Australian Government
Department of Health and Aged Care
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.

This document is an update of Version 2 (2 October 2016)

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Abbreviations

ABGC	Australian Banana Growers Council
ABS	Australian Bureau of Statistics
AFLP	Amplified fragment length polymorphism
APVMA	Australian Pesticides and Veterinary Medicines Authority
BAC	Bacterial Artificial Chromosome
BBTV	Banana Bunchy Top Virus
BSV	Black Streak Virus
CIAT	International Center for Tropical Research
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
CIRAD-FHLOR	CIRAD Departements Productions Frutières et Horticoles
DEEDI	Department of Employment, Economic Development and Innovation (Queensland)
DNA	Deoxyribonucleic acid
ELW	Environment, land and water (Queensland)
FAO	Statistics Division Food and Agriculture Organisation of the United Nations
FAOStat	Food and Agriculture Organisation
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)
HIA	Horticulture Innovation Australia Limited
INIBAP	International Network for the Improvement of Banana and Plantain
Mbp	Megabase pairs
MGIS	*Musa* Germplasm Information System
NSW	New South Wales
NSW DPI	New South Wales Department of Primary Industries
NT	Northern Territory
OGTR	Office of the Gene Technology Regulator
ORIA	Ord River Irrigation Area
Qld	Queensland
QBAN	Queensland Banana Accredited Nursery
QDAF	Queensland Department of Agriculture and Fisheries
QDPI	Queensland Department of Primary Industries
PHA	Plant Health Australia
PRP	Pathogenesis Related Protein
TBRI	Taiwan Banana Research Institute
USDA	United States Department of Agriculture
USDA-GRIN	United States Department of Agriculture Germplasm Resources Information Network
WA	Western Australia
WA DPIRD	Department of Primary Industries and Regional Development
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 the majority of world production and the cooking banana. 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 and 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 BCE), physician to Octavius Augustus, first emperor of Rome (Hyam and 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*. All genera are monocotyledons and, as such, are technically defined as 'herbs' even though some species can grow up to 15 m tall (Constantine and Rossel, 2008a). See Section 3.1 for more detail.

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 and 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 well-defined hybrid groups or even cultivars (Constantine and Rossel, 2008a). 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 and Shepherd, 1955) and later revised in 1987 (Silayoi and Chomchalow, 1995). This system basically assigns a

[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*).

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 World Checklist of Selected Plant Families (WCSP, website accessed September 2022) lists 86 accepted species of *Musa* and 3 hybrids, with a number of accepted subspecies and/or varieties. The United States Department of Agriculture Germplasm Resources Information Network (USDA-GRIN) lists 79 accepted species and 2 hybrids, with a number of accepted subspecies and varieties (USDA GRIN, accessed September 2022). The number of sections[2] within *Musa* is between two and six. Cheesman (1948) 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 containing 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 and Weatherup, 1990; Daniells et al., 2001) and subsequent studies have placed it in *Callimusa* (Häkkinen, 2013). Constantine and Rossel (2008b) 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 and USDA-GRIN lists 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. beccarii[b]	Borneo
			M. borneensis[c]	Borneo
			M. campestris[b]	Indonesia, Borneo
			M. coccinea	China, Indonesia, Vietnam
			M. exotica	Vietnam
			M. gracilis	Malaysia
			M. haekkinenii	Vietnam
			M. hirta	Indonesia, Borneo
			M. lawitiensis[b]	Borneo

[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. lokok	Borneo
			M. lutea	Vietnam
			M. monticola	Borneo
			M. muluensis	Borneo
			M. paracoccinea	China, Vietnam
			M. sakaiana	Borneo
			M. salaccensis	Indonesia
			M. splendida	Vietnam
			M. tuberculata	Borneo
			M. violascens	Malaysia
			M. viridis	Vietnam
			M. voonii	Borneo
		Australimusa	*M. × alinsanaya*	Philippines
			M. arfakiana	New Guinea
			M. boman	Papua New Guinea
			M. bukensis	Papua New Guinea
			M. fitzalanii	Australia
			M. jackeyi	Australia
			M. johnsii	Papua New Guinea
			M. juwiniana	Borneo
			M. lolodensis	Papua New Guinea
			M. maclayi[c]	Papua New Guinea
			M. peekelii[d]	Papua New Guinea, Philippines
			M. textilis	Philippines, Brunei, Moluccas
			M. troglodytarum L.	New Guinea
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	Japan, China
			M. celebica	Indonesia
			M. cheesmanii	India
			M. flaviflora	Bangladesh, Bhutan, India
			M. griersonii	Bhutan
			M. insularimontana	Taiwan
			M. itinerans[b]	China, India, Thailand, Vietnam
			M. lanceolata	Indonesia
			M. nagensium	China, India, Thailand
			M. ochracea	India
			M. schizocarpa	Indonesia, Papua New Guinea
			M. shankarii	India
			M. sikkimensis[b]	Bangladesh, Bhutan, India, Thailand
			M. thomsonii	India
			M. tonkinensis	Vietnam
			M. yamiensis	Taiwan
			M. yunnanensis[b]	China
		Rhodochlamys	*M. aurantiaca*[b]	India
			M. chunii	China
			M. kattuvazhana	India
			M. laterita	India, Burma, Thailand
			M. mannii[b]	India
			M. markkuana	Northern India
			M. ornata	Bangladesh, Burma, India, Borneo
			M. rosea	Bangladesh, Burma
			M. rubinea	China
			M. rubra	Burma, India

Chromosome number	Section	'Minor' Section	Species	Main Distribution
			M. sanguinea	Northern India, Burma, China
			M. siamensis	Thailand
			M. velutina	India, Burma
			M. zaifui	China
Not specified[f]			*M. × formobisiana*	Taiwan
			M. × paradisiaca L.	Widespread
			M. argentii	India
			M. arunachalensis	India
			M. corneri	Malaysia
			M. cylindrica	India
			M. inandamensis	India
			M. kamengensis	India
			M. markkui	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 and Häkkinen, 2022) and/or the USDA-GRIN taxonomy search (USDA, 2022). Further information is included from Simmonds and Weatherup (1990); Sharrock (2000); Häkkinen and Sharrock (2001); Pollefeys et al. (2004); Ploetz et al. (2007); Constantine and Rossel (2008b); Häkkinen (2013).

[b] These species are listed in WCSP as containing a number of distinct varieties

[c] These species are listed in WCSP and/or USDA-GRIN as containing a number of subspecies and distinct varieties

[d] These species are listed in WCSP as containing a number of subspecies

[e] Where there is some disagreement on the section or minor section under which a species is classified, the information in Häkkinen (2013) is used in this table.

[f] Species listed in WCSP or USDA-GRIN, for which no section or minor section was listed in the references used.

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 an herbarium specimen (Ross, 1987; Pollefeys et al., 2004; Queensland ELW, 2021c). 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 and Tripathi, 2007; Constantine and Rossel, 2008b). *Australimusa* species are noted as useful for fibre and fruit, *Eumusa* (*Musa*) 1 and *Eumusa* (*Musa*) 2 as fruit, vegetable, wrapping and ornamental (Constantine and Rossel, 2008b). Most of the cultivated sweet bananas and plantains belong to the Section *Musa* and are 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 and Shepherd, 1955). Detailed information about the development of edible bananas, including origins, taxonomy and cultivation is available in Jones and Daniells (2018). This reference provides lists and discussion of edible cultivars - with emphasis on the *Eumusa* and *Australimusa* sections – including regions of importance and main uses.

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

[3] Identified more recently as *M. banksii* (Govaerts and Häkkinen, 2022) and included in Table 1 under this name.

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, Article 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 gene pool for the improvement of cultivated bananas (Nwakanma et al., 2003). Later work examining the origins of ABB genomes, using newer sequencing tools, indicates the occurrence of several homologous exchanges in A and B genomes. This knowledge can provide insights into the origin of AAB genomes and may provide more information about genetic diversity of the B genome and potential for the introduction of desirable traits into banana lines (Cenci et al., 2020).

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 3% of Australian production. Dwarf Cavendish is the most widely distributed clone of edible banana worldwide (Ploetz et al., 2007).

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

[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 and Kester, 1975). Cultivars/varieties mentioned in this document are indicated in quotation marks e.g. 'Cavendish'.

Genome Group	Subgroup (Cultivar)[b]	Clone Set[b,c]	Examples of other common cultivar names[b]
	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	Maduranga, Pisang Abu Bujal
		Monthan	
		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 Musapedia - Diversity of Banana Cultivars (Accessed September 2021). 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 Musapedia cultivars 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 et al. (2007) for full list.

[e] In the Maoli subdivision

[f] FHIA = varieties bred at the Fundación Hondureña de Investigación Agrícola (FHIA) in Honduras

Naming of cultivars can be confusing, for example the name ʻLady ('s) Finger' has been used to name several distinct AA, AB and AAB clones. The Banana Cultivar checklist (Musapedia; accessed September 2021[6]) lists over 7000 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 (Vézina, 2020). More information about banana genome groups, subgroups and cultivars can be found at Musapedia – Diversity of banana cultivars.

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[7], 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 and 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 and Schwarzacher (2007). More recent work has sequenced the genome of DH-Pahang,

[6] Note that the Musapedia website was maintained by the ProMusa platform, which was discontinued in early 2021. It is not clear whether the Musapedia pages are being updated regularly since then, as some were updated in 2022.

[7] 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.

a doubled-haploid *M. acuminata* genotype of subsp. *malaccensis.* This work 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 and 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 and 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 (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 and 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 and 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 BCE. It is thought that traders from Arabia, Persia, India and Indonesia distributed banana suckers around coastal regions of the Indian Ocean (except in Australia) 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 and Rossel, 2008b). 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 (INIBAP, 2000). Based on current data, production of sweet bananas is the eighth highest of the food crops produced in the least developed countries[8] (18.4 million tonnes), and the twelfth highest worldwide. If plantains (which may also include other cooking bananas) are included in production totals, combined production ranks fifth behind rice, cassava, sugar cane and maize in the least developed countries (FAOStat, 2022). Millions of small-scale farmers in Africa, South Asia and Northern Latin America grow the fruit for household consumption and/or local markets.

Total world production of sweet bananas in 2020 was 119.8 million tonnes and 43.1 million tonnes of plantains. Bananas and plantains are produced in approximately 135 countries. The two major sweet banana producing countries are India and China, but neither exports significant quantities (see Table 3). By comparison Ecuador and Colombia, the fifth and tenth largest producers respectively, exported the majority of their production in 2020 (Table 3) and are the largest suppliers of sweet bananas to world trade (Table 4). The Philippines and Guatemala also export a significant proportion of their production (Table 3). The major importer of sweet bananas is the USA (Table 5). However, it is difficult to estimate overall trade of bananas as import and export figures include not only import and export volumes and values, but also re-import and re-export volumes and values, thus showing higher trade volumes than production volumes in some cases. Using regional production and trade figures[9] that exclude re-trade volumes, over the 10 years from 2011 to 2020, only 7.8% of total production is exported on average, with the Americas exporting the highest proportion of production (26.5%) and both Asia, which produces the largest volume of bananas, and Oceania, exporting less than 1% of total production (Statistics Division, Food and Agriculture Organisation of the United Nations Stat (FAOStat) data, sourced February 2022).

Table 3. Major sweet banana producing countries in 2020[a]

Country	Production ('000 tonnes)	% bananas exported[b]
India	31504.0	0.67
China[c]	11872.6	0.22
Indonesia	8182.8	0.10
Brazil	6637.3	1.25
Ecuador	6023.4	116.88
Philippines	5955.3	31.33
Guatemala	4476.7	56.15
Angola	4115.0	0.20
United Republic of Tanzania	3419.4	0.15
Colombia	2528.7	103.75

[a] Data source: FAOStat, accessed February 2022 (FAOStat, 2022).

[b] May include re-export of imported produce, hence numbers greater than 100.

[c] This is an aggregate figure including mainland China and other territories.

[8] Category used in FAOStat datasets, currently includes 46 countries. See FAOStat website (Definitions and Standards, Country Group) for more information.

[9] Regions used in FAOStat for reporting production and trade figures are Africa, Americas, Asia, Europe and Oceania. See FAOStat data pages for more information.

Table 4. Major sweet banana exporting countries in 2020[a]

Country	Export ('000 tonnes)[b]
Ecuador	7039.8
Costa Rica	2623.5
Guatemala	2513.8
Colombia	2034.0
Philippines	1865.6
Belgium	1006.7
Netherlands	879.4
Panama	700.4
United States of America	592.3
Honduras	558.6

[a] Data source: FAOStat, accessed February 2022 (FAOStat, 2022).
[b] May include re-export of imported produce.

Table 5. Major sweet banana importing countries in 2020[a]

Country	Import ('000 tonnes)
United States of America	4671.4
China[b]	1819.2
Russian Federation	1515.7
Germany	1323.4
Netherlands	1274.8
Belgium	1173.7
Japan	1067.9
United Kingdom	979.4
Italy	781.8
France	695.4

[a] Data source: FAOStat, accessed February 2022.
[b] This is an aggregate figure including mainland China and other territories.

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 'Tropical Race 4' (FocTR4) to which the Cavendish sub-group is susceptible, has evolved. This has affected plantations in more than 20 countries (Vézina, 2022) 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; Edmeades et al., 2006; Nelson et al., 2006; Pillay and 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 Fibres, 2007).

The sap of banana plants, particularly the Fe'i cultivars that have a distinctive reddish-violet sap (Sharrock, 2000), has been used as a dye and ink (Nelson et al., 2006; Pillay and 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).

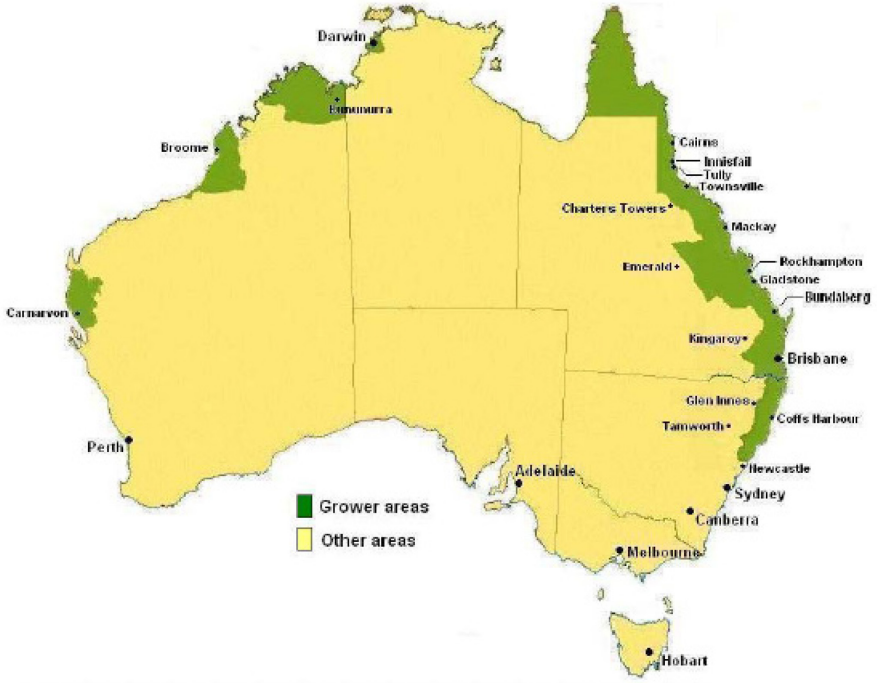
2.3 Cultivation in Australia

The earliest record of bananas being grown in Australia was in the early to mid-1800's near Carnarvon in Western Australia (WA) (Australian Banana Growers Council - ABGC, 2016b). 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, 2016b). '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 New South Wales (NSW) and by 1919 they owned or managed some 500 acres around the Mullumbimby 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, 2016b). By the 1960s, when NSW was producing 80% 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 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° C. Poor fruit production occurs if the temperature drops below 15° 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 (Queensland Department of Agriculture and Fisheries - QDAF, 2012d). In WA, bananas grown in the Ord River Irrigation Area (ORIA) receive annual irrigation applications of between 17 and 26 ML ha^{-1}, with 55 to 85 mm per hectare per week applied to banana crops in summer and 30 to 60 mm per hectare per week in winter (Western Australia Department of Primary Industries and Regional Development - WA DPIRD, 2021). In northern Queensland, annual requirement from drip or micro irrigation was estimated to be between 2 and 15 ML, while surveys indicated applications of 7.2 – 19.3 ML ha^{-1} (Growcom, 2018). Currently, Qld accounts for most of Australia's production – approximately 96% based on 2020/21 data (Australian Bureau of Statistics - ABS, 2022). Approximately 94% 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, 2018; ABS, 2022). 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.

Tissue cultured material is considered the best method to propagate banana planting material that is free of pests and diseases (QDAF, 2016a; State of Queensland, 2017; WA DPIRD, 2020c) using virus indexed material obtained from accredited nurseries and tissue culture facilities (QDAF, 2016a). Alternatively, an on-farm nursery can be established using tissue cultured plants obtained from accredited facilities, which is then used to provide planting material for the property. This carries a slightly higher biosecurity risk than planting directly with tissue cultured plants, but if established properly, carries less risk than planting with material from other parts of the same property (State of Queensland, 2017). In order to maintain good plant health and biosecurity, movement of plant material would ideally occur only within a single property,

on contiguous planting areas, with good records of where material was moved from, where it was moved to within the property and when (QDAF, 2016a).

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 and 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 Queensland Department of Primary Industries and Fisheries (QDPIF – now QDAF) established a banana clean planting scheme based on virus indexed tissue cultured plants.
- 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.

Historically, bits were 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. More information about planting material can be obtained from State department websites and from biosecurity guidelines for each state (see, for example, QDAF, 2016a; State of Queensland, 2017; WA DPIRD, 2020b, c). In Australia, strict controls on the movement and planting of banana plants are imposed to prevent the spread of banana diseases. State government websites have information about the restrictions and requirements for each state and region where bananas are grown.

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). A detailed description of banana propagation using bits and suckers can be found in Hamill (2018), including discussion of the advantages and disadvantages of these methods.

Advantages include:

- availability to all growers
- shorter planning and preparation times
- year-round availability
- durability for planting, no requirement for irrigation
- few off-types
- ability to choose material from plants that perform well under farm conditions
- reduced requirement for irrigation at planting
- bits and suckers can be stored for the short term without maintenance.

Disadvantages include:

- use of bits and suckers is the main means of spread for pests and pathogens
- bits and suckers are bulky and heavy, which can limit transport for smallholders
- a separate field nursery may be required for production of bits and suckers, with differing management practices.

In Australia, it is common for planting material to be sourced directly from hardened-off micropropagated (from tissue culture) 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; WA DPIRD, 2020c). However, historically there have been problems with somaclonal variation[10] 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 and 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 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 and 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). More recently, the proportion of off-types reported is much lower, approximately 3-5%, however culling and establishment practices must still account for this (WA DPIRD, 2020c).

The advantages and disadvantages of tissue culture for bananas have been summarised by Hamill (2018).

Advantages include:

- tissue culture plantlets are pest and disease free if from an accredited supplier (see below)
- plant material can be transported cheaply and safely enclosed over long distances (where allowed by regulations)
- tissue culture plants may be more productive in earlier stages of establishment
- plants can be sorted in the nursery to ensure uniformity, which may improve efficiency of management in the field, including targeting of bunching date
- the plants have a well-established root system and good survival rates (with irrigation)
- it can be used to store germplasm in order to maintain cultivars free from pests and diseases and weather effects.

Disadvantages include:

- expensive equipment and skilled staff required
- plants must be ordered a year ahead and can be expensive
- care must be taken to ensure the use of virus-free material and to plant into virus-free soil when establishing
- extra care and management, including irrigation, is required for planting out tissue cultured material
- number of off-types can be high if not managed
- tissue culture can activate banana streak virus (BSV) in cultivars with the B genome.

Tissue culture plants can be multiplied by micropropagation or by somatic embryogenesis methods, although embryogenesis is more commonly used for research (Hamill, 2018). The main concern for use of

[10] Somaclonal variation is a term coined (Larkin and 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).

somatic embryogenesis is high levels of somaclonal variation (Ghasemali et al., 2015; Moradi et al., 2016). However, little information is available on the occurrence of somaclonal variation in banana plants derived through somatic embryogenesis. 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 and Queensland DEEDI, 2009). There are legal restrictions 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 minimal fresh banana export and limited export (and import) of dried banana products. (HIA, 2022).

Approximately 97% of Australian fresh banana production is Cavendish varieties, with the remaining 3% Lady Finger (HIA, 2022). Qld accounts for approximately 94% of total banana production (HIA, 2022). In 2017-18, banana was the most valuable horticultural commodity produced in Queensland, with a value of $AU 580 million (State of Queensland, 2018). In a global list of banana cultivars, there are 38 entries listed in Australia, although for some cultivars, this includes different names for the same cultivar. The majority (20) are AAA genome group, with Giant Cavendish, Cavendish and Dwarf Cavendish the most common cultivars, with a further 12 cultivars of the AAB genome group and six ABB cultivars (Vézina, 2020).

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. In 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 synchronisation 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 (Horticulture Australia Limited - 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, with 372,433 t produced in 2019/20 and 346,035 in 2020/21 (Source: ABS Agricultural Commodities 7121.0, reports from 1998-2021; Accessed September 2022).

The ABS Agricultural Commodities data for 2020/21 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 2020/21[a]

Production Area	Production (t)	Area (ha)[b]	Average Yield (t/ha)	Number of businesses[c]
Australia	346,035	11,874	29.1	341
Qld	332,978	11,009	30.2	207
NSW	6,718	598	11.2	94
NT	1,733	46	37.5	8
WA	4,606	220	21.0	32

[a] Data source: ABS (2022).

[b] Production area, includes area with crops of bearing age, does not include areas with crops of non-bearing age

[c] Total number of properties with crops of bearing age does not include producers with no fruit-bearing crops

In 2005, prior to Cyclone Larry, Australia had approximately 1,850 banana growers (ABGC, 2007). Current data indicates there are approximately 341 properties with crops of bearing age, as shown in Table 6 (ABS, 2022). A summary of characteristics 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 QDAF (Broadley et al., 2004). Additional guidance is available through the ABGC Bunchy Top National Project regarding maintenance of banana plantings (ABGC, 2021). More recent best practice guides addressing environmental considerations (King, 2021), biosecurity considerations (State of Queensland, 2017) and management practices related to specific growing regions (WA DPIRD, 2020c, b, a, 2021) are available to provide further information on industry practices. Key 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). Once fruit is harvested, the 'parent' trunk is removed from head height. The remaining trunk nourishes the 'sucker' plants at the base, which will then produce their own bunches (Australian Bananas website, accessed March 2022). 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).

Growing conditions in WA are significantly different from those in Qld, although tissue culture material, if used, is sourced from Qld with appropriate quarantine permissions (WA DPIRD, 2020b, c). Specific guidance for cultivation of bananas in the ORIA in WA provides information on a number of aspects including selection of planting material (WA DPIRD, 2020c), preparation and management of plantation sites (WA DPIRD, 2020a, 2021), and risk management for WA conditions (WA DPIRD, 2020b).

Selection of suckers for producing the next crop is based on a number of factors. 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 control the production cycle in order to supply fruit year round, 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; Daniells and Linsday, 2014). This practice can also be used in the lead up to cyclone season to ensure a proportion of the plantation is smaller, unbunched, plants that will be less damaged by cyclones (Daniells and Linsday, 2014).

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 would reduce the competition for water (Broadley et al., 2004). For the ORIA, recommendations to suit specific conditions for this environment include a plant density of 2880 plants per ha (based on planting of 1440 bits per hectare and subsequent selection of two suckers from each parent), with planting 2.4 m apart in rows set 3 m apart (WA DPIRD, 2020b).

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, 2021) incorporating physical, cultural, biological and chemical controls to manage pests (King, 2021). Physical controls include factors such as plant spacing and maintenance of plants including de-suckering, deleafing, and management of weeds and pests that may harbour or spread disease (ABGC, 2021). 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 Australian Pesticides and Veterinary Medicines Authority (APVMA) website. Pests and diseases are discussed in more detail in Section 7.2.

Banana plants have high nitrogen (N) and potassium (K) 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 and climatic conditions, costs of fertilisers, but also environmental impacts of fertiliser applications in the broader environment. In general, older blocks and ratoons in tropical regions require 20-30 kg N, 60-70 kg K and 4-7 kg phosphorus (P) per hectare per month, however actual applications should be guided by testing soil and leaf material (King, 2021). Other information suggests fertilising with a rich source of N, P & K two or three times a year to maintain good production (ABGC, 2021). The 'Lady Finger' banana requires 10% more N and K than the 'Cavendish' banana (QDAF, 2012c). Minimising losses of N fertiliser through leaching requires management of a number of factors, including timing of fertiliser application, timing of planting to avoid wet season planting and cultural practices, such as use of permanent beds, together with understanding soil N status in order to tailor fertiliser applications (Daniells et al., 2015).

From 1 December 2020, new minimum practice agricultural standards apply for banana producers in some Qld regions (Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary regions) with respect to controlling runoff from banana farms to the Great Barrier Reef (Queensland Government, 2019a). More information can be found on the Qld Government website - requirements for banana growers and in the guides and best practice manuals related to this standard (Queensland Government, 2019b, c, 2020).

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. Carnarvon in WA relies almost entirely on irrigation. Banana cultivation in the ORIA requires an annual application of between 17 and 26 ML of irrigation (WA DPIRD, 2021). Production in eastern subtropical regions is generally rainfed and tropical regions may rely on irrigation during dry periods (King, 2021). In tropical north Qld, water requirement for irrigation with drippers or micro-irrigated crops ranged from 2-15 ML ha^{-1} annually, with applications of approximately 7-19 ML ha^{-1} annually producing yields of 24-32 t ha^{-1}, which is within the range noted for best practice yields (Growcom, 2018). 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, 2021), provided irrigation systems are suitable (King, 2021). Use of fertigation or a combination of fertigation and banded surface applications of fertiliser, based on weather conditions, are seen as best practice (King, 2021). While water is important for crop growth, overwatering can also cause problems (King, 2021).

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. This means one mature stem producing bananas, one follower that will produce the next bunch and one sucker (ABGC, 2021).

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).

Bananas are harvested in Australia 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°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).

Figure 3. Two types of plastic bunch cover.

Photo credit: Janet Gorst

Figure 4. Packing shed in a small commercial facility. Note 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). An average bunch with 150-200 bananas weighs approximately 35-50 kg (Australian Bananas website, accessed October 2022). 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 approximately 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 and 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 performed, a method that 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) and can be used to manage production cycles to meet year-round demand or to manage supply following natural disasters such as cyclones (Daniells and Linsday, 2014).

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 and Jain, 2004) but *in vitro* mutation breeding has, so far, delivered the most promising results (Smith et al., 2005). Globally, banana improvement was tackled through ProMusa, which was established in 1997 through the efforts of the International Network for the Improvement of Banana and Plantain (INIBAP - now amalgamated in Bioversity International) to foster international cooperation. ProMusa was "a platform for sharing news, knowledge and information on bananas, with the objective of improving the understanding of this atypical crop", however although its content is still available online it is not being updated (as of early 2021). In 2001, the Global *Musa* Genomics Consortium (GMGC) was established to apply new technologies to the sustainable improvement of banana (Frison et al., 2004). This organisation was active from 2001 until 2015 and more recently other organisations and alliances between organisations have evolved to provide further genomic information that can be harnessed in efforts to develop new cultivars. 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, 2016). Databases of literature and images for bananas are available from Musanet.

In addition to the GMCG, 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 March 2022, there were over 3600 accessions managed by 28 participating institutions (MGIS collections website, accessed March 2022). The MGIS remains active and provides a resource for researchers who can use it to identify the most appropriate germplasm to be used in trials.

Since 1988, QDAF (previously QDPI) at its Maroochy facility (Nambour), has maintained one of the world's larger *in vitro* repositories of banana germplasm, with the intent to multiply and distribute pathogen-free germplasm for planting and breeding programs to meet industry research needs. Currently QDAF maintains banana germplasm collections at Maroochy (*in vitro* collection) and South Johnstone (field collection) facilities (J. Daniells, QDAF, pers. comm. November 2022).

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; Frison et al., 2004; Kahl, 2004; Smith et al., 2005; Heslop-Harrison and Schwarzacher, 2007; Pillay and Tripathi, 2007).

The Musa genome was sequenced in 2012 (D'Hont et al., 2012). Subsequent research has provided further insights into banana genomes including information about recombination events within and between genomes, implications for segregation and aneuploidy in triploids (Martin et al., 2017; Baurens et al., 2019; Martin et al., 2020) and 'anchoring' reference genome information to chromosomes (Šimoníková et al., 2019). Exploration of the banana genome using such tools will likely provide targets for banana improvement in terms of disease resistance (Dash and Rai, 2016; Dupouy et al., 2019), plant architecture, fruit ripening and potentially other valuable parameters (Dash and Rai, 2016).

A number of networks were developed for collaborative research and discussion to ensure the availability of banana genetic material and information for research. Of these, INIBAP and International Plant Genetic Resources Institute (IPGRI) jointly adopted the name Bioversity International and curated and coordinated banana genetic information as part of its focus on agricultural biodiversity and research for development. Bioversity International has now joined with the International Center for Tropical Research (CIAT) as The Alliance. This group has 'research-based solutions that harness agricultural biodiversity and sustainably transform food systems to improve people's lives in a climate crisis'. Other resources such as the Banana Genome Hub and the MGIS, which provide databases of Musa genomics, enabling searches for genome information on particular banana cultivars and literature related to banana genomics.

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 and 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 and 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 and Crouch, 1997) and selection for fertility can increase the efficiency of pollination (Ortiz and 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 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). Other work is focussing on understanding the basis of race 1

resistance and potential targets that may be used for marker-assisted breeding efforts for resistance to both race 1 and FocTR4 (Ahmad et al., 2020).

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 QDPIF (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 (System Administrator et al., 2020). It also has good fruit quality and postharvest performance (Seberry and Harris, 1998). More information about FHIA-01 and FHIA-18 is available on the Musapedia website (System Administrator, 2020; System Administrator et al., 2020).

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 and DeLanghe, 1986; Horry et al., 1997; Pillay and Tripathi, 2007) but commercial attributes such as yield, water use efficiency, fruit dimensions, fruit flavour and ripening characteristics could also benefit from improvement (Heslop-Harrison and Schwarzacher, 2007; Pillay and Tripathi, 2007). An extensive discussion of banana breeding can be found in Pillay and Tripathi (2007).

A different approach to conventional breeding was developed by CIRAD-FLHOR and CARBAP involving 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 and 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 and 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 somaclonal lines (GCTV-119 and GCTV-Formosana) from TBRI are being tested in the NT but results 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: 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 (Vuylsteke, 2000). A problem with the strategy is that the outcome is not predictable and cannot be targeted and, in reality, there have been few commercially useful variants produced (Tang, 2005).

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-Escoffié et al., 2005), microprojectile bombardment (Becker et al., 2000; Houllou-Kido et al., 2005) and electroporation of protoplasts (Sági et al., 1995; Sági 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* (Foc, 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). 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). 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 and Harding, 2003). Work addressing resistance to Panama disease in bananas has been a focus of research for GM banana development. A glasshouse trial with GM 'Lady Finger' banana lines transformed with genes related to inhibition of apoptosis, showed the significantly lower disease ratings when challenged with Foc race 1, than wild type or susceptible 'Lady Finger' lines (Paul et al., 2011). Field trials of GM bananas in the NT demonstrated resistance to FocTR4 in some GM lines with either a gene related to inhibition of apoptosis, or a resistance gene from *M. acuminata ssp. malaccensis* (Dale et al., 2017). For lines expressing the resistance gene, levels of disease resistance as measured by the presence or absence of external and vascular tissue symptoms, were inversely correlated with transgene expression. Lines with no or a low percentage of infected plants had higher levels of resistance gene expression

compared to non-GM controls or GM lines with higher percentages of infected plants. The mechanisms of this resistance are still under investigation (Dale et al., 2017). Additionally, results indicated that the Cavendish cultivar has analogous endogenous loci which are not sufficiently expressed to provide protection against FocTR4 infection, and it was thought that other cultivars probably contain these loci, so this is an area of interest (Dale et al., 2017).

One limitation to conventional breeding has been the presence of endogenous banana streak virus in the B genome of plantains (AAB), resulting in detrimental effects on banana plants with the B genome, under stress. This limits the possibility of using such lines for introgresssion of desirable traits. Research investigating the use of gene editing to inactivate endogenous banana streak virus has shown that 75% of the edited events showed no symptoms under water stressed conditions in glasshouse trials (Tripathi et al., 2019). This has implications for use of such plants in future breeding programs.

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 and Arntzen, 1995). Despite considerable research, this vision has still not been realised (Arntzen, 2005) and recent searches for information about the progress of such options has not provided further information about research in this area.

The use of GM bananas as a source of provitamin A (which is converted to vitamin A after consumption) is one approach to addressing vitamin A deficiencies and related health effects, particularly in areas where bananas are a staple food source. A review by Amah and colleagues (2018) outlines the background to this issue, together with a discussion of the approaches, both through conventional breeding and production of GM bananas to provide biofortified bananas. 'Golden bananas' that produce suitable levels of provitamin A have been developed and products from the bananas have undergone some sensory analysis in Uganda. Additionally, trials to determine the bioconversion rates in humans have been performed (Paul et al., 2018) although the results of those were not available at the time of publication. The authors suggested that the GM bananas may be deregulated by the end of 2021 (Paul et al., 2018), however, as at January 2023, no decisions for commercial release of GM bananas are listed on GMO approvals databases (International Service for the Acquisition of Agri-Biotech Application (ISAAA) GMO database, Biosafety Clearing House, USDA Animal and Plant Health Inspection Service Biotechnology (USDA-APHIS-BRS), EU register of GM food and feed, Organisation for Economic Co-operation and Development (OECD) BioTrack Product Database, EUginius (EUropean GMO INItiative for a Unified Database System).

Field trials of GM banana have been approved in Australia for disease resistance or enhanced nutrition (see OGTR website for details).

SECTION 3 MORPHOLOGY

3.1 Plant morphology

Detailed morphological descriptions of the banana plant can be found in numerous publications (Simmonds, 1959a; Barker and Steward, 1962; Purseglove, 1972; Morton, 1987; Ross, 1987; Simmonds and Weatherup, 1990; Espino et al., 1992; Karamura and Karamura, 1995; Rieger, 2006; Pillay and 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 and 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 and 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 (I) emerging through the top of the pseudostem; B) Developing inflorescence which has bent down, showing the bell shape, peduncle (P), 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.

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).

Photo credit: Janet Gorst

Figure 8. A) Close-up of female flowers showing the remains of the white, tubular tepals (T) and the fruits (F) 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.

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 and 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 and 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 and 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 and 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 and 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 and 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 and 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 N 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 Interactions (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*, *M. sobrinus* and *Eonycteris spelaea* are implicated in long distance pollination of wild banana species (Nur, 1976; Fujita and 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 and Lean, 1999).

Honeybees and birds are also regarded as pollinators of *Musa* in other parts of the world (Ortiz and Crouch, 1997). These visit flowers during the day and, hence alternate with the nocturnal bat pollinators. The sunbird *Arachnothera longirostris* (family *Nectariniidae*) pollinates *M. 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 and 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 and 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 and 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 Interactions (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 and Cox, 1962; Stotzky et al., 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°-18 °C/6-12 h at 27°-35° 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 and 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 2-10% 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 and 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 germinates. 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 and 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; QDAF, 2012e) 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 10 shows representative levels of nutrients and minerals that can be found in the sweet banana. The banana fruit contains relatively high levels of K. 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 10. 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
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 Standards 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 and 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 and 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 and 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 (Möller 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 K, 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 and 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 and 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 and Mehta, 1989, 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°N and 30°S, with mean air temperature of 26.7°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). In WA's ORIA growers were applying 55-85 mm per ha per week in summer and 30-60 mm per ha per week in winter, equating to an annual application of 17 – 26 ML per ha (WA DPIRD, 2021). Optimal root growth occurs between 22-25°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 topsoil 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 and Lindsay, 2006).

6.1 Abiotic stresses

6.1.1 Nutrient stress

Soils with a low pH solubilise elements such as aluminium (Al) and manganese (Mn) that can be toxic and result in reduced root growth. Macronutrients required by banana plants include N, K, P, calcium (Ca), magnesium (Mg) and sulphur (S). They require particularly large amounts of N and K. Deficiencies in N, K and Mg can all cause leaf yellowing and for N also, discoloration of petioles. Deficiency in Ca can result in deformed leaves (QDAF and HIA, 2018c). A lack of K 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 K can restore the buoyancy of the fruit. Other micronutrients required by bananas include boron (B), iron (Fe), Mn, copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl) and cobalt (Co). 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; QDAF and HIA, 2018c). Boron deficiency can result in fruit that does not 'fill' (Broadley et al., 2004). Nutrient stress may also contribute to leaf bunching at the tops of banana plants (QDAF and HIA, 2018d), poor bunch emergence (QDAF and HIA, 2018a), rusting or bronzing of fruit, and mixed or premature ripening of fruit in the field (QDAF and HIA, 2018b).

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 and Doerffling, 1993; Gomes et al., 2002). Salt toxicity may cause dead edges or patches on leaves (QDAF and HIA, 2018c).

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°C; frosts kill the plant although the corm normally remains viable (Broadley et al., 2004) and may cause plant

stems to shatter (QDAF and HIA, 2018d). Leaves at the top of the plant may be deformed as a result of cold stress (QDAF and HIA, 2018d). Planting on sunny hills of elevations of 60 m to 300 m 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 and Turner, 2003; QDAF and HIA, 2018b). Choking occurs when the bunches fail to emerge properly from the pseudostem and are thus susceptible to sunburn (Treverrow and Turner, 2003; QDAF and HIA, 2018b).

Heat stress may result in distorted bunches (QDAF and HIA, 2018a), or in plants that kink or bend (QDAF and HIA, 2018d). Heat stress effects may also be compounded by water stress, such as in drought conditions.

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 and Lindsay, 2006). Plant roots become stunted or die, or root hairs do not develop (QDAF and HIA, 2018e), thus plants can no longer access required water or nutrients 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, leaf bunching at the top of plants, distorted bunches, reduced fruit length and increased nematode damage (QDAF, 2012d; QDAF and HIA, 2018c, a, d, e).

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 and 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; QDAF and HIA, 2018b). Water stressed plants, which can include over- or under-watered plants, are more likely to suffer from a range of symptoms, including leaf damage, dropping green leaves, leaf bunching at the top of plants, small or stunted plants, plants that may kink and bend, longer crop cycles, smaller bunches with shorter fruit, mixed or premature ripening of fruit, and increased pest and disease susceptibility (QDAF and HIA, 2018c; King, 2021). Water stress is often compounded by temperature stress and/or high evaporations rates.

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 Fe, Al and Mn; 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 Ca. Careful fertiliser management reduces soil acidification. A pH higher than 6.5, can reduce the availability of trace elements such as boron, Zn, Cu and Fe (Broadley et al., 2004; QDAF and HIA, 2018e). Soil compaction and fertiliser burn may also result in root death or lack of root hairs (QDAF and HIA, 2018e).

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 (QDAF and HIA, 2018c) 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 and Sexton, 1972). Wind damage may also be associated with poor bunch emergence (QDAF and HIA, 2018a) and with scabbing of fruit caused by young fingers rubbing against fruit bags or leaves in windy conditions (QDAF and HIA, 2018b).

Damage may also be caused by herbicide spray drift, which may have a range of impacts including effects on bunch emergence, leaf damage or discolouration, stem damage or discolouration, and leaf bunching at the top of plants, with the impact of such effects depending on levels of exposure (QDAF and HIA, 2018a, c, d).

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 weed species have been identified as alternative hosts for Panama disease (*Fusarium oxysporum*, different races). These include, but are not limited to, *Chloris inflata* (purpletop rhodes grass), *Euphorbia heterophylla* (milk weed), *Tridax procumbens* (coat buttons, Mexican daisy), *Cyanthillium cinereum* (vernonia), *Paspalum fasciculatum* (Mexican crown grass), *Panicum purpurascens* (syn. *Urochloa mutica*, para grass), *Ixophorus unisetus* (foxtail millet, Mexican grass), *Commelina diffusa* (scurvy weed), and *Megthyrsus maximum* (para grass) (State of Queensland, 2017).

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, 2021).

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 Qld banana biosecurity zones and the NT banana freckle eradication zones[11].

Further information about State regulations can be found in the Queensland Biosecurity Manual (Queensland Government, 2022), Banana Industry Biosecurity Guideline (QDAF, 2016a), Plant Quarantine Manual for New South Wales (NSW DPI, 2016b), NT Government website and WA DPIRD 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 Department of Primary Industries (NSW DPI) banana site. The Banana Best Management Practices Manual also contains information about integrated pest and disease management strategies for banana (King, 2021).

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, 2021). 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.

Worldwide, a range of pests and diseases impact the cultivation of bananas and plantains, whether on a broad commercial scale. More information about these can be found through the ProMusa website via the Musapedia Pests and diseases portal.

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, 2021).

Major invertebrate pests of banana in Australia, their effects and possible control strategies are summarised in Table 11.
The banana scab moth (*Nacoleia octasema*) is a frequent and severe pest of bananas (QDAF, 2017f). 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 sordidus)* 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. Two insect pests not currently present in Australia (spiralling whitefly (*Aleurodicus dispersus*) and Banana skipper (*Erionota thrax*) - are listed as Biosecurity Alert species, which must be notified if suspected or identified (QDAF and HIA, 2018c)). A number of minor pests are also listed for bananas causing minor or sporadic damage to leaves (QDAF and HIA, 2018c), or to roots and corms (QDAF and HIA, 2018e). More information about these can be found on the PHA Banana webpage, the Better Bananas Problem Solver webpages and QDAF website.

[11] Note this eradication zone for the NT and the associated map (See Appendix 2b) are no longer listed in the NT Government website, so information about it is provided for context only.

Table 11. Invertebrate pests affecting commercial bananas in Australia

Common and Scientific name	Occurrence	Damage	Prevention/Control	References
Banana aphid (*Pentalonia nigronervosa*)	Southern and northern Qld	The vector for BBTV or sooty mould; direct damage by the aphid is rare.	Biological control through ladybird beetles, earwigs and lacewing. Chemical control only if predator numbers are not sufficient.	(QDAF, 2017b; QDAF and HIA, 2018d, b)
Spider mite (*Tetranychus lambi*)	Frequent and widespread in banana growing regions	Leaf damage and wilting which may lead to reduction of plant growth, leaf discolouration, damage to fruit causing purple colour and cracking	Reduction of dust on road and good farming practices. Agricultural control through weed management, minimising plant stress and plant density management. Predator insects may assist control including ladybirds, beetles and mites. The suitability of chemical control must consider plant health and environmental conditions.	(Biosecurity Australia, 2007; QDAF, 2017g; QDAF and HIA, 2018b, c; King, 2021; PHA, 2021b)
Two-spotted mite (*T. urticae*)	Common in Qld	Feeding on underside of leaves may cause leaf damage such as bronzing, damage to edges, spotting; may also cause fruit bronzing. Damage is minor and infrequent.	Predatory beetles may control, otherwise application of miticide, including under leaves, taking care not to disrupt beneficial species or damage leaves.	(QDAF and HIA, 2018b, c; Business Queensland, 2022)
Rust thrip (*Chaetanophothrips signipennis*) and Silvering thrip (*Hercinothrips bicinctus*)	Qld and the North coast of NSW	Rusty red to brown-black discolouration, mainly on top hands, with skin splitting in serious cases for rust thrip (major and frequent). Infects fruit. Silvery speckling with silvering thrip (minor and infrequent).	Silvering thrip usually controlled by predator insects. Rust thrip managed by effective predators, use of thrip-free planting material, trimming leaves around emerging bunches, plus chemical controls including soil treatments. Must consider chemical resistance management.	(Treverrow, 2002; Broadley et al., 2004; QDAF, 2017e; QDAF and HIA, 2018b; CropLife Australia, 2021a; King, 2021)
Banana flower thrip (*Thrips hawaiiensis*)	Throughout banana growing areas, major pest in SE Qld and northern NSW, minor in N Qld	Causes corky scabs in fruit, mostly on the outer curve near bunch stalks; spots on fruit	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, 2017c; QDAF and HIA, 2018b; King, 2021)

Common and Scientific name	Occurrence	Damage	Prevention/Control	References
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, 2017d; QDAF and HIA, 2018b)
Banana fruit fly (*Bactrocera musae*)	Coastal regions north of Townsville. Native to Qld.	Destruction of fruit flesh, fruit spotting at early stages.	Minor only, especially in commercial banana plantations.	(Biosecurity Australia, 2007; QDAF and HIA, 2018b; Royer, 2021)
Queensland fruit fly (*Bactrocera tryoni*)	Western districts of Qld occasionally further south	Destruction of fruit flesh	Attack the maggot stage and reduce population of subsequent generations. Spot spraying selected areas using dimethoate if chemical treatment is required and the areas bordering the plantation should be targeted.	
Sugarcane bud moth (*Opogona glycyphaga*)	Qld, NSW and Carnarvon in WA	Superficial scarring of fruit	Spiders aid in the biological control of the moth. Planting away from sugarcane helps to control infestation of bananas. Severe infestations can be combated with chemical dusting at bagging.	(QDAF, 2017j; QDAF and HIA, 2018b; King, 2021)
Banana scab moth (*Nacoleia octasema*)	Only found north of Ingham in north Qld	Frequent and major damage. 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, 2017f; QDAF and HIA, 2018b; King, 2021)
Fruit-piercing moth (*Eudocima spp.*)	From northern NSW to Darwin, dies out in southern areas over winter	Major but sporadic damage. Piercing of skin causing bruising and dry areas, secondary rots and secondary feeding occurs at these sites.	Control methods not determined but some predatory wasps may assist, with fruit bagging or netting of plants.	(QDAF, 2017i)
Banana-spotting bug (*Amblypelta lutescens lutescens*)	Coastal, sub-coastal southern Qld	Major and frequent damage, although only when preferred hosts are not available. Black spots in fruit, may be fruit shedding of younger fruit, larger fruit dimpled, may be confused with fruit-fly damage.	Egg parasites are under investigation, green tree ants and assassin bugs provide some control. Regular chemical spraying. Planting bananas away from uncleared scrub.	(QDAF, 2017a; QDAF and HIA, 2018b)

Common and Scientific name	Occurrence	Damage	Prevention/Control	References
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 ^{o}C for 20 minutes - or in solutions of non-volatile Nemacur or Mocap. Stalk injection with glyphosate. Injecting the corms with glyphosate. Sugarcane ash has been shown to suppress nematodes. Chemical control. In general: IPM including physical, biological, cultural, non-host fallow crops and chemical controls.	(Morton, 1987; Bridge et al., 1997; Stirling et al., 2002; Hodda, 2003; Lindsay et al., 2003; Broadley et al., 2004; Biosecurity Australia, 2007; Grice et al., 2009; QDAF and HIA, 2018d, e; King, 2021)
Root burrowing nematode (*Radopholus similis*), spiral nematode *Helicotylenchus multicinctus* and root-knot nematode (*Meloidogyne spp.*)	All banana growing regions	Not deemed very important; may cause plants to be stunted or to fall over or may cause damage symptoms in roots and corms		
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	Listed as causing minor and infrequent damage in north Queensland, having higher impact in southern banana growing areas. 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; small or stunted plants.	Good plantation hygiene practices, cane-toads ants and beetles can provide a level of 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. Chemical control must consider the chemical resistance history of the area.	(Meldrum et al., 2013; QDAF, 2017h; QDAF and HIA, 2018d, e; CropLife Australia, 2021a; King, 2021)

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. Panama Disease FocTr4, Cavendish competent Foc tropical race 1, Banana Freckle Disease and BBTV 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; QDAF and HIA, 2018d, e; PHA, 2021a). There are also a number of diseases that are not present in particular areas of Australia that are considered a potential threat in these areas because of their presence in other banana growing regions in Australia. For example, FocTR4, banana bunchy top virus, and banana streak disease are not present in the ORIA, but are present in other Australian banana growing areas (DAFWA, 2016). Diseases of economic significance in the ORIA are yellow sigatoka (see below), banana speckle (*Mycosphaerella musae*) or leaf speckle (*Deightoniella torulosa*), fruit speckle and corm rot/soft rot (*Erwinia carotovora*/*Erwinia spp*.) (WA DPIRD, 2018).

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 Guideline provide further information (NSW DPI, 2016b; QDAF, 2016a; State of Queensland, 2016). Specific standards and guidelines and legislative requirements are in place in Qld for Panama disease tropical race 4 (QDAF, 2015, 2016c), which will be discussed further in the section on that disease following Table 12. NSW also controls the movement of banana material for control of diseases (Biosecurity (Banana Bunchy Top Virus) Control Order 2021 (NSW Government, 2021). The NT has had restrictions on movement and planting of bananas with focus on prevention of banana freckle and declared eradication zones for control of that disease. In the NT, banana freckle is declared a pest under the Northern Territory Plant Health Act 2008 and more information about banana freckle control can be found on the NT Government website (accessed 24 January 2023). Legislative requirements for WA are managed through the Biosecurity Management Act 2007 (Western Australia, 2019).

Table 12 summarises the major banana diseases in Australia. These are discussed in more detail following the table.

A number of other fungal and bacterial diseases are also identified as minor or sporadic diseases of bananas rarely requiring control. These may affect leaves (QDAF and HIA, 2018c), fruit (QDAF and HIA, 2018b), bunches (QDAF and HIA, 2018a), plant architecture or integrity (QDAF and HIA, 2018d), and/or roots and corms (QDAF and HIA, 2018e).

Table 12. Major diseases affecting commercial bananas in Australia

Disease + causal organism	Occurrence	Damage	Prevention/Control	References
Fungal diseases				
Panama disease: *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 in Tully (Qld). As of March 2022, confirmed on five North Qld properties (160 plants).	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; Ploetz, 2015a, b; QDAF, 2016b, c, d; Kukulies and Veivers, 2017; NSW DPI, 2017b; Daniells and Lindsay, 2018; Lindsay, 2018; QDAF and HIA, 2018c, d, e; WA DPIRD, 2018; Business Queensland, 2020b; QDAF, 2020; PHA, 2021f; Vézina, 2021; Vézina and Rouard, 2021; PHA, 2022; Vézina, 2022)
Yellow Sigatoka (leaf spot): *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; QDAF and HIA, 2018c; WA DPIRD, 2018; System Administrator and Vézina, 2020; CropLife Australia, 2021b)
Black Sigatoka (black leaf disease): *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; Grice et al., 2009; QDAF, 2011, 2012b; NSW DPI, 2013b; QDAF and HIA, 2018c; Business Queensland, 2020a; Vézina et al., 2020b; PHA, 2021d)
Banana freckle: *Phyllosticta cavendishii* and *P. maculata* (*Guignardia musae*)	Has occurred in NSW, Qld and more recently in Cavendish in remote areas of WA. In 2013 it was detected in Cavendish in the NT. Eradication programs were implemented and the NT was declared free of banana freckle in February 2020.	Severe infections result in yellowing of the leaf with subsequent withering and death	Cannot be eradicated by chemical application, plants must be removed. An eradication program is underway in the NT.	(Biosecurity Australia, 2007; NT Government, 2016; Business Queensland, 2019b; NT Government, 2020a; PHA, 2021c)
Viral diseases				
Banana bunchy top virus (BBTV)	South eastern Qld, south of Cooloobin and the Tweed and Brunswick River	Yellowing of the leaf with subsequent withering and death	There is no treatment, affected plants must be destroyed. There are strict	(Biosecurity Australia, 2007; ABGC, 2016a; NSW DPI,

Disease + causal organism	Occurrence	Damage	Prevention/Control	References
	valleys of northern NSW but has not been detected in WA, the NT, North Qld or the Coffs Harbour region of NSW		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.	2016a; QDAF and HIA, 2018c, d, b, a; WA DPIRD, 2018; Business Queensland, 2019a; Vézina et al., 2020a; PHA, 2021e)
Banana Streak Disease: the virus banana streak virus (BSV)	Minor importance in Cavendish and Lady finger in Qld, more serious in newer hybrid cultivars. In these, viral genome becomes incorporated into 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; QDAF and HIA, 2018a, d, b, c; Vézina, 2019)

Panama Disease

Panama disease manifests as both internal and external symptoms. 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 (QDAF, 2016b; Business Queensland, 2020b; PHA, 2021f). Fruit of infected plants appears symptomless (NSW DPI, 2017b). Primary hosts of this disease include cultivated banana, *M. acuminata* (wild banana) and *M. textilis* (Manila hemp).

There are four 'physiological' races of Panama disease - Races 1, 2, 3 and 4 - based on their difference in pathogenicity. Race 4 consists of strains that infect Cavendish cultivars (Vézina and Rouard, 2021), but also affects cultivars susceptible to Races 1 and 2 (including Gros Michel, Silk, Pome and Bluggoe) and varieties not affected by other races, such as 'Lakatan' and 'Pisang mas' (Vézina, 2022). This race has been subdivided further into another two strains, Subtropical race 4 and FocTR4 (Vézina and Rouard, 2021; Vézina, 2022).

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 (QDAF, 2016b; PHA, 2021f). Cavendish cultivars generally only show symptoms after a period of cold stress (QDAF, 2016b; PHA, 2021f; Vézina, 2022).

Tropical race 4 (FocTR4) was detected near Darwin in 1997. In 2015, it was detected at a property in Qld and has since been detected in 160 plants at five properties in far north Qld (NSW DPI, 2017b; QDAF, 2020; PHA, 2022). A recent review (Biosecurity Queensland, 2021) has examined the epidemiology of FocTR4 in the Tully valley in Queensland with the aim of providing information on the effective management of the disease into the future. Worldwide, it was present in over 20 countries as of January 2020 (Vézina, 2022). FocTR4 is particularly destructive as 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, 2016b). Spores can persist in soil for 30-40 years (QDAF, 2016b). The fungus cannot be controlled by fungicides or by use of soil fumigants to remove it from infested soils (Vézina, 2021). There have been some reports of soil types that may suppress the disease, including some in Australia (Pegg et al., 2019; Biosecurity Queensland, 2021; Vézina, 2021), however the disease has been found in a range of soil types (Biosecurity Queensland, 2021). There is also some indication that soil microbial activity may play a role in suppressing fusarium wilt (Pattison et al., 2020), or that certain banana varieties are more resistant to FocTR4, however this is mainly based on field trials (Vézina, 2021).

Strict quarantine practices have helped in restricting the spread of this disease. The Queensland Biosecurity Regulation 2016 (State of Queensland, 2016) and the Queensland Biosecurity Manual (Queensland Government, 2022) detail biosecurity requirements for Queensland, including those related to banana production. A surveillance program for 2020/21 was implemented for commercial banana farms in far north Qld. Confirmed TR4 infested properties are checked every eight weeks, Tully Valley properties every three months and all other commercial banana properties from Cardwell to Lakeland once every 12 months (QDAF, 2020).

There is also investigation of whether the banana weevil borer is a vector for FocTR4 (Meldrum et al., 2013; Pegg et al., 2019) although there seems to be little conclusive information about their role. Likewise, the involvement of nematodes in disease development has also been investigated but there is no clear link (see review by Pegg et al., 2019). 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). A summary of the available information regarding alternative weed hosts for TR4 is given by Pegg and colleagues (2019).

Reviews summarise the available information about FocTR4, the history and pathology of the disease and cultivars which are resistant to this pathogen (Ploetz, 2015a, b; Pegg et al., 2019) and research is ongoing, as this pathogen has spread into different banana growing areas worldwide. There is no evidence of dispersal of the disease in fruit (Pegg et al., 2019). In Australia, research has also focussed on producing best practice guidance for preventing disease spread and managing commercial banana production

(Kukulies and Veivers, 2017; Daniells and Lindsay, 2018; Lindsay, 2018). A wide range of approaches are being assessed globally, including improved detection of infection, prevention of disease spread and managing infected plantations (Carvalhais et al., 2019; Johnson, 2021).

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. Both leaf speckle and yellow sigatoka are referred to as 'leaf spot' (QDAF, 2016a). If spots are large, they may form large dead areas (Grice et al., 2009; System Administrator and Vézina, 2020). 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 conidial 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, 2021b).

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 Australian banana industry (Grice et al., 2009; NSW DPI, 2013b). There are six stages of symptom development (NSW DPI, 2013b; Vézina et al., 2020b) and symptoms can be quite similar to Yellow sigatoka and to Eumusa streak, which is not present in Australia (QDAF, 2011; NSW DPI, 2013b; PHA, 2021d). Outbreaks 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 regained disease-free status for black sigatoka in 2005 (QDAF, 2011; PHA, 2021d). 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 (QDAF, 2012b; Vézina et al., 2020b). A number of cultivars are considered to be resistant to black sigatoka: Blue 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 (Queensland Government, 2021).

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 (ABGC, 2016a; NSW DPI, 2017a; Vézina et al., 2020a). BBTV infection is transmitted through an aphid vector *Pentalonia nigronervosa* and over longer distances by infected planting material (ABGC, 2016a; NSW DPI, 2017a). Details of mandatory aphid control and the subsequent destruction of infected plants are prescribed by Biosecurity (Banana Bunchy Top Virus) Control Order 2021 under the NSW *Biosecurity Act 2015* (NSW Government, 2021). Restrictions on movement of banana planting material and products is also specified by the same order for the NSW Banana Bunchy Top Virus Control Zone, which is all land within the local government areas of Ballina Shire, Byron Shire, City of Lismore and Tweed Shire (NSW Government, 2021). To date, the disease has occurred in south eastern Qld, south of Cooloobin, and the Tweed and Brunswick River valleys of northern NSW, but does not occur in the Coffs Harbour region of NSW (NSW DPI, 2022). The virus infects cultivated and wild bananas in the *Musaceae* family (NSW DPI, 2022).

Banana freckle

Banana freckle is caused by the fungi *Phyllosticta cavendishii* and *P. maculata* (previously *Guignardia musae* - Mycobank, accessed 16 September 2021). The principal hosts of banana freckle are *Musa* species, including a range of edible banana and plantain cultivars (NSW DPI, 2013a). The *P. maculata* fungus infects Lady Finger and Bluggoe and related varieties, 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; NT Government, 2016; PHA, 2021c). Banana freckle was detected in the NT in 2013 (NSW DPI, 2013a; NT Government, 2016) where an eradication program commenced (NT Government, 2019). Infected plant material had to be removed within the eradication zone (see Appendix 2b) as banana freckle fungus cannot be eradicated by chemical treatment (NT Government, 2016, 2019). The NT was declared banana freckle free in 2019, although banana freckle remains a declared pest under NT plant health legislation (NT Government, 2019, 2020b). However, in May 2022 *P. cavendishii* was again detected in the NT and an eradication program has been approved, involving the removal of plants from properties where the fungus has been detected (NT Government website, accessed October 2022). The native banana *M. acuminata* subsp. *banksii* (*M. banksii*) is susceptible to the disease (Biosecurity Australia, 2007).

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 lifespan 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. It is noted as having a

stable population and is classified as being a species of 'Least Concern'[12] for conservation (Queensland ELW, 2021b). *M. jackeyi* is found near Innisfail and Babinda in north-east Qld and is listed as Endangered (Queensland ELW, 2021d). Neither of these species is classed as a weed (Queensland ELW, 2021b, d). A third endemic species, *M. fitzalanii*, is listed as Extinct[13] (Queensland ELW, 2021c).

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). More recent information lists *M. acuminata* as an Environmental Weed in Qld (Queensland ELW, 2021a). 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 (NSW DPI, 2018). 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 and 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 runoff 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 (Government of Queensland, 1999).

No *Musa* species are listed on the Weeds of National Significance (WoNS) list, nor are any species listed as invasive weeds on the Weeds Australia website (accessed September 2022).

8.3 Weediness in agricultural ecosystems

Commercially grown bananas in Australia only reproduce vegetatively. 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. Weedy *M. acuminata* has also been found in several locations in and around Lismore, Bellingen and south of Sydney NSW (NSW DPI, 2018) and is classed as an environmental weed in Qld (Queensland ELW, 2021a). Seeded bananas, *M. velutina* and *M. ornata*, occur in isolated areas near Nimbin, Murwillumbah and Lismore in northern NSW, although the distribution and extent of occurrence is not known. They have previously been identified as a priority for control in and near National Parks and Conservation areas in those regions (NSW OEH, 2011). 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

[12] Ratings of status used are Nature Conservation Act 1992 (NCA) Status.

[13] Extinct status under NCA and 'Extinct in the Wild' under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC).

authorities target these plants for removal and control (Biosecurity Australia, 2007; NSW DPI, 2018). These plants have the capacity to spread through seeds being eaten by vertebrates, such as bats, birds, possums and other mammals (NSW DPI, 2018). 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 Qld must treat unmanaged banana plants by removing and cutting plant material as specified in the Queensland Biosecurity Manual (Queensland Government, 2022).

Chemical destruction of bananas is achieved via 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, are an essential component of integrated pest management (Lindsay et al., 2003). Injecting the corms with glyphosate is also an 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 and banana plants can be undertaken using chemicals approved under 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.

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 and Turner, 2005).

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 crosses made within and between wild species of the *Musa* and *Rhodochlamys* sections (Table 13).

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 and 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 and Turner, 2005).

Table 13. The viability of hybrids obtained from crosses between species from *Musa* and *Rhodochlamys*[a]

Male parent / **Female parent**	***Musa*** *acuminata*	*balbisiana*	*basjoo*	*itinerans*	***Rhodochlamys*** *laterita*	*ornata*	*sanguinea*	*velutina*
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*

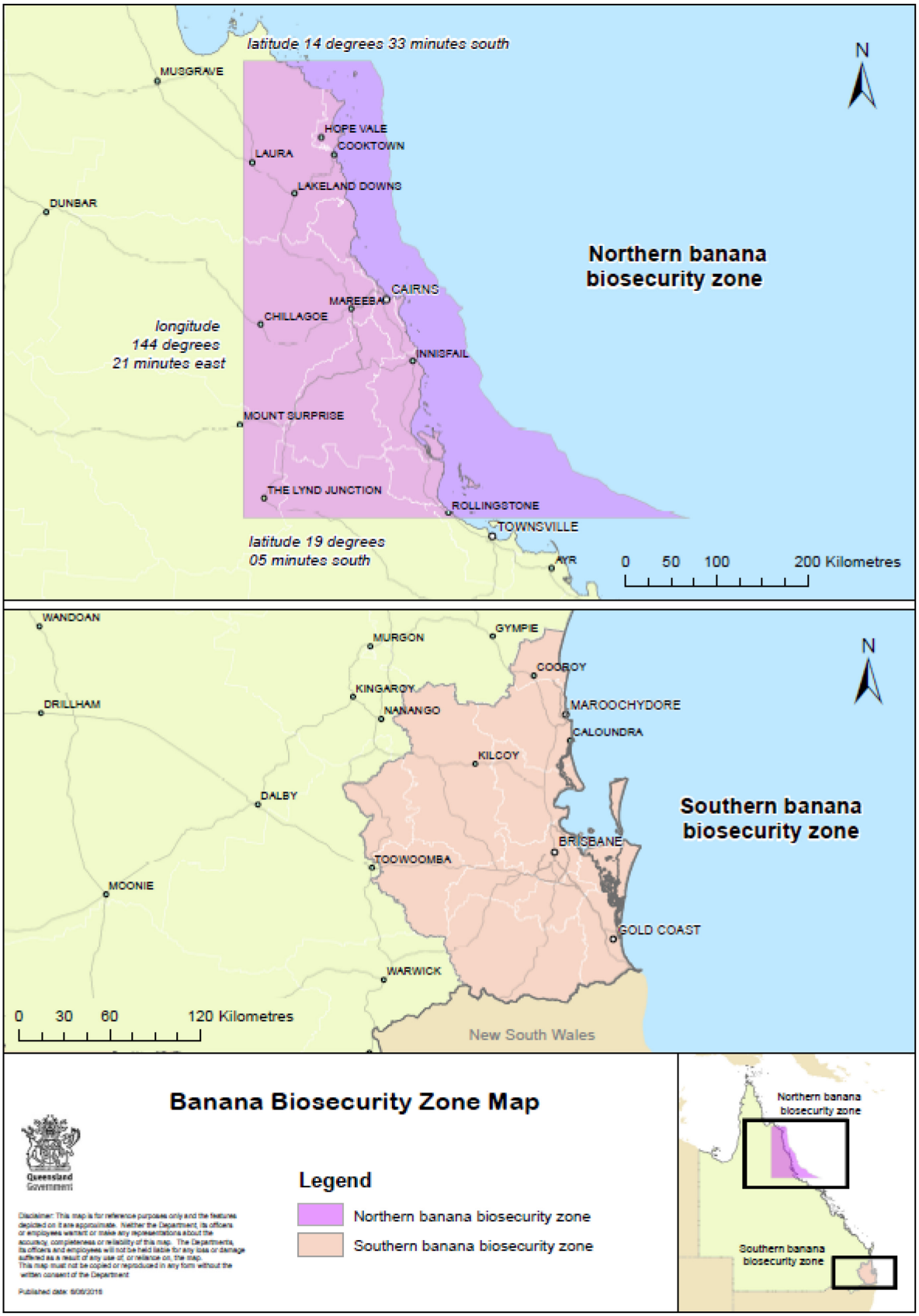
[a] Data for Appendices 1a and 1b derived from the Database of Neotropical Bat/Plant Interactions (Geiselman et al., 2002). The plant and bat names are as reported in the original publication and are not necessarily currently accepted names.

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

M. 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*

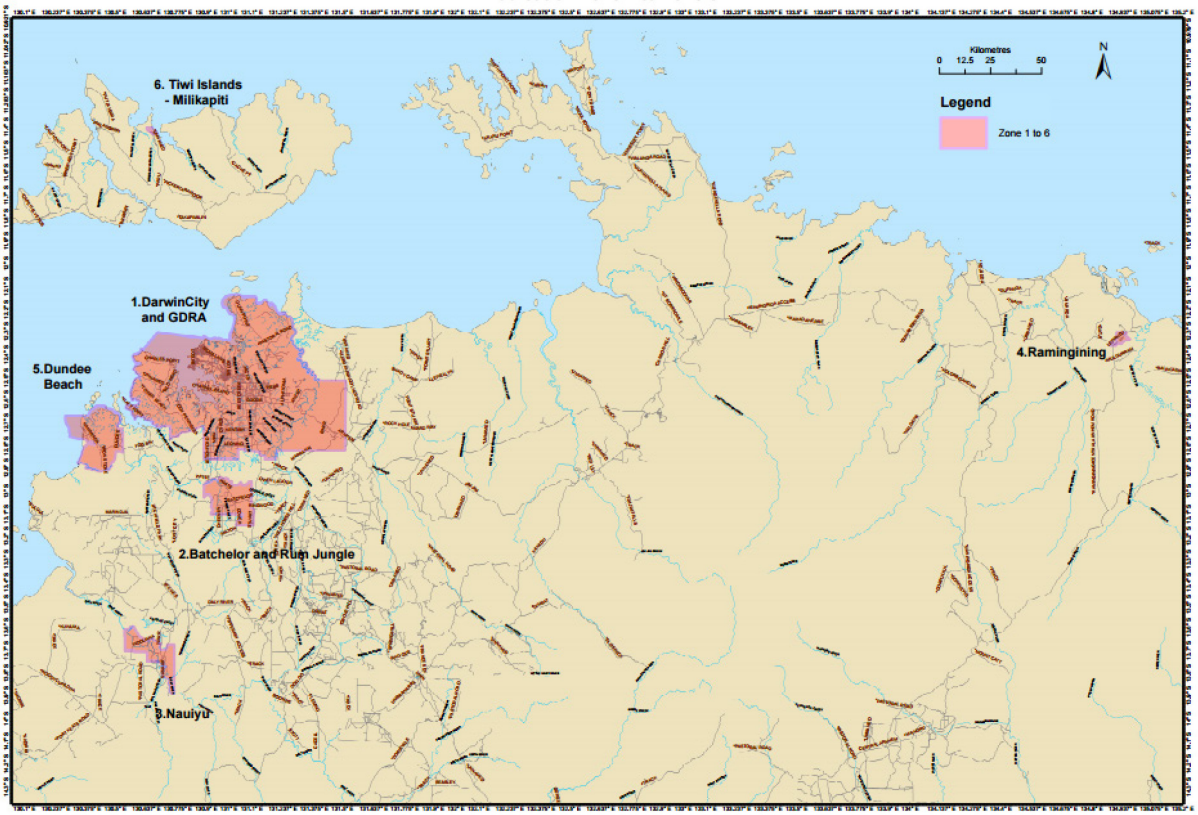
[a] Data for Appendices 1a and 1b derived from the Database of Neotropical Bat/Plant Interactions (Geiselman et al., 2002). The plant and bat names are as reported in the original publication and are not necessarily currently accepted names.

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: NT banana freckle eradication zones



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

Note this eradication zone is no longer listed in the NT Government website, so information is provided for context only.

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, 2008). 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 2023. 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** 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 can spread seeds from seeded varieties, but as cultivated bananas produce negligible seed this does not occur. 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** Wild land-based animals are unlikely to spread viable banana plant parts, such as corms or pieces of corms. The lack of reports of weedy cultivated bananas also suggests that this does not happen often or at all.

Invasiveness questions	Banana
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 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	
11a. Does banana provide food and/or shelter for pathogens, pests and/or diseases in the land use?	**Rating: Minor** Banana plants are susceptible 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.

Impact questions	Banana
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 density 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.