). None of these occurs in Australia. Old world bats such as *Macroglossus minimus*, *Macroglossus sobrinus* and *Eonycteris spelaea* are implicated in long distance pollination of wild banana species (Nur 1976; Fujita & Tuttle 1991; Liu et al. 2002) and have been attributed with the maintenance of genetic diversity both between and within populations (Ge et al. 2005); again, these do not occur in Australia. Australia does, however, have a number of *Pteropus* (flying fox) species (see Section 4.3) and while there is no specific record of their pollinating seeded banana types it is possible that they may do so; the hair on the heads of the flying foxes is modified with hooks which can entrap pollen. The majority of these flying foxes feed during the night within a radius of 30 km from their camp, however, they may commute up to 50 km and thus are regarded as long distance pollinators (Eby 1995).

Syconycteris australis (Common blossom bat) is a nectar feeder that occurs in northern Qld. It is known to feed on the blossoms of the native species *M. acuminata* subsp. *banksii* (Law 2001) and its range also coincides with the native *M. jackeyi* (see Section 8). As such, it could have a role in the pollination of these two species. *S. australis* is often forced to forage on the nectar of cultivated bananas because of fragmentation of its native habitat. For the reason given above concerning the lack of pollen (and hence protein) in commercial bananas, this reliance on commercial banana nectar has been offered as an explanation for the atypically male-biased sex ratio of *S. australis* on the Atherton Tableland in northern Qld (Law & Lean 1999).

Honeybees and birds are also regarded as pollinators of *Musa* in other parts of the world (Ortiz & Crouch 1997). These visit flowers during the day and, hence alternate with the nocturnal bat pollinators. The sunbird *Arachnothera longirostris* (family *Nectariniidae*) pollinates *Musa itinerans* in southwestern China (Liu et al. 2002). *Nectarinia jugularis*, known as the yellow-bellied sunbird in Australia, is the only member of the *Nectariniidae* in Australia (Maher 1992). It occurs in northern Qld and its range coincides with the two native *Musa* species (Slater et al. 1986). It has been observed pollinating *M. acuminata* subsp. *banksii* (Armstrong 1979). Nectar-feeding marsupials such as the sugar glider (*Petaurus breviceps*) may also play a role in pollination of the native *Musa* species in Australia. Sugar gliders are troublesome in commercial plantations in Australia because they may damage developing fruit as they forage for nectar (Broadley et al. 2004).

4.3 Fruit/seed development and seed dispersal

The fruits of triploid sweet banana cultivars are parthenocarpic (develop without fertilisation) and, while the ovules initially are larger than those of seeded banana cultivars, these ovules usually shrivel within 9 – 14 days of anthesis (Simmonds 1953; Fortescue & Turner 2005) leaving only vestiges that may be visible as brown specks in the centre of the fruit (Simmonds 1959a; Morton 1987). It is possible, however, for cultivars of some parthenocarpic triploid bananas (e.g. 'Awak Legor') to be pollinated and some seeds may develop; the presence of seeds has a stimulatory effect on pulp production (Simmonds 1953). If there is no pollination in the seeded cultivars, the ovaries of the female flowers will swell slightly but they then shrivel after a few weeks (Simmonds 1959a).

The maximum number of fruit that may potentially develop in a bunch is correlated with the climatic conditions occurring during the very early formation of the flowers at the time when the last 3 – 4 leaves are developing (Simmonds 1959a). Whether this number is realised depends upon conditions during the time when functional differences arise between male and female flowers.

Fruit development in parthenocarpic fruit appears to be mediated by autonomous production of auxin in the ovary (Simmonds 1959a); this stimulus replaces the stimulus in seeded fruits that derives from the developing seeds. Development may follow a concave volume curve in some cultivars (e.g. 'Gros Michel') or a convex curve in others (e.g. 'Bluggoe') (Simmonds 1953). The immature fruit contains a high amount of starch that is rapidly degraded into sugars during ripening. Genes producing enzymes such as starch phosphorylase (da Mota et al. 2002), sucrose-phosphate synthase (Oliveira do Nascimento et al. 1997) and starch synthase (Clendennen & May 1997) are up- or down-regulated. These, along with other proteins, are activated in response to the burst of ethylene production that signals the beginning of the climacteric (Clendennen & May 1997; Peumans et al. 2002). The climacteric is an increase in cellular respiration that occurs during the ripening of many fruits including banana. Increased ethylene synthesis precedes, and is responsible for, many of the ripening processes in climacteric fruits. The unripened fruit of bananas also contains bitter tasting latex; this is broken down during ripening.

Banana fruits left on the plant ripen much slower than those that are removed (Purgatto et al. 2001; Peumans et al. 2002) and this is thought to be due to the transport of metabolites from the plant that inhibit the conversion of starch to sucrose. At least two candidates for this inhibition are indole-3-acetic acid (Purgatto et al. 2001) and gibberellic acid (Rossetto et al. 2003). However, the protein composition of the pulp and peel of detached fruits is similar to that of fruits left to ripen on the plant (Peumans et al. 2002).

The main external sign of a ripe fruit is the change to yellow of the skin. Continued ripening eventually results in blackening of the skin, emission of a disagreeable aroma and a change of the pulp to a gelatinous texture.

Wild *Musa* types are fully seeded and their fruits develop only after pollination. Fruit size depends on the number of seeds and a parenchymatous pulp develops around each seed. The growth volume curve is sigmoidal (Simmonds 1953).

The Database of Neotropical Bat/Plant Intercations (Geiselman et al. 2002) lists a number of species of new world tropical bats dispersing seed of *Musa* spp. (see Appendix 1b). None of these occurs in Australia.

In Australia flying-foxes (sometimes referred to as fruit bats) have been considered a pest species by fruit growers since the beginning of European settlement because they eat a wide range of commercial and backyard fruit including bananas (Tidemann et al. 1997), although their main diet is assumed to come from native plants (Birt et al. 1997). Grey-headed flying-foxes (*Pteropus poliocephalus*), Little Red Flying-fox (*Pteropus scapulatus*) and Black Flying-fox (*Pteropus alecto*) all occur in banana growing regions and have been observed in NSW feeding on cultivated banana fruits (Eby 1995). Other species that also occur in banana growing areas include the Spectacled Flying-fox (*Pteropus conspicillatus*), Tube-nosed flying fox (*Nyctimene robinsoni*), and Common blossom bat (*Syconycteris australis*). There is no scientific literature detailing the eating of seeded banana cultivars by flying foxes. However, it is pertinent to note that flying foxes have a very short digestive tract and food will pass through the gut within 12 – 30 min (Birt et al. 1997). This suggests that seeds are unlikely to be digested and could germinate after being passed in the faeces. Animals may also hold seeds in cheek pouches for extended periods and then deposit them beneath trees in which they are feeding or camping (Eby 1995). However, it is noted that seeds larger than 9 mm (such as may occur in banana) are not carried in this way (Eby 1995). The long distances that *Pteropus* spp. can travel, and thus potentially disperse seed, has already been discussed in Section 4.2.

4.4 Seed dormancy and germination

Simmonds (1959b) has detailed the results of a number of experiments on the germination of banana seeds and described the early growth of the seedling.

Seeds, if produced, have a thick, hard testa (seed coat) that can prevent the oxygen and water that are essential for germination from entering the seed. Simmonds (1959b) determined that the highest germination is obtained from mature seeds extracted from ripe fruits, cleaned and sown immediately. Use of immature seed or seed extracted from rotting fruits had lower viability. Studies using seeds of *M. balbisiana* (Stotzky et al. 1962; Stotzky & Cox 1962) have shown that, under artificial germination conditions, chipping of the testa to expose the endosperm and at least 9 cycles of exposure to an alternating temperature regime with a large amplitude (e.g. 12-18 h at 12^{o} – 18^{o} C/6 – 12 h at 27^{o} - 35^{o} C) improved germination. Normally, the seeds of *M. balbisiana* do not begin germination for 3 – 6 weeks. Germination may then proceed in a flush or be spread over a 3 – 15 week period. The percentage germination is highly variable and depends on factors such as the maturity of the fruit at seed harvest, the post-harvest age of the seed and the method of storage (Stotzky et al. 1962).

While the actual seed viability of triploids, tetraploids and hybrid diploids may be poor (Karamura & Karamura 1995) banana seed has the potential to remain dormant in the soil for at least a year and seeds of the related species *Ensete* may survive for up to 25 years (Ellis et al. 1985). This is despite the fact that the seeds may be exposed to the warmth and moisture that causes rapid loss of viability in artificially stored seed. Relatively high carbon dioxide levels in the soil may contribute to this longevity and Simmonds (1959b) determined that two to ten per cent% CO_2 levels were favourable for preservation of viability.

In general, germination of widely grown cultivars of *Musa* in soil may be less than 1% (Pillay et al. 2002). However, seeds that remain in the soil in a viable state can germinate en masse when the site is disturbed. Fire, landslip, and land clearing stimulate germination (Simmonds 1959b; Stotzky & Cox 1962). This has been observed in several species including *M. acuminata* subsp. *banksii* in forest in Qld (Simmonds 1959b). A striking example is also the wild species *M. balbisiana* that produces approximately 10,000 seeds, which become distributed around the base of the plant after the fruit has fallen to the ground and decayed. Following disturbance a dense mat of seedlings germinate. Such prolific germination does not, however, lead to a dense stand of mature plants as most seedlings die due to competition (Simmonds 1962).

4.5 Vegetative growth

Banana leaves can unfurl at the rate of one per week in summer but only one per month may be produced in the sub-tropics in winter (Morton 1987; Espino et al. 1992). Most banana plants produce 30 – 40 leaves in a lifetime (Pillay & Tripathi 2007) but as older leaves are pushed outwards they eventually die leaving 5 – 15 fully functional leaves on a mature plant. A minimum of 8 -10 functional leaves are required to allow proper maturation of a bunch of fruit (Rieger 2006).

The pseudostem dies back after flowering but axillary buds of the corm are able to elongate into rhizomes (underground stems) from which suckers (or offsets) are produced, forming a clump called a 'stool' or 'mat'. Once the bunch has ripened and is removed the mother stem dies and the remaining suckers develop into mature plants (Broadley et al. 2004). In unmanaged plants, the oldest sucker generally develops into the next pseudostem and this process of succession can continue indefinitely although, as successive generations of suckers tend to be borne closer to the soil surface, plants become more weakly anchored and may eventually fall over (Espino et al. 1992). Also, if too many pseudostems develop at one time, as can happen, the entire mat is weakened (Boning 2006) because of competition for light and space. The successive development of pseudostems where extension growth is from lateral axes rather than the original tip is termed 'sympodial' growth.

Cultivars vary in the rate and time of suckering (Espino et al. 1992). There are two types of suckers that can be produced (Espino et al. 1992; DPI&F 2005) and their occurrence has implications for management of commercial crops that are ratooned (see Section 2.3.3):

- *'Sword leaf' suckers* develop on the corm of a current bearing plant. The growth of the suckers is held back by correlative inhibition from the 'parent' (on which the suckers rely for nutrition) and normal leaves are unable to develop until after flower initiation. The leaves that do develop prior to flowering of the parent are very narrow and hence are referred to as sword leaves. Plants derived from sword leaf suckers can progress to inflorescence emergence as soon as 6 months after development of the first normal leaf, under optimal environmental conditions (Espino et al. 1992).
- *'Water' suckers* often form on the corm of an already harvested plant and develop normal leaves early. Plants derived from water suckers are not nourished by a parent plant and therefore mature early and show early nutritional deficiency with the result that small, uneconomical bunches of fruit are produced (Espino et al. 1992; Broadley et al. 2004).

Roots are produced continuously until flowering (Price 1995). Extension rates can reach up to 2-4 cm per day in the lowland humid tropics and daylight growth is up to 30% higher than night time growth (Price 1995). [For abiotic factors influencing root growth see also Section 6]. Studies have shown that root system development during vegetative growth can be estimated from the above ground shoot growth characteristics and that diseases such as Black Sigatoka adversely affect root development due to the reduction in functional leaf area (Blomme et al. 2001).

SECTION 5 BIOCHEMISTRY

The biochemical composition of banana fruits depends on the cultivar, abiotic factors such as climate, cultivation method and nature of the soil (del Mar Verde Mendez et al. 2003). Table 11 shows representative levels of nutrients and minerals that can be found in the sweet banana. The banana fruit contains relatively high levels of potassium. Vitamin A content is generally low in the commercially grown 'Cavendish' and 'Lady Finger' varieties but some of the Fe'i banana cultivars grown in Micronesia contain high levels of vitamin A (Englberger et al. 2003).

Table 11. Nutrient values of banana fruit without peel /100g[a]

Component	Cavendish	Lady finger
Energy, including dietary fibre (kJ)	385	475
Starch (g)	6.8	6.8
Moisture (g)	76.2	68.8
Ash (g)	1	1
Total sugars (g)	12.8	18.3
Fructose (g)	6.2	6.4
Glucose (g)	6.7	6.7
Sucrose (g)	0	5.1
Dietary fibre (g)	2.4	3.7
Fat (g)	0.3	0.1
Protein (g)	1.4	1.5
Nitrogen (g)	0.22	0.24
Potassium (K) (mg)	346	322
Magnesium (Mg) (mg)	31	38
Calcium (Ca) (mg)	5	10
Zinc (Zn) (mg)	0.16	0.2
Iron (Fe) (mg)	0.29	0.4
Iodine (I) (ug)	0.4	0
Selenium (Se) (ug)	0.2	0
Arsenic (As) (ug)	0.6	NR
Chromium (Cr) (ug)	1.2	0
Copper (Cu) (mg)	0.091	NR
Fluoride (F) (ug)	80	NR
Manganese (Mn) (mg)	0.379	NR
Molybdenum (Mo) (ug)	4.3	3.3

Component	Cavendish	Lady finger
Nickel (Ni) (ug)	4	4
Phosphorus (P) (mg)	21	NR
Sodium (Na) (mg)	0	2
Retinol equivalents (ug)	6	8
Vitamin C (mg)	4	19
Vitamin E (mg)	0.12	NR
Thiamin (B1) (mg)	0.02	0.04
Riboflavin (B2) (mg)	0.047	0.07
Niacin (B3) (mg)	0.35	0.4
Niacin Equivalents (mg)	0.6	0.83
Alpha carotene (ug)	23	20
Beta carotene (ug)	23	35
Beta carotene equivalents (ug)	34	45
Tryptophan (mg/g N)	68	104
Tryptophan (mg)	15	25

[a] Data sourced from Food Science Australia New Zealand (FSANZ 2010).
NR – data not recorded

5.1 Toxins

There are no known significant toxic properties of the banana. Bananas contain high levels of biogenic amines such as dopamine and serotonin. High level intake of banana has previously been implicated in the occurrence of endomyocardial fibrosis (Foy & Parratt 1960). However, another study determined that serotonin is rapidly removed from circulating plasma and does thus not contribute to elevated levels of biogenic amines in healthy individuals (Ojo 1969). Subsequent studies by Shaper (1967) also determined that there is no evidence for implicating the banana/plantain as a factor in the cause of endomyocardial fibrosis.

5.2 Allergens

Allergic reactions to banana fruit occur and can take two different forms. One type of allergic reaction is related to an allergy to tree pollen such as birch (Informall 2006) and results in the oral allergy syndrome; symptoms include itching and swelling of the mouth and throat usually within one hour of ingestion. The allergic reactions are due to the allergen Mus xp 1, a profilin, which is an actin-binding protein of the cytoskeleton. The profilins are moderately stable proteins belonging to the pathogenesis related proteins (PRPs, Informall 2006), that are thought to be produced by the plant in response to infections or adverse environmental conditions (Breiteneder 2004). The profilins are more stable than Betv 1, a major birch-pollen related allergen, which also belongs to the PRP group of proteins. Profilin is an important mediator of IgE cross reactivity of antigens from different sources; cross reactivity between the banana profilin and birch profilin, Bet v 2 and the latex profilin Heb b 8 have been demonstrated (Grob et al. 2002). As a result of the widespread IgE cross-reactivity, this has led to the description of profilins as pan-allergens (Wagner & Breiteneder 2002).

A second type of allergic reaction to banana fruit is associated with a latex allergy. This type of allergy causes urticaria (severely itchy skin) and gastrointestinal symptoms. Anaphylaxis and recurrent loss of consciousness have been reported in severe cases (Cinquetti et al. 1995; Woltsche-Kahr & Kranke 1997). Anaphylaxis can also occur in people who are not allergic to latex (Reindl et al. 2002). People with latex allergy often also show an allergy to other fruits such as avocado, mango and kiwi fruit, and common IgE epitopes in latex, banana and avocado extract have been identified (Moller et al. 1998). Two of the major allergens of banana involved in the fruit-latex syndrome are the 32-33 and 34-37 kD class I chitinases known as Ba 1 and Ba 2, respectively. These are thermolabile proteins and cross react with hevein (Sanchez-Monge et al. 1999). Hevein-like, chitin-binding domains are highly conserved in many plant defence proteins. These proteins also belong to the PRP family PR3 and may have anti-plant pathogen activity.

Leone et al (2006) isolated a thaumatin like protein (TLP) from banana, Ban-TLP, which has a similar tertiary structure to the thaumatin like PR5 proteins. Some PR5 proteins have anti-fungal properties but the banana TLP is devoid of anti-fungal activity (Barre et al. 2000). X-ray crystallography has indicated that conserved residues of exposed epitopic determinants are likely to be responsible for the allergenic properties of this protein. It shares some structurally conserved IgE-binding epitopes with similar proteins from other fruits and pollen such as that of the mountain cedar (*Juniperus ashei*) (Leone et al. 2006).

5.3 Other undesirable phytochemicals

Several lectins have been isolated from banana fruit, including BanLec, which belongs to the mannose-specific jacalin-related lectins (Peumans et al. 2000). This lectin is an important murine T-cell mitogen and can induce human T-cell proliferation (Koshte et al. 1990). It is thought that the lectins in banana form a carbohydrate-protein complex in the pulp, since relatively low amounts of free lectin are present in the pulp prior to the addition of glucose or methyl-mannoside (Koshte et al. 1990; Mo et al. 2001). Jacalin-like lectins also have insecticidal properties and may play a possible role in plant defence (Peumans et al. 2000).

5.4 Beneficial phytochemicals

Banana fruits contain high levels of potassium, which has been shown to be important as a blood pressure regulating chemical. The banana is thus a food potentially beneficial to people with medical conditions associated with high blood pressure and hypertension (Whelton et al. 1997). The sweet banana contains a variety of beneficial chemicals; high levels of the biogenic amines such as dopamine and serotonin, and other antioxidants like vitamin C, vitamin E, beta carotene and flavonoids such as catechins, indole alkaloids and vitamin K. Banana pulp contains high levels dopamine and vitamin C (Kanazawa & Sakakibara 2000). The peel contains even higher levels of dopamine; it is thought that the production of high levels of antioxidants may minimise the damage from the oxidative stress resulting from intense sunlight. Dopamine has been determined to protect against intestinal mucosal injury through modulation of eicosanoid (signalling molecules) synthesis (MacNaughton & Wallace 1989; Alanko et al. 1992). Antiscorbitic (anti-scurvy) properties of the banana have also been demonstrated (Lewis 1919). The common sweet banana is relatively low in vitamin A. However two Fe'i banana cultivars, 'Uht en Yap' and 'Karat', which originate from regions in Asia, have up to 10 -275 times more β-carotene (a type of provitamin A carotenoid) than conventional Cavendish bananas (Englberger et al. 2003).

Green bananas have been reported to reduce the severity and duration of persistent diarrhoea (Rabbani et al. 2001; Rabbani et al. 2004). It is thought that the high levels of amylase resistant starch aids in this process through the stimulation of colonic salt and water absorption (Binder & Mehta 1989; Binder & Mehta 1990; Rabbani et al. 1999). It also protects against damage of the mucosal lining and improves peptic ulcers (Rabbani et al. 2001).

SECTION 6 ABIOTIC INTERACTIONS

Musa species have limited ranges of temperature tolerances within their natural habitats, which occur in warm or hot climates. No species is frost tolerant (Simmonds 1962). Sweet bananas are restricted to subtropical or tropical areas between 30^{o}N and 30^{o}S, with mean air temperature of 26.7^{o}C and a mean rainfall of 100 mm per month with no more than a 3 month dry season. Generally bananas require 20 - 60 mm per week as rainfall or supplied through irrigation (QDAF 2012d). Optimal root growth occurs between 22-25^{o}C; lower temperatures will slow root growth. Bananas can be grown in a wide range of soil types but perform best in well drained, clay-loam soil, preferably to a top soil depth of 50 cm. A north-easterly, north-westerly aspect, frost free and protected from cold, strong winds is preferred, with a slope of less than 15% (Broadley et al. 2004; Pattison & Lindsay 2006).

6.1 Abiotic stresses

6.1.1 Nutrient stress

Soils with a low pH solubilise elements such as aluminium and manganese that can be toxic and result in reduced root growth. Macronutrients required by banana plants include nitrogen, potassium, phosphorus, calcium, magnesium and sulphur. They require particularly large amounts of nitrogen and potassium. A lack of potassium can result in reduced buoyancy, which can interfere with post-harvest production line processes; the fruit sinks when the fruit is dipped in hot water for the treatment against certain diseases (Morton 1987). Supplementation of the soil with extra potassium can restore the buoyancy of the fruit. Other micronutrients required by bananas include boron, iron, manganese, copper, zinc, molybdenum, chlorine and cobalt. Deficiencies in these elements can lead, for example, to morphological malformation of the leaves, reduced growth and yield and poor fruit quality (Nelson et al. 2006). Boron deficiency can result in fruit that does not 'fill'(Broadley et al. 2004).

Bananas do not thrive in areas of high salinity, although some varieties are more tolerant than others. High levels of sodium result in reduced crop growth due to a reduction in osmotic pressure of the soil, which leads to an increase in ions that are toxic to the plant (Richards 1992; Bohra & Doerffling 1993; Gomes et al. 2002).

6.1.2 Temperature stress

Cool temperatures retard growth although susceptibility to the cold varies among cultivars (Broadley et al. 2004). Some examples of impact of cold on plant growth include: if low temperatures occur at the time of flowering the bud may not emerge from the stem; root growth will cease at temperatures below 13^{o}C; frosts kill the plant although the corm normally remains viable (Broadley et al. 2004). Planting on sunny hills of elevations of 60m to 300m assists in preventing cold air from reaching the plantation.

The fruit is also adversely affected by the cold and bunches may not fill or fruit may be discoloured (Broadley et al. 2004). November Bunch, associated with cool temperatures during bunch initiation, results in abnormal flowers, a reduction of hands of fruit and irregular sized, twisted fruit (Treverrow & Turner 2003). Choking occurs when the bunches fail to emerge properly from the pseudostem and are thus susceptible to sunburn (Treverrow & Turner 2003).

6.1.3 Water stress

Bananas have high water requirements, however waterlogging of the soil can result in oxygen starvation of the roots due to air spaces being filled with water. Oxygen deficiency for more than 6 hours results in root tip death, which in turn leads to branching of the roots (Pattison & Lindsay 2006). Plant roots become stunted or die, thus plants can no longer access required water or nutirents and plants are poorly anchored. A range of damage resulting from poor drainage and waterlogging include shallow root systems, smaller plants and bunches, choking, pseudostem breakage, discolouration or scorching of leaves, reduced fruit length and increased nematode damage (QDAF 2012d).

No species is highly drought resistant but there is a considerable range of drought tolerance. Very broadly, response to drought is correlated with natural habitat and ranges from natives of non-seasonal climates (*Australimusa* and *Callimusa*) being intolerant, to those from extreme monsoonal areas that have severe drought seasons (*Rhodochlamys*) showing drought evasion by dying down to the corm in dry weather and sprouting again with rain. Members of section *Musa* tend to show variable tolerance with *M. balbisiana* able to withstand weeks of dry weather while the Australian native species *M. acuminata* subsp. *banksii* has a much greater requirement for water (Simmonds 1962).

Periods of drought can lead to a reduction of root growth and root tip death. When sufficient water becomes available and roots recommence growing, it may result in multiple branching giving a 'witches broom' appearance (Pattison & Lindsay 2006). Plants can tolerate short periods of drought because of their water-filled energy reserves but may only produce small bunches of bananas (Nelson et al. 2006). Lack of water may also result in bunches that don't 'fill' (Broadley et al. 2004). Periodic water stress is also associated with 'maturity bronzing' manifested by discolouration of mature bananas and cracking of the skin (Nelson et al. 2006). Water stressed plants, which can include over- or under-watered plants, are more likely to suffer from a range of symptoms, including longer crop cycles, smaller bunches with shorter fruit, and increased pest and disease susceptibility (King 2013).

6.1.4 Other stresses

A soil pH of 5.5-7.5 is suitable for growing bananas, with a pH of 5.5 considered optimal (Broadley et al. 2004). Most soils in north Qld are naturally acidic. A low pH however solubilises elements like iron, aluminium and manganese; these can be toxic and have negative effects on the plant such as reduced root growth. This is exacerbated when the soil becomes waterlogged or has low carbon levels. A low pH also reduces the availability of other nutrients such as calcium. Careful fertiliser management reduces soil acidification. A pH higher than 6.5, can reduce the availability of trace elements such as boron, zinc, copper and iron (Broadley et al. 2004).

All *Musa* species grow best in the open sun providing moisture is not limiting (Simmonds 1962). While, they can withstand shade of up to 80%, a maximum of 50% shade is recommended. If they are shaded, plants have thinner pseudostems, reduced leaf production and suckering, delayed fruiting and production of smaller bunches. Deep shade causes stools to die (Simmonds 1962; Nelson et al. 2006).

Fire will generally not kill the banana plant; they recover by regrowing from the corm (Nelson et al. 2006).

High humidity, >95%, during the final stages of ripening can lead to 'splitting' of the fingers (Nelson et al. 2006).

Bananas are also susceptible to strong winds, which can twist and distort the crown, and, in extremes, uproot whole plantations especially after heavy rains. In areas prone to windy conditions, dwarf varieties are often grown (Nelson et al. 2006). The leaves can also be shredded by winds thus interfering with metabolism. Note, however that because of the large dimensions of the banana leaf, some tearing is believed to be beneficial as it effectively causes the leaf to be split into many smaller segments that lead to a more favourable photosynthesis to transpiration ratio during times of environmental stress (Taylor & Sexton 1972).

6.2 Abiotic tolerances

Musa species are tolerant of a wide range of soil types. The plants will grow and produce fruit in very poor soil conditions but will not flourish or be economically productive (Simmonds 1962; Morton 1987).

SECTION 7 BIOTIC INTERACTIONS

The most conspicuous biotic factor in banana ecology is competition with other plants and all species are quickly killed by deep shade, are intolerant of root competition and are particularly sensitive to the presence of grasses. This has important implications for plantation management (Simmonds 1962).

7.1 Weeds

Weeds compete with the banana plants for nutrients, especially nitrogen (Morton 1987). They can also be a refuge for pests and act as intermediates for diseases. Weeds are more of a problem in planted crops, as crops that are ratooned tend to shade out weeds (Broadley et al. 2004).

A number of methods are recommended for weed control in banana crops, including physical controls (slashing, suppression, mulching), cultural controls (companion planting, sprayed mulches) and chemical controls (King 2013).

7.2 Pests and diseases

The control of pests and diseases in the banana industry is vital to maintain the industry in Australia. A range of measures including restrictions on movement and cultivation of bananas and movement of related material are in place in the states and territories. As mentioned in Section 2.3.1, both Qld and NSW have adopted the QBAN system for production and distribution of banana plant material, and WA also has requirements for use of QBAN material. Individual state and territory websites have relevant information, which may be updated regularly to respond to specific pest or disease threats. Banana biosecurity zones are defined for states and territories. See Appendix 2 for maps of the Queensland and NSW biosecurity zones and the NT banana freckle eradication zones.

Further information about State regulations can be found in the Queensland Biosecurity Manual (Wilson 2015), Banana Industry Biosecurity Guideline (QDAF 2016a), Plant Quarantine Manual for New South Wales (NSW DPI 2016e), NT Government website and DAFWA website.

Information regarding pests and diseases of bananas can be accessed via state and territory websites in particular the QDAF and Business Queensland sites, as well as NSW DPI banana site. The Banana best management practices manual produced by QDAF (formerly DAFF) also contains information about integrated pest and disease management strategies for banana (King 2013).

NSW DPI also produces exotic pest alerts for pests that are considered a biosecurity risk due to the presence in neighbouring countries or regions and their potential to cause damage to the Australian banana industry (NSW DPI 2014; NSW DPI 2016c). Likewise, Plant Health Australia (PHA) has fact sheets on exotic pests which pose a biosecurity risk to the Australian banana industry that can be accessed through links contained in the Bananas page of their website.

7.2.1 Pests

Vertebrate pests, including nectar feeding birds, flying-foxes (also referred to as fruit bats) and sugar gliders can cause considerable damage to the banana fruit. Feral pigs have been known to cause damage to the banana plant and can also facilitate the spread of Panama Disease (Broadley et al. 2004). The common blossom bat (*Syconycteris australis*) is also known to feed on the blossoms of the native banana *M. acuminata* subsp. *banksii* (*M. banksii*) and commercial banana cultivars. Covering fruit adequately, use of other deterrents such as fragrant compounds, netting, scare guns and fake predatory birds as well as keeping ripe fruit out of crop paddocks are recommended as part of integrated pest management systems (King 2013).

Major invertebrate pests of banana in Australia are given in Table 12. The banana scab moth (*Nacoleia octasema*) is a frequent and severe pest of bananas (QDAF 2016b). *Heliconia* and *Pandanus* are the alternate host for this insect. The larvae feed on the young fruit causing superficial scarring which later forms a black callous in the curve of the finger adjacent to the bunch stalk, making the fruit unmarketable. The infestations are most severe in hot weather. The weevil borer (*Cosmopolites sordidu)* can have a large impact in southern areas. The larvae inflict damage on the plant by tunnelling within the corm just below the soil surface and large infestations can result in tunnelling a short distance up the pseudostem. This tunnelling weakens the plant and it may become susceptible to wind damage. Impact on the plant tends to be greater on slow growing and neglected plants.

Table 12. Major invertebrate pests affecting commercial bananas in Australia

Common and Scientific name	Occurrence	Damage	Prevention/Control	References
The banana aphid (*Pentalonia nigronervosa*)	Southern and northern Qld	The vector for the Banana Bunchy Top Virus (BBTV)	Biological control through ladybird beetles, earwigs and lacewing. Chemical control only if predator numbers are not sufficient.	(QDAF 2012g)
The spider mite (*Tetranychus lambi*)	Frequent and widespread in banana growing regions	Leaf damage and wilting which may lead to reduction of plant growth, damage to fruit causing purple colour and cracking	Reduction of dust on road and good farming practices. Predator insects may assist control including ladybirds, beetles and mites	(Biosecurity Australia 2007; QDAF 2012g; King 2013).
Silvering thrip and rust thrip (*Hercinothrips bicinctus* and *Chaetanophothrips signipennis*)	Qld and the North coast of NSW	Infects fruit. Silvery speckling with silvering thrip. Rusty red to brown-black discolouration , mainly on top hands,with skin splitting in serious cases for rust thrip.	Silvering thrip usually controlled by predator insects. Rust thrip some predators are effective, use of thrip-free planting material plus chemical controls including soil treatments.	(Treverrow 2002; Broadley et al. 2004; QDAF 2012g; King 2013)
Banana flower thrip (*Thrips hawaiiensis*)	Throughout banana growingareas, major pest in SE Qld and northern NSW, minor in N Qld	Causes corky scabs n fruit, mostly on the outer curve near bunch stalks	Predatory insects including bugs, ladybirds and lacewings. Removal of male bell to reduce populations and use of overhead irrigation may help control. Chemical treatment via bunch injection.	(QDAF 2012g; King 2013)
The banana fruit caterpillar (*Tiracola plagiata*)	Southern Qld especially plantings close to nearby scrub or rainforest, otherwise less important	Attacks the foliage and fruit of the banana plant	Sprays for sugarcane bud moth and rust thrip generally provide adequate control	(QDAF 2012g)
The banana fruit fly (*Bactrocera musae*)	Coastal regions north of Townsville	Destruction of fruit flesh	Minor infestations controlled naturally by several parasitoids that attack the maggot stage and reduce population of subsequent generations. Spot spraying selected areas using dimethoate is used if chemical treatment is required and the areas bordering the plantation should be targeted.	(Biosecurity Australia 2007; QDAF 2012g)
Queensland fruit fly (*Bactrocera tryoni*)	Western districts of Qld occasionally further south	Destruction of fruit flesh		

Common and Scientific name	Occurrence	Damage	Prevention/Control	References
The sugarcane bud moth (*Opogona glycyphaga*)	Qld, NSW and Carnarvon in WA	Superficial scarring of fruit	Spiders aid in the biological control of the moth. Severe infestations can be combated with chemical dusting at bagging.	(QDAF 2012g; King 2013)
Banana scab moth (*Nacoleia octasema*)	Only found north of Ingham in north Qld	Superficial scarring which later forms a black callous in the curve of the finger, can make fruit unmarketable	Biological control by spiders and natural predators, synchronised bunch cycle can aid control. Chemical control through bunch injections.	(QDAF 2012g; King 2013)
Fruit-piercing moth (*Eudocima spp.*)	From northern NSW to Darwin, dies out in southern areas over winter	Major but sporadic damage. Pierce skin causing bruiing and dry areas, secondary rots and secondary feeding occurs at these site.	Control methods not determined but some predatory wasps may assist, with baggin or netting.	(QDAF 2012g)
Banana-spotting bug (*Amblypelta lutescens lutescens*)	Coastal, sub-coastal southern Qld	Black spots in fruit, may be fruit shedding of youger fruit, larger fruit dimpled, may be confused with fruit-fly dmage	Egg parasites are under investigation, green tree ants and assassin bugs provide some control. Regular chemical spraying.	(QDAF 2012g)
The root lesion nematodes (*Pratylenchus coffeae* and *Pratylechus goodeyi*)	*Pratylenchus coffeae* in Northern Qld and *Pratylechus goodeyi* in NSW	Damage to the root system can lead to stunted growth, low bunch weight and longer ripening times, toppling in high winds	Immersing of the corm in either hot water-55 degrees for 20 minutes or in solutions of non-volatile Nemacur or Mocap. Injecting the corms with glyphosate. Sugarcane ash has been shown to suppress nematodes. Chemical control.	(Morton 1987; Bridge et al. 1997; Stirling et al. 2002; Hodda 2003; Lindsay et al. 2003; Biosecurity Australia 2007). (Broadley et al. 2004; Grice et al. 2009; King 2013)
Root burrowing nematode (*Radopholus similis*)**, spiral nematode** *Helicotylenchus multicinctus* and **root-knot nematode** (*Meloidogyne* spp.)	All banana growing regions	Not deemed very important		
The weevil borer (*Cosmopolites sordidus*)	Qld especially southern regions The potential threat of the weevil has increased due to the development of resistance to cyclodienes and organophosphates	Tunnelling within the corm just below the soil surface, large infestations can result in tunnelling a short distance up the pseudostem, weakening the plant making it susceptible to wind damage.	Good plantation hygiene practices, cane-toads ants and beetles can provide a level biological control. Injection of old stems with insecticides, use of bait systems; gouge bait, axe baits and wedge baits. Butt spraying is the most effective method of control.	(King 2013; Meldrum et al. 2013)

7.2.2 Diseases

Bananas can be affected by a variety of diseases, and the relative susceptibility of bananas to important banana diseases differs between cultivars. Currently Panama Disease (*Fusarium oxysporum* f. sp. *cubense*) tropical race 4 (Foc Tr4), Cavendish competent *Fusarium oxysporum* f. sp. *cubense* tropical race 1, Banana Freckle Disease and Banana Bunchy Top Virus (BBTV) are are listed as 'banana pests' for the purpose of biosecurity regulations in Qld (State of Queensland 2016). Several diseases including Moko, Blood Disease, Eumusae leaf spot and Banana Bract Mosaic Virus are currently not a problem in Australia, while Black Sigatoka was eradicated in 2005 following an outbreak in Qld in 2001 (NSW DPI 2013b). However, these diseases are considered a biosecurity threat due to their presence in nearby regions and their potential to cause damage to the local banana industry (Grice et al. 2009; PHA 2014; NSW DPI 2016d). There are also a number of diseases that are not present in particular areas of Australia, but are considered a potential threat in these areas because of their presence in other banana growing regions in Australia. For example, Foc TR4, banana bunchy top virus, and banana streak disease are not present in the Ord River Irrigation Area (ORIA), but are present in other Australian banana growing areas (DAFWA 2016b).

Biosecurity restrictions in various states and territories are designed to protect against pests and diseases. There are four biosecurity zones in Qld, including the northern banana biosecurity zone and the southern banana biosecurity zone. There are restrictions on growing bananas in the biosecurity zones including specifications on the number of plants and disease resistance status of cultivars grown in these areas (State of Queensland 2016). Strict controls are in place regarding the movement of banana pest carriers (including plant material and related items such as soil or equipment) into, out of and within biosecurity zones and material to be moved must be certified free of a number of banana diseases and pests . The Biosecurity Regulation 2016 and the Banana Industry Biosecurity Guidleline provide further information (State of Queensland 2016; QDAF 2016a). Specific standards and guidelines and legislative requirements are in place in Qld for Panama disease tropical race 4, which will be discussed further in the section on that disease following Table 13. NSW also controls the movement of banana material for control of diseases (Banana Bunchy Top Virus and Panama Disease) Order 2015 (OR121)) (NSW DPI 2016b). The NT has restrictions on movement and planting of bananas with focus on prevention of banana freckle and has declared eradication zones for control of that disease.

Table 13 summarises the major banana diseases in Australia. These are discussed in more detail following the table.

Table 13. Major diseases affecting commercial bananas in Australia

Disease + causal organism	Occurrence	Damage	Prevention/Control	References
Panama disease: the fungus *Fusarium oxysporum* f. sp. *cubense* (Foc)	Race 1: Qld and NSW; Race 2: contained in north Qld Race 3: not considered a problem Race 4 : Found in the NT. Detected in 2015 and confirmed in 2016 in Tully (Qld). So far has not spread beyond this property.	Spreading of infection in the plant causing death	Eradicating infections, weed control within the banana plantations and strict quarantine practices have restricted the spread. The development of resistant varieties is considered to be the long term solution. Work still needed on disease development to enable understanding which may be used for development of long-term controls.	(Hennessy et al. 2005; NSW DPI 2015; Ploetz 2015a; Ploetz 2015b; DAFWA 2016b; QDAF 2016c; PROMUSA 2016f)
Yellow Sigatoka (leaf spot): the fungus *Mycosphaerella musicola*.	Serious in tropical growing regions	Delay in bunch filling, resulting in mixed ripened bunched and ultimately reduced marketability	Deleafing, fungicide application	(QDAF 2012b; CropLife Australia 2015; QDAF 2016a; DAFWA 2016b; PROMUSA 2016i)
Black Sigatoka (black leaf disease): the fungus *Mycosphaerella fijiensis*	Cape York, Weipa and Daintree (not in commercial mainland plantations). Successfully eradicated, mainland Australia's disease-free status for black Sigatoka in 2005.	Fruit losses occur due to the reduction in functional leaf surface area resulting in loss of photosynthetic capabilities. Symptoms can be confused with Yellow sigatoka or with Eumusae spot (not currently in Australia).	Deleafing; fungicides for pre-necrotic stages of disease.	(Biosecurity Australia 2007; QDAF 2011; QDAF 2012b; NSW DPI 2013b; PROMUSA 2016c)
Banana bunchy top virus (BBTV)	South eastern Qld, south of Cooloobin and the Tweed and Brunswick River valleys of northern NSW but has not been detected in WA, the NT, North Qld or the Coffs Harbour region of NSW	Yellowing of the leaf with subsequent withering and death	There is no treatment, affected plants must be destroyed. There are strict quarantine restrictions to prevent movement of contaminated planting material. Control of banana aphids is recommended. The NSW Plant Diseases (Banana Bunchy Top Virus and Panama Disease) Order 2013 requires aphid treatment and destroying of affected plant material.	(Biosecurity Australia 2007; ABGC 2016a; QDAF 2016a; NSW DPI 2016b; DAFWA 2016b; PROMUSA 2016d)
Banana freckle: the fungi *Phyllosticta cavendishii* and	Has occurred in NSW, Qld and more recently in Cavendish in remote areas of	Severe infections result in yellowing of the leaf with	Cannot be eradicated by chemical application, plants must be removed. An	(Biosecurity Australia 2007; PHA 2015; NT Government

Disease + causal organism	Occurrence	Damage	Prevention/Control	References
Guignardia musae	WA. In 2013 it was detected in Cavendish in the NT.	subsequent withering and death	eradication program is underway in the NT.	2016)
Banana Streak Disease: the virus banana streak virus **(BSV)**	Minor importance in Cavendish and Lady finger in Qld, more serious in newer hybrid cultivars. Inthese viral genome becomes incorporatied in to banana genome and is carried latently, can emerge to produce infections.	Variable can disappear and reappear. Commonly chlorotic and necrotic streaks, symptoms can include splitting of leaf sheaths and pseudostems and bunch effects.	Plantings of BSV free material; quarantine restrictions.	(Grice et al. 2009)

Panama Disease

Panama disease manifests as both internal and external symtoms. Internal symptoms include discolouration of vascular tissue in roots and corms with colouring varying with increased time of infection. External symptoms include yellowing of leaves, beginning at leaf edges and moving inwards, and wilting of leaves. Leaf symptoms progress from oldest to youngest leaves, with older leaves turning brown, wilting and collapsing while younger leaves initially remain upright and green (NSW DPI 2015; QDAF 2016d). Fruit of infected plants appears symptomless (NSW DPI 2015).

There are four 'physiological' races of Panama disease based on their difference in pathogenicity, Races 1, 2, 3 and 4. Race 4 has been subdivided further into another two strains, Subtropical race 4 and Tropical race 4 (FocTR4).

Subtropical race 4 is present in southern Qld and northern NSW but has not been detected in WA. It has been under quarantine control in south east Qld, northern NSW and WA for some time (NSW DPI 2015; DAFWA 2016a; QDAF 2016d). Cavendish cultivars generally only show symptoms after a period of cold stress (QDAF 2016c).

Tropical race 4 (Foc Tr4) was detected near Darwin in 1997 and in 2015 it was deteted at a property in Qld, which remains under quarantine. So far it has not spread to other properties (QDAF 2016c; QDAF 2016d). Foc Tr4 is particularly destructive in that it attacks unstressed plants. The disease is spread through infected planting material, via root contact, from parents to suckers and through movement of soil, water or contaminated equipment (QDAF 2016c). There is also investigation of whether the banana weevil borer is a vector for Foc Tr4 (Meldrum et al. 2013). Primary hosts of this disease include cultivated banana, *M. acuminata* (wild banana) and *M. textilis* (Manila hemp). Strict quarantine practices have helped in restricting the spread of this disease. Weeds collected within banana plantations were also shown to be infested with FocTR4 in northern Australia, illustrating the importance of weed control within banana plantations (Hennessy et al. 2005). Reviews summarise the available information about Foc Tr4, the history and pathology of the disease and cultivars which are resistant to this pathogen (Ploetz 2015a; Ploetz 2015b).

Yellow Sigatoka

Yellow sigatoka infection develops through a number of distinct stages, from light yellow or green-brown streaks parallel to the veins through to mature grey-dark brown/black spots sometimes with a yellowish halo. If spots are large they may form large dead areas (Grice et al. 2009; PROMUSA 2016i). The fungus produces two types of spores, conidia and ascospores . The conidia are produced on the top of the leaf surface and disperse in wet and windy weather, with infection most likely in southern Qld from December to March, although the disease occurs year round. Ascospores are produced within the plant tissue and are produced in warm, moist conditions. These ascospores generally produce tip-spotting in young leaves, unlike conoidial infections which produce line-spotting or scattered infection (Grice et al. 2009).

Banana growers in the northern banana biosecurity zone are required to remove infested leaves from the plant and leave them to rot on the soil surface (QDAF 2016a). Infection is also treated with fungicides and specific guidelines are available for far north Qld and other areas to manage resistance to fungicides (CropLife Australia 2015).

Black Sigatoka

Black sigatoka (*Mycospaerella fijiensis*; also referred to as Black leaf streak) is more virulent, has a shorter lifecycle and is harder to control than Yellow sigatoka (Grice et al. 2009). It is considered a biosecurity risk to the Autralian banana industry (Grice et al. 2009; QDAF 2011; NSW DPI 2013b; PROMUSA 2016c). There are six stages of symptom development (NSW DPI 2013b) and symptoms can be quite similar to Yellow sigatoka and to Eumusa streak (not present in Australia) (QDAF 2011). Outbreaks of the infection have been recorded in several regions (not in commercial plantations)

including Cape York, Weipa and Daintree. However, it has been eradicated each time it was encountered and has not spread outside Cape York Peninsula. One outbreak occurred in a commercial production area, but the disease was eradicated and Australia has regained disease-free status for black sigatoka (QDAF 2011). Infection is favoured by hot humid and windy weather (Grice et al. 2009; QDAF 2011). Treatment involves deleafing to reduce the spread of the disease and spraying with fungicide (PROMUSA 2016c). A number of cultivars are considered to be resistant to black sigatoka: Blua Java, Bluggoe, Ducasse, FHIA 01 (Goldfinger), FHIA 02, FHIA 25, Kluai Namwa Khom (Dwarf Ducasse), Pisang Ceylan (Mysore type), SH 3436, Simoi, Tu–8 and Yangambi Km5 (Wilson 2015).

Banana bunchy top virus (BBTV)

Upon initial infection with BBTV, dark green streaks appear on leaves, midribs and stalks. Streaks sometimes appear on flower bracts as the disease progresses. Short, narrow leaves and upright clustering of leaves at the top of the plant may also occur. Infected plants rarely produce fruit and any fruit is usually stunted (NSW DPI 2016a; ABGC 2016a). BBTV infection is transmitted through an aphid vector *Pentalonia nigronervosa* and over longer distances by infected planting material (NSW DPI 2016a; ABGC 2016a). Details of mandatory aphid control and the subsequent destruction of infected plants are prescribed by Plant Diseases (Banana Bunchy Top Virus and Panama Disease) Order 2013 (NSW Department of Primary Industries reference Order OR117) (New South Wales Government 2013) and are outlined in industry and government publications (ABGC 2016a; NSW DPI 2016b). Restrictions on movement of banana planting material and products is also specified by the same order (NSW DPI 2016b) for the NSW banana protected area (see Appendix 2b). To date, the disease has occurred in south eastern Qld, south of Cooloobin and the Tweed and Brunswick River valleys of northern NSW, but has not been detected in WA, the NT, northern Qld or the Coffs Harbour region of NSW (NSW DPI 2016a). The virus infects cultivated and wild bananas in the *Musaceae* family (NSW DPI 2016a).

Banana freckle

Banana freckle is caused by the fungi *Phyllosticta cavendishii* and *P. maculata* (previously *Guignardia musae* - Mycobank, accessed 16/09/2016). The *P. maculata* fungus infects Lady Finger and Bluggoe and related varietes, while *P. cavendishii* infects Cavendish banana (NSW DPI 2013a; NT Government 2016). Outbreaks of *P. cavendishii* are a biosecurity concern for the industry. Symptoms include dark brown/black spots that can run together to form streaks on the leaves and fruit. Severe infections result in yellowing of the leaf with subsequent withering and death. The disease spreads through transport of infected plant material or through spores; conidia and ascospores. Spread through conidia occurs in the wetter months, while ascospore-mediated spread occurs in the drier cooler months (Biosecurity Australia 2007; Grice et al. 2009; NSW DPI 2013a; PHA 2015; NT Government 2016). Banana freckle was detected in the NT in 2013 (NSW DPI 2013a; PHA 2015; NT Government 2016) where an eradication program is underway. All banana plants were removed before May 2015 in six eradication zones ('red' zones) and, as of May 2016, banana plants can be purchased under strict guidelines with permits for replanting(NT Government 2016). For more information, see the NT Government Banana freckle eradication site. The native banana *M. acuminata* subsp. *banksii* (*M. banksii*) is susceptible to the disease (Biosecurity Australia 2007). Infected plant material must be removed as banana freckle fungus cannot be eradicated by chemical treatment (NT Government 2016).

SECTION 8 WEEDINESS

Weeds are plants that spread and persist outside their natural geographic range or intended growing areas such as farms or gardens. Weediness in Australia is often correlated with weediness of the plant, or a close relative, elsewhere in the world (Panetta 1993; Pheloung et al. 1999). The likelihood of weediness is increased by repeated intentional introductions of plants outside their natural

geographic range that increase the opportunity for plants to establish and spread into new environments, e.g. escapes of commonly used garden plants (Groves et al. 2005).

Characteristics in plants that are generally associated with weediness include prolonged seed dormancy, long persistence of seeds in the soil, germination under a broad range of environmental conditions, rapid vegetative growth, short lifecycle, very high seed output, high seed dispersal and long-distance seed dispersal (Keeler 1989; Keeler et al. 1996).

8.1 Weediness status on a global scale

Although plants in the genus *Musa* are generally persistent and compete well with other plants in an agricultural setting, they are not considered to be invasive. The seeds of some varieties have the potential to spread and become pests through being eaten by birds, bats and other vertebrates (Nelson et al. 2006). As described in Section 4.3, the vast majority of cultivated sweet bananas are seedless and generally do not reproduce sexually.

In the wet tropics, wild banana plants tend to briefly occupy a site during the process of ecological succession and their existence is quickly terminated by competition. Wild species rarely propagate vegetatively although it is possible for suckers to be broken off a parent plant and carried away by water or landslip. Seed propagation and a short life-span appear to be the normal life cycle. This is in contrast to cultivated bananas where vegetative propagation is so significant (Simmonds 1962).

8.2 Weediness status in Australia

There are two recognised *Musa* species that are native to Australia, *M. acuminata* subsp. *banksii* (*M. banksii*) and *M. jackeyi* (Ross 1987). *M. acuminata* subsp. *banksii* is the most common and can be found along the tip of Cape York and northern Qld. It produces large viable seed. *M. jackeyi* has been reportedly found in Bellenden Ker and Cooktown and is considered rare by the World Conservation Monitoring Center (WCMC). Neither of these species is classed as a weed.

Other species such as *M. acuminata* and *M. x paradisiaca* are classified as a 'class 1' weed in Qld. Class 1 weeds may be naturalised and a minor problem but do not warrant control at any location (Groves et al. 2003). Some diploid banana species have been found in northern NSW and these have the capacity to spread through seeds being eaten by vertebrates, such as bats, and birds (Bevan 2006). In the Northern Australia feral bananas tend not to be a significant problem because they die during the dry season, unless irrigated (DPIFM 2006). Banana seed has the potential to be dormant in the soil for at least a year (Ellis et al. 1985).

Any banana plants that belong to the *Musa* or *Ensete* genus, other than those that produce edible fruit (e.g. commercial cultivars), or are a non-volunteer indigenous plant, are considered to be potential weeds. This is especially the case in isolated areas where control would be difficult (Lindsay et al. 1999). The fruits of these plants often contain viable seeds that can be spread by animals that feed on them. In addition these plants can harbour pests and diseases that affect edible bananas. *Musa* plants that have potential to become weeds in Australia are ornamentals that may 'escape' from domestic gardens and include *M. basjoo* (Japanese banana), *M. ensete*, *M. ornata*, *M. paradisiaca royalii*, *M. velutina* and *M.violacea*.

Commercial banana cultivars do not pose a weed problem in Australia, mainly because of their low fertility (see Section 4.1.2). Compared with the diploid *M. acuminata* with 71% pollen viability, commercial triploid cultivars have low viability, for example 'Ducasse' with 20%, 'Gros Michel' 13.5% and 'Dwarf Cavendish' 9% (Fortescue & Turner 2004). Extreme erosion as a result of heavy rains or cyclone associated weather can result in exposure of the roots and suckers of banana plants, especially those that are planted on slopes. In such cases the suckers of the banana plant could be dislodged and become part of the run off thus allowing the plant to be spread outside of the plantation setting. However, there are no reports of this occurring. Furthermore, State Legislation to

prevent the spread of disease is also effective in ensuring that any volunteers must be destroyed (Queensland Government 1999).

8.3 Weediness in agricultural ecosystems

Commercially grown bananas in Australia reproduce vegetatively only. They are not known to be a weed, except if previous crops have not been removed properly prior to the planting of subsequent 'crops'. Removal of unwanted corms prior to cultivation of the subsequent crop is achieved using the methods outlined in Section 8.5.

8.4 Weediness in natural ecosystems

Near Tumbulgum in northern NSW, individual plants of seeded bananas are an ongoing problem. These bananas are similar to the 'Ducasse' variety, but distinctly different from varieties such as 'Cavendish', 'Lady Finger' and 'Goldfinger' and can contain up to 50 small pebble sized seeds. More recently a weedy diploid species has also been found in several locations in and around Lismore, NSW (NSW DPI 2006). In 2012, seeded bananas were noted as a potential new weed incursion in northern NSW, with information supplied regarding the identification, dispersal, habitat and control of seeded bananas in NSW (FNCW & CMA Northern Rivers 2012). Seed from illegally obtained varieties, such as *M. ornata, M. velutin*a and *Ensete ventricosum*, may exist in natural ecosystems, along creek beds and forests, and other inaccessible areas, even though authorities target these plants for removal and control (Biosecurity Australia 2007). These plants have the capacity to spread through seeds being eaten by vertebrates, such as bats, birds, possums and other mammals (Bevan 2006; FNCW & CMA Northern Rivers 2012). Feral plants can also be spread when the rhizomes of ornamental varieties are discarded by householders.

Spread of bananas through seeds in a natural environment is dependent on a variety of factors. *M. acuminata* and *M. balbsiana* seeds that are released into the environment in ripe fruit that has fallen to the ground in general do not have a high survival rate or viability. Seeds that become buried in the soil may have their viability somewhat preserved, with carbon dioxide concentration implicated as an important factor in preserving seed viability (Simmonds 1959b).

Normally wild bananas that grow in natural environments rely on the dispersal of their seeds by vertebrates such as bats and birds. Seeds of *M. acuminata* that fall to the ground may, under optimal conditions remain dormant for up to a year (Simmonds 1959b). In general, seeds that have fallen to the ground and survive may germinate but then die. Seeds are known to germinate after disturbance of the site after for example, a landslide. Simmonds (1959b) observed a number of germinated, small seedlings of *M. acuminata* subsp. *banksii* in Qld in the last century.

8.5 Control measures

Bananas can be killed through either chemical or non-chemical means. Non-chemical destruction involves digging out the pseudostem, suckers, corms or rhizomes, using a modified crowbar or special desuckering shovel, and chopping them up. This is very laborious and all remaining eyes need to be destroyed to avoid re-shooting. Land owners or occupiers in the far northern biosecurity zones 1 and 2 in Queensland must treat unmanaged banana plants by removing and cutting plant material as specified in the Queensland Biosecurity Manual (Wilson 2015).

The chemical destruction method uses an application of a solution of 2,4-dichlorophenoxyacetic acid (2,4-D) amine, glyphosate or diesel to the cut stumps, or injection into the stem close to the growing point (Lindsay et al. 2003). Destruction or removal of unwanted suckers involves application of mixtures of 2,4-D, diesel distillate and kerosene. Good management practices including the killing and removal of unwanted corms is an essential component of integrated pest management (Lindsay et al. 2003). Injecting the corms with glyphosate is an also effective method in pest management; the corms die faster thus removing any live plant material available as a breeding ground for pests and pathogens (Lindsay et al. 2003). Chemical destruction of suckers or of banana plants can be

undertaken using chemicals approved under Australian Pesticides and Veterinary Medicines Authority (APVMA) regulations and as specified in permits from the APVMA.

More information about control of banana plants can be found through the state and territory departments and the ABGC.

SECTION 9 POTENTIAL FOR VERTICAL GENE TRANSFER

9.1 Intraspecific crossing

The commercial sweet banana cultivars are effectively sterile and therefore the chances of natural intraspecific hybridisation are remote (see also Sections 2.4.1. and 4.1.2.). In addition, the agricultural practices of covering bunches (see Section 2.3.5), would prevent any seeds that may develop being eaten for example, by bats and birds (Fortescue & Turner 2005; Bevan 2006).

Introgression (backcrossing of hybrids of two plant populations to introduce new genes into a wild population) between subspecies of *M.acuminata* can theoretically occur in nature providing that the parents are sympatric (share the same geographical range). There is genetic evidence of spontaneous hybridisation of *M. acuminata* with wild relatives (Ellstrand 2003). In cultivation, hybrids produced from crosses within subspecies of *M. acuminata* tend to be vigorous and fairly fertile (Simmonds 1962). *M.acuminata* subsp. *banksii* is a native diploid banana found in northern Qld and has the potential to cross with cultivated triploid and tetraploid cultivars with a *M. acuminata* background. However, the commercial varieties grown in Australia are both male and female sterile and as such rarely produce viable pollen or viable seed.

9.2 Natural interspecific crossing

Generally, species within the genus *Musa* are regarded as being reproductively isolated (Simmonds 1962). It is, however, relevant to consider the possibility of hybridisation in terms of species with the same chromosome number. As noted in Section 9.1, the realisation of natural hybridisation can only occur when species are sympatric. Species within the sections *Musa* and *Rhodochlamys* both have 2n = 2x = 22. Although the composition of the sections has changed somewhat since Simmonds (1962) wrote about reproductive isolation within and between the sections, his comments provide a useful background. He suggests that species within *Musa* are highly differentiated and thus reproductively isolated, while those in *Rhodochlamys* are less differentiated and introgression between wild populations is likely providing the species are sympatric. Interestingly, crosses between *M. acuminata* (*Musa*) and species within *Rhodochlamys* can produce hybrids albeit with low fertility.

Species within *Australimusa* and *Callimusa* both have 2n = 2x = 20. Those within *Australimusa* generally cross readily and yield vigorous hybrids. The crossing relationships within C*allimusa* have not been widely studied.

Simmonds (1962) noted that the following natural interspecific crosses had been observed:

- *M. balbisiana* x *M. acuminata* (*Musa* x *Musa*)
- *M. nagensium* x *M. balbisiana* (*Musa* x *Musa*)
- *M. balbisiana* x *M. sikkimensis* (*Musa* x *Musa*)
- *M. balbisiana* x *M. textilis* (*Musa* x *Australimusa*)
- *M. flaviflora* x *M. velutina* (*Musa* x *Rhodochlamys*)

There are a number of factors that should be considered in relation to interspecific crosses within the genus (Simmonds 1962):

- *Pollen tube growth and fertilisation*. Even in very distant crosses, which differ in basic chromosome numbers, ovule swelling occurs after pollination. This indicates that isolation occurs at or before fertilisation.

- *Seed yields from interspecific crosses*. Results are highly variable but suggest that wide natural crosses (e.g. *M. balbisiana* x *M. textilis*) can still yield some viable seed.
- *Hybrid viability*. Results from a range of wide crosses indicate that resulting hybrids may show a spectrum of viability ranging from zygote inviability through to weak young plants to vigorous, flowering mature plants.
- *Hybrid meiosis and fertility*. The pairing of chromosomes at first metaphase of meiosis in a hybrid varies from normal to extremely low and can contribute significantly to reproductive isolation. Irrespective of the degree of pairing, fertility tends to be much lower than in the parents. In wild species, there is usually seed fertility of 200 – 700 seeds/1,000 ovules whereas in hybrids, even in those between parents with the same chromosome number, fertility may be 0 – 180 seeds /1,000 ovules.
- *Meiotic breakdown*. This occurs frequently in interspecific hybrids and may lead to female flowers that produce giant embryo sacs and undesirable pentaploid progeny following pollination, and male flowers that are sterile.

The above discussion, while relevant to a consideration of crosses between wild species of *Musa*, is not particularly relevant to crosses involving a cultivated variety that may carry a varying incidence of sterility factors superimposed on parthenocarpy (see Section 4.1.2 for a more detailed discussion). The outcome of this is to render the likelihood of successful natural crossing close to zero where a cultivated variety is one of the parents.

9.3 Crossing under experimental conditions

Hybridisation is possible with judicious selection of male and female parents (Simmonds 1962). With regard to crosses involving a cultivated parent: *M. balbisiana* is an ineffective male parent in crosses with AAA genome types (e.g. 'Cavendish', 'Williams', 'Mons Mari') but is better with AAB (e.g. Lady Finger') and ABB (e.g. 'Bluggoe') genomes. *M. acuminata*, on the other hand, is a less effective pollen parent than *M. balbisiana* for the AAB and ABB genomes. Female fertility in the resulting hybrid, however, increases with increasing *M. balbisiana* contribution (see Section 4.1). Edible AA diploids have been used both as female and male parents. The AA cultivar 'Pisang Lilin' is a particularly good male parent (50% male fertile) and has produced many viable diploids when crossed to other edible diploids but it is a poor female parent (Simmonds 1962).

Simmonds (1962) listed the viability of hybrids of a number of crosses made within and between wild species of the *Musa* and *Rhodochlamys* sections (Table 14).

Even if seed is obtained the seed yield of hybrids in breeding programs is usually low and germination is extremely variable and relatively difficult (Stotzky et al. 1962). This often means that germination with a large number of seeds has to be attempted in order for a few viable seedlings to be produced. *In vitro* embryo culture has been proposed as a method for obtaining seedlings although it is a painstaking task to remove the 0.7 – 1 mm diameter embryo from inside the hard seed coat. The technique has been applied successfully to non-hybrid embryos from seeds of *M. velutina* (Pancholi et al. 1995) and *M. balbisiana* (Afele & De Langhe 1991).

The recent finding that it may be the incorrect positioning of embryo sacs in ovules that leads to the lack of fertility in many triploids (see also Section 4.1.2) would suggest that breeding potential could be more effectively exploited by removing the ovules from the flowers of triploids and pollinating them *in vitro* (Fortescue & Turner 2005).

Table 14. The viability of hybrids obtained from crosses between species from *Musa* and *Rhodochlamys*[a]

Male parent / Female parent	*ac*	*ba*	*bj*	*it*	*la*	*or*	*sa*	*ve*
Musa *acuminata (ac)*		weak	weak - inviable	***fairly vigorous***	***vigorous***	***vigorous***	barely viable	seedlings weak, but ***vigorous if plants reach maturity***
balbisiana (ba)	**vigorous**		***fairly vigorous***	inviable	***vigorous***	weak - inviable	very weak seedlings ***but vigorous if plants survive***	weak
basjoo (bj)	weak - inviable	inviable		fairly vigorous	weak	inviable	very poor germination	crossing difficult
itinerans (it)	***fairly vigorous***	inviable	weak - inviable		weak	inviable	inviable	weak – inviable
Rhodochlamys *laterita (la)*	***vigorous***	***moderately vigorous***	weak	weak		inviable	very. poor germination	***fairly vigorous***
ornata (or)	***vigorous***	weak - inviable	inviable	inviable	seedlings weak ***but vigorous if plants survive***		inviable	Vigorous
sanguinea (sa)	barely viable	weak - inviable	very poor germination	inviable	very poor germination	inviable		Weak
velutina (ve)	seedlings weak	***fairly vigorous***	crossing difficult	weak - inviable	***poorly vigorous***	weak - inviable	vigorous	

[a] Adapted from Simmonds (1962)

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APPENDICES

Appendix 1a: Species of new world tropical bats pollinating *Musa* spp.[a]

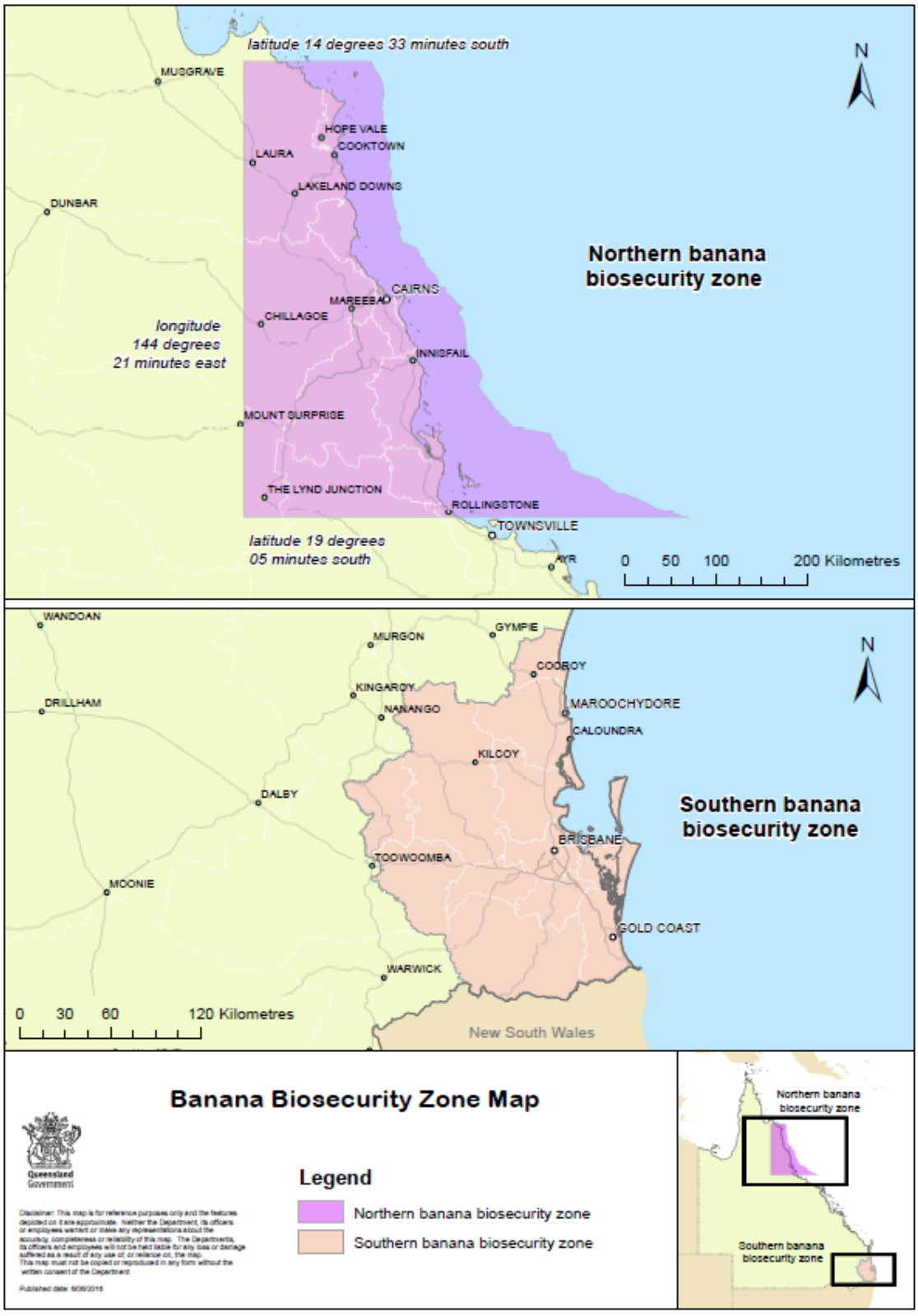
Musa Species	Bat Species
M. acuminata	*Carollia perspicillata*
M. acuminata	*Glossophaga soricina*
M. acuminata	*Platyrrhinus lineatus*
M. paradisiaca	*Anoura caudifer*
M. paradisiaca	*Phyllostomus hastatus*
Musa (unspecified)	*Artibeus jamaicensis*
Musa (unspecified)	*Carollia perspicillata*
Musa (unspecified)	*Choeronycteris harrisoni*
Musa (unspecified)	*Choeronycteris mexicana*
Musa (unspecified)	*Glossophaga commissarisi*
Musa (unspecified)	*Glossophaga soricina*
Musa (unspecified)	*Hylonycteris underwoodi*
Musa (unspecified)	*Leptonycteris curasoae*
Musa (unspecified)	*Leptonycteris nivalis*
Musa (unspecified)	*Leptonycteris sanborni*
Musa (unspecified)	*Leptonycteris yerbabuenae*
Musa (unspecified)	*Lonchophylla concava*
Musa (unspecified)	*Lonchophylla mordax*
Musa (unspecified)	*Lonchophylla robusta*
Musa (unspecified)	*Lonchophylla thomasi*
Musa (unspecified)	*Musonycteris harrisoni*
Musa (unspecified)	*Phyllostomus discolor*
Musa (unspecified)	*Vampyrops lineatus*

Appendix 1b: Species of new world tropical bats dispersing seed of *Musa* spp.[a]

Musa Species	Bat Species
M. paradisiaca	*Anoura caudifer*
M. paradisiaca	*Artibeus jamaicensis*
M. paradisiaca	*Artibeus lituratus*
M. paradisiaca	*Glossophaga soricina*
M. paradisiaca	*Micronycteris megalotis*
Musa (unspecified)	*Phyllostomus hastatus*
Musa (unspecified)	*Carollia brevicauda*
Musa (unspecified)	*Carollia perspicillata*
Musa (unspecified)	*Glossophaga soricina*
Musa (unspecified)	*Phyllostomus discolor*
Musa (unspecified)	*Phyllostomus hastatus*
Musa (unspecified)	*Sturnira lilium*
Musa (unspecified)	*Sturnira mordax*
Musa (unspecified)	*Uroderma bilobatum*

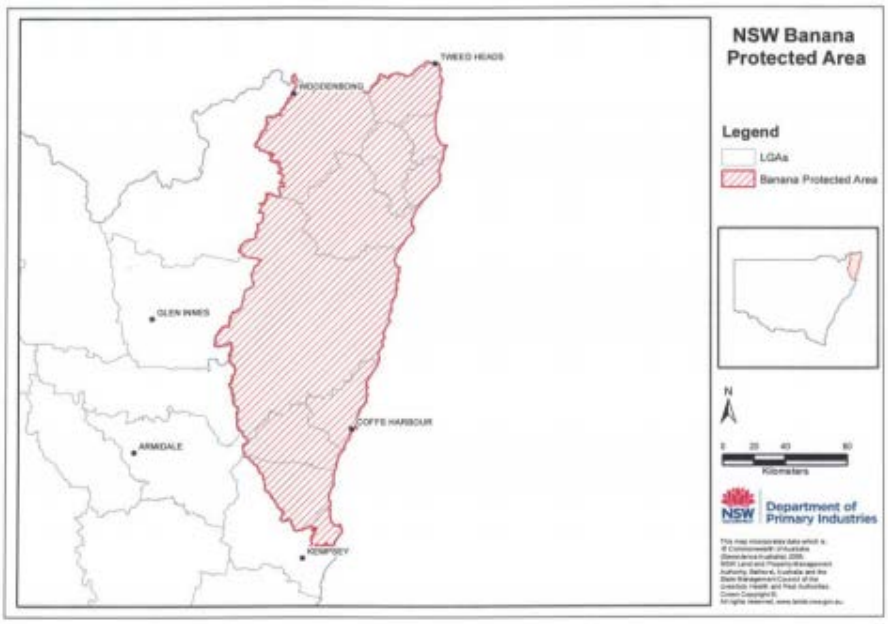
[a] Data for both Appendices derived from the Database of Neotropical Bat/Plant Interactions (Geiselman et al. 2002). The plant and bat names are as reported in the original publication and are not necessarily currently accepted names.

Appendix 2a: Queensland banana biosecurity zones map



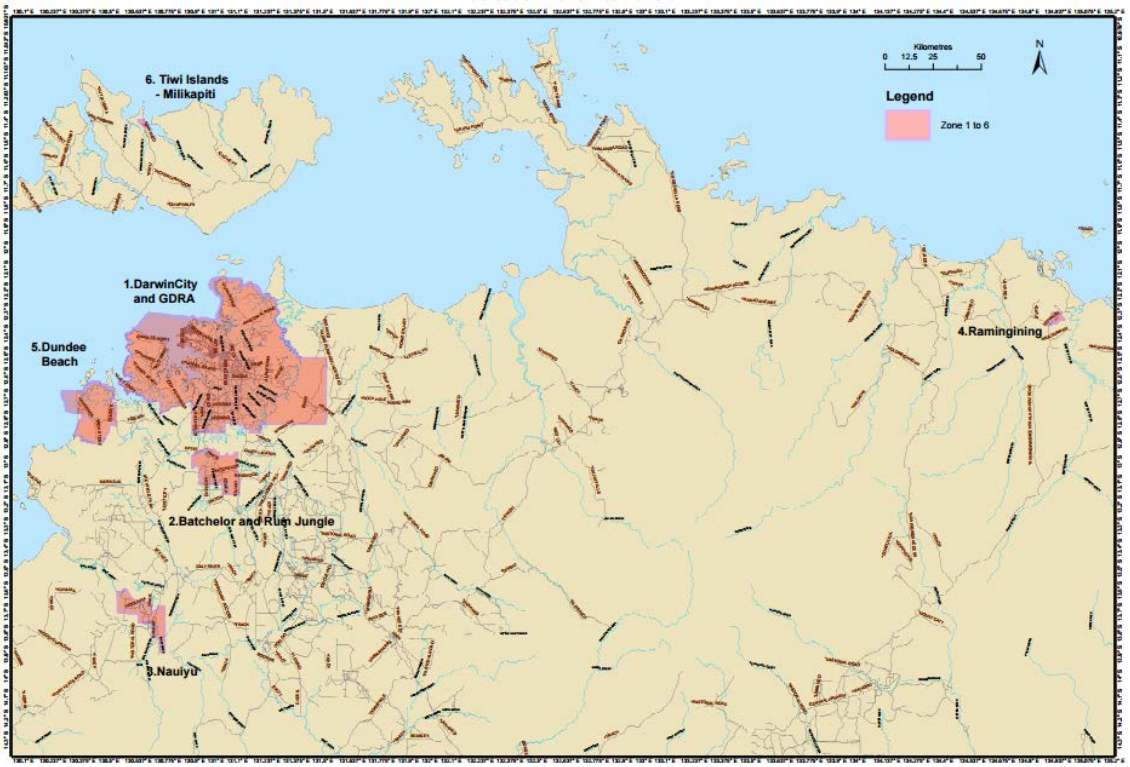
Source: Queensland Department of Agriculture and Fisheries Sourced 14/09/2016. Map published 06/05/2016.

Appendix 2b: NSW banana protected area



Source NSW DPI Sourced 14/09/2016

Appendix 2c: NT banana freckle eradication zones



Source: NT Government Banana freckle eradication program. Sourced 29/09/2016

WEED RISK ASSESSMENT OF BANANA

Species: *Musa* L.

Relevant land uses:

1. Perennial horticulture (ALUM classification 3.4.1 Tree Fruits)

Background: The Weed Risk Assessment (WRA) methodology is adapted from the Australian/New Zealand Standards HB 294:2006 National Post-Border Weed Risk Management Protocol. The questions and ratings (see table) used in this assessment are based on the South Australian Weed Risk Management Guide (Virtue 2004). The terminology is modified to encompass all plants, including crop plants.

Weeds are usually characterised by one or more of a number of traits, these including rapid growth to flowering, high seed output, and tolerance of a range environmental conditions. Further, they cause one or more harms to human health, safety and/or the environment. Banana has been grown globally for centuries, without any reports that it is been become a serious weed. In Australia, banana is grown mainly in northern NSW and Qld, with smaller areas of planting in WA and the NT. Unless cited, information in this weed assessment is taken from the document *The Biology of* Musa *L.* (*Banana*) (OGTR 2016). This WRA is for non-GM banana volunteers in the land use area identified above. This WRA is in reference to cultivated bananas, produced for food, not wild species or ornamental species. Reference is made to banana as a cultivated crop only to inform its assessment as a volunteer.

Movement, planting and cultivation of bananas and of material related to banana production (soil, machinery equipment) are strictly controlled by biosecurity legislation in banana-producing states and territories. In addition, some states have a requirement to control any 'unmanaged' banana plants or have had eradication programs to remove banana plants from certain areas. These legal requirements have impacts on the likelihood and impacts of volunteer banana populations and therefore affect the ratings in this weed risk assessment. Banana plants are also large and distinctive, thus quite easily detected in an area outside a commercial cultivation site.

Invasiveness questions	Banana
1. What is banana's ability to establish amongst existing plants?	Rating: **Low** Locally and globally there are no reports of weedy populations of cultivated bananas in areas where plantations have not previously been established. Weeds can compete vigorously with banana plants.
2. What is banana's tolerance to average weed management practices in the land use?	**Rating: Low** Bananas are controlled by physical (chopping of banana plant materials into small pieces, disk ploughing of corms) and chemical means (usually by herbicide injections into banana plant material), separately or in combination. Although laborious, these means control banana plants and suckers.
3. Reproductive ability of banana in the land use:	
3a. What is the time to seeding in the land uses?	**Rating: Low** Cultivated bananas are parthenocarpic (reproduce without seed) and seed production in these cultivars is negligible. Time from planting of vegetative material to first harvest is generally 16 – 18 months, or 6 to 12 months from setting of suckers to fruiting in ratoon crops (Rieger 2006).
3b. What is the annual seed production in the land use per square metre?	**Rating: None to Low.** As above. Negligible seed production by cultivated bananas.
3c. Can banana reproduce vegetatively?	**Yes** Cultivated bananas are generally produced from vegetative material via either tissue culture, planting of 'bits' from banana plants or by suckers from the main pseudostem of established plants. Control of suckers in banana crops by 'de-suckering' is required on a regular basis.
4. Long distance seed dispersal (more than 100m) by natural means in land uses	
4a. Are viable plant parts dispersed by flying animals (birds and bats)?	**Rating: Unlikely** Birds and bats are capable of spreading seeds from seeded varieties, but as cultivated bananas produce negligible seed this is unlikely. Spread of vegetative material suitable for production of new banana plants – such as corms of parts of corms – from non-seeded varieties is unlikely via birds and bats.
4b. Are viable plant parts dispersed by wild land based animals?	**Rating: Unlikely**

Invasiveness questions	Banana
	Wild land-based animals are unlikey to spread viable banana plant parts, such as corms or pices of corms. The lack of reports of weedy cultivated bananas also suggests that this does not happen often or at all.
4c. Are viable plant parts dispersed by water?	**Rating: Unlikely** In extreme conditions plant parts could be transported by flooding, however it is unlikely that any viable plant material could be transported and deposited in a way which would allow establishment of banana plants. No reports of dispersal in this manner.
4d. Are viable parts dispersed by wind?	**Rating: Unlikely** In extreme conditions plant parts could be transported by wind but anecdotally, even in cyclone conditions banana plants are more likely to be blown over but to remain onsite. No reports of dispersal in this manner.
5. Long distance seed dispersal (more than 100m) by human means in land uses:	
5a. How likely is deliberate spread via people?	**Rating: Common** Banana (plant materials, fruit, equipment involved in cultivation) movement is controlled by strict quarantine and biosecurity regulations, which require permits and certification of plant material and banana cultivation equipment before moving. However, for the establishment of new crops or rejuvenation of older plantations, vegetative material is deliberately moved (with appropriate permits) by people.
5b. How likely is accidental spread via people, machinery and vehicles?	**Rating: Unlikely** Banana movement is governed by strict quarantine and biosecurity regulations, which require permits and certification of plant material and banana cultivation equipment before moving. It is unlikely that any plant material capable of establishing vegetatively would be accidentally spread by people, machinery or vehicles.
5c. How likely is spread via contaminated produce?	**Rating: Unlikely** Banana (plant materials, fruit, equipment involved in cultivation, soil) movement is governed by strict quarantine and biosecurity regulations, and the product of cultivation is the fresh banana for human

Invasiveness questions	Banana
	consumption, which are highly unlikely to contain viable seeds. It is unlikely that bananas would be spread via contaminated produce.
5d. How likely is spread via domestic/farm animals?	**Rating: Unlikely** Grazing of animals in banana producing areas is highly unlikely and feeding of bananas to domestic animals is not common practice. In addition, cultivated bananas are essentially seedless so no seeds are likely to be spread in this way.

Impact questions	Banana
6. Does banana reduce the establishment of desired plants?	**Rating: None or < 10% reduction** No reports of establishment of cultivated bananas as weeds.
7. Does banana reduce the yield or amount of desired plants?	**Rating: None or < 10 % reduction** No reports of establishment of cultivated bananas as weeds.
8. Does banana reduce the quality of products or services obtained from the land use?	**Rating: None or < 10 % reduction** No reports of establishment of cultivated bananas as weeds.
9. What is the potential of banana to restrict the physical movement of people, animals, vehicles, machinery and/or water?	**Rating: None or < 10 % reduction** No reports of establishment of cultivated bananas as weeds. Any banana plants remaining in an abandoned plantation are required by law to be destroyed and effective means of control are available. Therefore the density of any banana volunteers is likely to be extremely low.
10. What is the potential of banana to negatively affect the health of animals and/or people?	**Rating: Low** There is no evidence that bananas are toxic to humans. Bananas do contain allergens that affect some people, although it is expected that people with known allergies to bananas would avoid consuming bananas The numbers of banana volunteers likely to occur means that exposure to these allergens is highly unlikely.
11. Major positive and negative effects of banana on environmental health in the land use	

Impact questions	Banana
11a. Does banana provide food and/or shelter for pathogens, pests and/or diseases in the land use?	**Rating: Minor** Banana plants are susceptable to a range of pests and diseases and weedy bananas could therefore potentially provide shelter for pests or disease of bananas, even in small numbers.
11b. Does banana change the fire regime in the land use?	**Rating: No effect** No reports of cultivated bananas establishing and persisting in weedy populations sufficient to affect fire regimes.
11c. Does banana change the nutrient levels in the land use?	**Rating: No effect** The number and density of banana volunteers is expected to be extremely low, and would not be expected to affect nutrient levels.
11d. Does the species affect the degree of soil salinity in the land use?	**Rating: No effect** No reports. The number and density of banana volunteers is expected to be extremely low, and would not be expected to affect soil salinity.
11e. Does the species affect the soil stability in the land use?	**Rating: Minor or no effect** No reports as a volunteer. Could possibly aid in soil stability due to ground coverage and corm material in the ground, but this is unlikely at low density.
11f. Does the species affect the soil water table in the land use	**Rating: No effect** No reports as a volunteer. The number and densitiy of banana volunteers is expected to be extremely low, and would not be expected to affect soil water tables. In addition banana root systems are not very deep, so this would further reduce their likelihood of affecting soil water tables.
11g. Does the species alter the structure of nature conservation by adding a new strata level?	**Rating: No effect** No reports as a volunteer. The very low chance of spreading viable material into areas of native vegetation means that any establishment and persistence in areas of native vegetation are highly unlikely. Thus, the number and density of banana volunteers is expected to be extremely low, and would not be expected to add a new strata level.