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Field evaluation of six Gros Michel banana accessions (*Musa* spp., AAA group) for agronomic performance, resistance to Fusarium wilt race 1 and yellow Sigatoka

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ABSTRACT

Three Gros Michel mutants ('IBP 5-B', 'IBP 5–61' and 'IBP 12') from the Cuban Instituto de Biotecnología de las Plantas, two semi-dwarf Gros Michel varieties ('Highgate' and 'Cocos') and a Thai accession ('Hom Thong Mokho') were evaluated in Australia over a five year period. They were screened for their resistance to Fusarium wilt Race 1 (*Foc*R1) caused by the pathogen *Fusarium oxysporum* f.sp. *cubense*, as well as resistance to yellow Sigatoka (*Pseudocercospora musae* Zimm [teleomorph *Mycosphaerella musicola* Leach]). They were also grown for a plant and ratoon crop in the tropics (17°S) and a plant crop in the subtropics (28°S) with no disease pressure to record their agronomic characteristics. They were compared with Australian industry standards, 'Williams' (AAA, Cavendish subgroup) and 'Lady Finger' (AAB, Pome subgroup). In the subtropics the Gros Michel mutants and semi-dwarf accessions were sensitive to cold and very susceptible to *Foc*R1 and yellow Sigatoka while their agronomic performance in the tropics was good, with 'Highgate' having the best bunch weight on a shorter, more manageable plant. Of the six accessions evaluated, 'Hom Thong Mokho' showed the highest level of resistance to *Foc*R1 although it had poor cold tolerance, as did the other Gros Michel selections, and consequently had low productivity compared to 'Williams' and even 'Lady Finger'. However in the warmer, more humid tropics 'Hom Thong Mokho's performance was much better and it was less susceptible to yellow Sigatoka than the other Gros Michel selections. Subsequent genetic analysis by Christelová et al. (2011) has revealed that although 'Hom Thong Mokho' is marketed as a Gros Michel variety in Asia, it is closer to the Rio subgroup (AAA) of dessert bananas.

1. Introduction

'Gros Michel' (AAA) was once the dominant banana in world trade and established a reputation as a dessert banana with heavy, symmetrical bunches of large fruit, consistently yellow colour at full ripeness with fine eating quality and good fruit green-life as well as shelf-life (Stover and Simmonds, 1987; Daniells, 2009). However 'Gros Michel' is very susceptible to Panama disease (Fusarium wilt) and was at the centre of one of the world's most serious plant disease epidemics as whole plantations in many countries succumbed to Race 1 of this devastating disease during the first half of the 20th Century (Stover and Simmonds, 1987). Fortunately, other varieties with resistance to race 1 were available and 'Gros Michel' was replaced by Cavendish (AAA) varieties in the 1960s. Cavendish is quite different in many respects to 'Gros Michel', including being more productive under a range of environmental conditions, but also more susceptible to nematodes and leaf spot pathogens and more prone to damage during postharvest handling and has a shorter shelf-life (Stover and Simmonds, 1987).

Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense; Foc*) is a lethal disease of banana which colonizes and occludes the xylem of susceptible cultivars to cause a terminal wilt (Stover, 1972; Ploetz, 1994; Ploetz and Churchill, 2011). There are no effective chemical control measures against Fusarium wilt, and even though management strategies to lower inocula levels and strict adherence to quarantine controls

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allow for production from infested sites, the most effective strategy for sustainable production relies on genetic resistance to the pathogen. Fusarium wilt Race 1 (*Foc*R1) is widespread in many parts of the world and contributed to the collapse of banana production based on the variety 'Gros Michel'. Fusarium wilt *Foc*R1 has also severely impacted on the production of 'Lady Finger' (AAB) in southern Queensland and New South Wales for the past century and overall production has only been maintained by planting in new non-infested areas. Yellow Sigatoka (*Pseudocercospora musae* Zimm [teleomorph *Mycosphaerella musicola* Leach]) is the principal leaf spot pathogen of bananas in Australia and the fungus invades the leaf tissue causing necrosis which leads to loss of functional leaf area and diminished yield (Jacome et al., 2003). In contrast to Fusarium wilt, yellow Sigatoka is controlled primarily with protectant fungicides in combination with a program of regular de-leafing of affected leaves. Systemic fungicides are also used when necessary, but only sparingly to avoid the development of fungicide resistance, and following guidelines developed by CropLife Australia (2014).

Bermúdez et al. (2002) from the Cuban Instituto de Biotecnología de las Plantas (IBP) irradiated micropropagated 'Gros Michel' plantlets from a ^{60}Co source (25 Gy) and resistant plants were selected following inoculation with a spore suspension of *Foc*R1 (isolate INIFAT-1, most likely VCG 01210) and planting in a *Foc*R1 infested field. 'IBP 5-B', 'IBP 5–61' and 'IBP 12' all had less than 4% of the plants expressing Fusarium symptoms after repeated cycles of pot and field screening and with agronomic and bunch characteristics as good, or better, than the mother plant. These three mutants, together with two semi-dwarf accessions ('Gros Michel' is a very tall cultivar typically 5–6 m in ratoons), 'Cocos' and 'Highgate', and a popular Gros Michel variety from Thailand, 'Hom Thong Mokho', were imported into Australia (Daniells, 2009) for further evaluation. Hence, the objectives of this study were to test these six Gros Michel varieties for their level of resistance to Fusarium wilt Race 1, resistance to yellow Sigatoka, and agronomic characteristics both in the subtropics and in the tropics. These new varieties and selections may provide economic alternatives for the Australian industry standards, 'Williams' (AAA, Cavendish subgroup) and 'Lady Finger' (AAB, Pome subgroup), particularly in those areas affected by Fusarium wilt.

2. Materials and methods

2.1. Plant materials

Tissue cultured plantlets of the Gros Michel (AAA) varieties were kindly supplied by the International Transit Centre for *Musa* germplasm located at the Katholieke Universiteit Leuven, Belgium. Locally grown cultivars 'Lady Finger' (AAB, Pome subgroup) and 'Williams' (AAA, Cavendish subgroup) were initiated into tissue culture from local sources. A description and rationale for selecting these varieties for evaluation in Australia is given in Table 1. These plants were micropropagated and established in the field for experimental work when they reached a height of 15 cm in 300 mL tube stock cells.

2.2. Establishment and maintenance of field trials

The subtropical Duranbah, New South Wales site (28°S, 154°E and an altitude of 50 m with an annual average rainfall of 1800 mm) is located on a north-facing, slightly sloping (5%) block and the soil is classified as a red ferrosol (McKenzie et al., 2004). It was part of a commercial 'Lady Finger' plantation that was abandoned in the late 1970s due to losses caused by Fusarium wilt and no banana cultivation occurred until 2011 when it was replanted with tissue cultured 'Lady Finger' and 'Williams' plants scattered around the 2 ha site as sentinels to determine whether the pathogen was still present in the soil. Within 12 months, and after 32 years without banana cultivation on the site, all of the 'Lady Finger' plants expressed symptoms of Fusarium wilt and subsequent analysis showed that they were infected with *Foc*R1 (VCG 0124), while the 'Williams' were unaffected. Isolation of *Foc* VCG 0124 from infected 'Lady Finger' plants was multiplied *in vitro* and re-introduced to the lower half of the block at planting to ensure even distribution of inoculum (see experimental procedure below) and this portion was used exclusively for *Foc*R1 experiments and screening. The upper half of the block, separated by a 10 m grass buffer, was used for agronomic evaluation with no further introduction of artificial inocula. Biosecurity and disinfestation measures were taken on-site to minimise the likelihood of movement of inocula from the heavily infested *Foc*R1 screening trial to the agronomic trial.

The tropical South Johnstone Research Station site (17°38′S) in north Queensland, near the town of Innisfail, has a humid tropical climate with an average annual rainfall of 3300 mm. The soil type is a brown dermosol. As well as agronomic evaluation, this site was selected for yellow Sigatoka ratings. Another site was selected on a nearby grower's farm at East Palmerston that was infested with *Foc*R1. This was the first site selected for evaluating *Foc*R1 resistance in the tropics, however a second site was also selected on a grower's farm at South Johnstone that included 'Hom Thong Mokho'.

A series of field trials were carried out over an extended period, commencing in February 2012 and concluding in June 2017 (Table 2). At Duranbah plants were established at a density of 1666 plants/ha with a spacing of 2 m between plants in a row with an inter-row distance of 3 m. Plants were grown using standard commercial practices for the subtropics (Broadley et al., 2004), however fertiliser as N, P, K plus trace elements (Nitrophoska®, Incitec Pivot) was broadcast by hand at the rate of 150–200 g per plant every 3 months and water was supplied through under-tree sprinklers. Weeds were controlled by spot-spraying Basta® (glufosinate-ammonium, Bayer) during the early phase of plant establishment and glyphosate during the warmer months. Pheromone traps were used to control banana weevil borer (*Cosmopolites sordidus*). At South Johnstone plants were established at a density of 1333 plants/ha with a spacing of 1.5 m between plants in a row with an inter-row distance of 5 m. Plants were grown using standard commercial practices for the tropics (Lindsay et al., 1998).

2.3. Agronomic measurements

Blocks were visited weekly and when banana plants started

Table 1
Description and rationale for selecting varieties for evaluation.

Variety	Description and rationale
'Cocos' (AAA)	Semi-dwarf Gros Michel cultivar; improved productivity
'Highgate' (AAA)	Semi-dwarf Gros Michel cultivar; improved productivity
'Hom Thong Mokho' (AAA)	Popular Gros Michel cultivar from Thailand
'IBP 5-B' (AAA)	Resistant to *Foc*R1; reduced plant stature; more fingers per bunch
'IBP 5–61' (AAA)	Resistant to *Foc*R1; reduced plant stature; faster cycling
'IBP 12' (AAA)	Resistant to *Foc*R1; reduced plant stature; more fingers per bunch
'Lady Finger' (AAB)	Susceptible control to *Foc*R1; Grows well in tropics and subtropics
'Williams' (AAA)	Resistant control to *Foc*R1; Grows well in tropics and subtropics

Table 2
Outline of experiments conducted to assess performance of Gros Michel varieties with standard cultivars.

Name of site: Location	Planting date	Completion date	Assessment
Subtropical *Foc*R1 screening site: Duranbah (28°S), NSW	Feb. 2012	Feb. 2014	*Foc*R1[a]; Plant and ratoon crop at bunching
Tropical agronomic evaluation site: South Johnstone Research Station (17°S), QLD	Aug 2012	Feb. 2015	Agronomic; Plant and ratoon crop harvest
Tropical yellow Sigatoka evaluation site: South Johnstone Research Station (17°S), QLD	Aug 2012	Jul. 2015	Yellow Sigatoka[b]; nurse sucker after ratoon crop
First tropical *Foc*R1 evaluation site: East Palmerston (17°S), QLD	Jan. 2013	Feb. 2015	*Foc*R1; Plant crop at bunching
Second tropical *Foc*R1 evaluation site: South Johnstone (17°S), QLD	Aug 2015	June 2017	*Foc*R1; Plant crop at bunching
Subtropical agronomic evaluation site: Duranbah (28°S), NSW	Jan. 2014	Jan. 2016	Agronomic; Plant crop harvest

[a] Assessment for resistance to Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense*) Race 1.
[b] Assessment for resistance to yellow Sigatoka (*Mycosphaerella musicola*).

bunching, date of bunching, pseudostem height (from soil surface to the underside of bunch stalk where it bends over), and pseudostem girth (at 75 cm above ground) was recorded. At harvest, hand and finger number per bunch, date of harvest (criteria of harvest – bunches of all varieties were harvested weekly and included those which had reached a third hand caliper diameter of 3.45 cm), bunch weight, weight of fruit in following size categories - ≥ 26 cm; < 26 cm–22 cm; < 22 cm–20 cm; < 20 cm, and following sucker height were recorded. Productivity (t/ha/yr) was calculated as tonnes of fruit (bunch weight minus stalk weight) produced per hectare over a year. In the case of the ratoon crop data both the plant crop and the first ratoon fruit weights were combined.

2.4. Assessment of Fusarium wilt infection

At planting, 200 mL of Japanese millet grain (*Echinochloa esculenta*) colonised by a *Foc*R1 VCG 0124 isolate previously obtained from the trial site (BRIP 61873, characterised by vegetative compatibility group (VCG) testing, Ploetz and Correll, 1987) was placed in each planting hole immediately prior to introducing the banana plant.

Plants were judged to have external symptoms of disease if they displayed any sign of wilting, yellowing of foliage, petiole buckling or splitting of the pseudostem base. However, the most definitive test was to rate plants on internal symptoms of Fusarium wilt which were recorded at or near harvest of the plant crop and, for those plants still surviving, the first ratoon. Plants were cut transversely through the rhizome about one-quarter of the way above the rhizome's base. The cut surface of the rhizome was rated for discolouration on a scale of 1–6 (Orjeda, 1998): 1, no vascular discolouration; 2, isolated points of vascular discolouration; 3, less than one-third of the vascular tissue discoloured; 4, one-to two-thirds of the vascular tissue discoloured; 5, greater than two-thirds of the vascular tissue discoloured; and 6, total discolouration of vascular tissue. Samples of infected pseudostem or rhizome tissue from diseased plants were collected for confirmation of the pathogen through VCG testing.

In addition to the Fusarium wilt screening site in the subtropics at Duranbah there was a need to screen varieties in the tropics where plants experience much less cold stress. The Cuban Gros Michel accessions plus some resistant and susceptible check varieties were planted in January 2013 on a cooperating grower's farm at East Palmerston near Innisfail where Race 1 of Fusarium wilt had previously destroyed a planting of the cultivar 'Ducasse' (ABB, Pisang Awak). The north Queensland assessments were more qualitative in nature compared to the Duranbah site in the subtropics. External Fusarium wilt symptoms on each plant were recorded on a 6-weekly basis. Plants were noted as they succumbed to Fusarium wilt in the plant crop. At bunch harvest the rhizome was cut and examined for the presence of discoloured vascular tissue and from each diseased cultivar in the trial, tissue was collected for VCG analysis. The second *Foc*R1 site at South Johnstone was established in August 2015 and the same experimental approach was used.

2.5. Assessment of resistance to yellow Sigatoka disease

Following completion of data collection of the first ratoon in the agronomic evaluation at South Johnstone all the sample plants were nurse suckered (Daniells and O'Farrell, 1988) in early December 2014 to obtain a uniform developmental stage among varieties. The varieties were then assessed prior to bunching for resistance to yellow Sigatoka on 24 April and 5 June during the 2015 wet season. 'Williams' guard plants had already been strategically located at the ends of all plots at the commencement of the agronomic evaluation to provide a source of *P. musae* inoculum throughout the trial, once the leaf disease control program ceased at the completion of the first ratoon crop. Plots of three check/control varieties had also been included at the commencement of the agronomic trial – 'Williams' (Highly Susceptible, HS), 'Dwarf French Plantain' (Resistant, R) and 'Kluai Namwa Khom' (Highly Resistant, HR).

Yellow Sigatoka damage was assessed using youngest leaf spotted (YLS) and youngest leaf with 33% necrosis (YL33). YLS was determined by counting down from the first fully unfolded leaf to the youngest leaf with 10 or more mature lesions (Stover and Dickson, 1970) and for YL33 counting was continued down to the youngest leaf with at least 33% of the lamina destroyed by disease (Jones, 1993). Leaf emergence rate (LER) between rating occasions was also determined.

2.6. Experimental design and statistical analyses

At Duranbah the *Foc*R1 screening site was a randomized block design with four blocks of eight varieties laid out in plots of four plants each in a row with a spacing of 2 m between plants, while the subtropical agronomic evaluation site was part of a larger trial with a total of 16 varieties in a randomized complete block with three plants per plot replicated six times.

At South Johnstone the agronomic and yellow Sigatoka evaluation site was designed as a randomized complete block. The varieties reported on here also constituted part of a larger trial with a total of 14 varieties and two replications (28 plots). Each plot consisted of nine plants with data collected from the central five plants. At East Palmerston the first tropical *Foc*R1 screening site was a randomized complete block design with single plant plots of eight varieties replicated six times. At South Johnstone the second tropical *Foc*R1 site was also a randomized complete block design with single plant plots of seven varieties replicated eight times. We will report here on the 'Hom

Table 3
Results of field evaluation of banana varieties for resistance to Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense* Race 1) at Duranbah[a] in the subtropics.

Variety	Internal symptoms *Foc*R1 Plant Crop (Rating 1–6)[b]	Internal symptoms *Foc*R1 First Ratoon (Rating 1–6)[b]
'Cocos'[c]	5.50 bcd	6.00 b
'Highgate'	4.44 b	6.00 b
'Hom Thong Mokho'	1.13 a	1.19 a
'IBP5-B'	6.00 d	6.00 b
'IBP5-61'	5.88 cd	6.00 b
'IBP12'	5.94 d	6.00 b
'Lady Finger'	4.81 bc	5.64 b
'Williams'	1.00 a	1.00 a
95% LSD	1.11	0.78

[a] Planted trials at Duranbah (28°S) February 2012 and rated for reaction to *Foc*R1 at or near harvest of plant crop in September 2013 and at or near harvest of the ratoon crop in February 2014.
[b] Scale: 1 = Rhizome completely clean, no vascular discolouration, 2 = Isolated points of discolouration in vascular tissue, 3 = Discolouration of up to one-third of vascular tissue, 4 = Discolouration of between one-third and two-thirds of vascular tissue, 5 = Discolouration greater than two-thirds of vascular tissue, and 6 = Total discolouration of vascular tissue and/or death of plants. Values in a column followed by the same letter are not significantly different ($P > 0.05$).
[c] Plants were all somaclonal variants that arose during *in vitro* propagation.

Thong Mokho' in comparison with the three control varieties for this second site.

The plot means for all variables measured was calculated and analysed using analysis of variance (ANOVA) for the various sites, with the exception of the ratoon crop at South Johnstone, which used residual maximum likelihood (REML). ANOVA was not used for the ratoon crop due to some plots producing no data resulting in an unbalanced dataset. Plant height was fitted as a covariate in the REML analysis of the disease ratings. All tests were performed at the 0.05 level of significance and pairwise comparisons were made using Fisher's protected 95% least significant difference (LSD). All analyses were conducted in GenStat for Windows, 16th Edition (VSN International, 2013).

3. Results

3.1. Assessment of Fusarium wilt infection

As expected, the Gros Michel varieties, 'Cocos' and 'Highgate', were very susceptible to *Foc*R1 (Table 3). However, the Cuban Gros Michel accessions, 'IBP5-B', 'IBP5-61' and 'IBP12', which had been selected for their resistance to *Foc*R1 in Cuba were also very susceptible to the local strain of *Foc* recovered from the Duranbah block. Furthermore they were also severely affected by the cold weather, exhibiting poor growth and signs of chilling injury such as yellowing of the lamina and blackening of petioles and the leaf midribs. In fact none of these five Gros Michel varieties survived for a ratoon crop.

Of even more interest was the response of 'Hom Thong Mokho' to *Foc*R1. Not only did it show resistance to *Foc*R1 in the plant crop, with only a few plants expressing any disease symptoms, the resistance carried through to the ratoon crop. As expected, 'Williams' showed total resistance to *Foc*R1 while 'Lady Finger' showed a typical susceptible reaction (Table 3).

Given that Gros Michel varieties are not tolerant to low temperatures compared to most Cavendish and Lady Finger types (Stover and Simmonds, 1987), *Foc*R1 screening was also carried out in the tropics on a north Queensland farm. Here all plants in the plant crop of 'Gros Michel', 'IBP 12', 'IBP 5-B', 'IBP 5–61' were severely wilted due to Fusarium wilt and did not produce a bunch. One plant only of 'Dwarf Ducasse' (very susceptible control) produced a very small bunch whilst the others were severely stunted due to Fusarium wilt and did not produce a bunch. Three of the six 'Lady Finger' (moderately susceptible control) plants showed some external yellowing of lower leaves and associated internal vascular discolouration but all produced satisfactory bunches in the plant crop, which has been noted before in the wet tropics (Daniells, 2010). 'Williams' (highly resistant control) did not express any evident disease symptoms. Interestingly 'Highgate' also had no disease symptoms evident in the plant crop, nor was there any rhizome discolouration evident. This was despite it being susceptible at the subtropical Duranbah site. VCG analysis of samples from each of the diseased cultivars returned a positive result for the Race 1 strain 0124. At the second tropical *Foc*R1 site no symptoms of Fusarium wilt were evident on any of the 'Hom Thong Mokho' plants in the plant crop, while all 'Dwarf Ducasse' (very susceptible control) had severe Fusarium wilt symptoms (as per site 1). Two of the 'Lady Finger' plants had Fusarium wilt symptoms and none of the 'Williams' were affected by Fusarium wilt.

Table 4
Yellow Sigatoka leaf disease ratings at South Johnstone.

Musa Germplasm	YLS[a] (av. of April and June assessments)	YL33[a] (av. of April and June assessments)	Av LER[a] (L/wk)	Disease Reaction[b]
AAA Genome				
Gros Michel subgroup				
'Gros Michel'	7.1 $_{bd}$	10.4 $_{abc}$	0.76 $_{bc}$	VS
'IBP 5-B'	6.4 $_{ab}$	10.0 $_{ab}$	0.71 $_{abc}$	VS
'IBP 5–61'	5.9 $_{ac}$	9.4 $_{a}$	0.64 $_{a}$	VS
'IBP 12'	5.8 $_{ac}$	10.1 $_{ab}$	0.69 $_{ab}$	VS
'Highgate'	6.4 $_{ab}$	8.8 $_{a}$	0.74 $_{bc}$	VS
'Hom Thong Mokho'	9.5 $_{e}$	11.6 $_{bc}$	0.79 $_{c}$	S
Cavendish Subgroup				
'Williams'	7.63 $_{cd}$	11.8 $_{c}$	0.70 $_{ab}$	VS check
AAB Genome				
'Dwarf French Plantain'	14.7 $_{f}$	14.2 $_{d}$	0.74 $_{bc}$	R check
ABB Genome				
'Kluai Namwa Khom'	16.9 $_{g}$	16.8 $_{e}$	0.88 $_{d}$	HR check
95% LSD	1.5	1.6	0.09	

[a] YLS = Youngest Leaf Spotted; YL33 = Youngest Leaf with 33% necrosis; LER = Leaf Emergence Rate (leaves/week).
[b] Disease Reaction: HR = Highly Resistant; R = Resistant; S = Susceptible; VS = Very Susceptible. Values in a column followed by the same letter are not significantly different ($P > 0.05$).

3.2. Assessment of resistance to yellow Sigatoka disease

The results of the yellow Sigatoka disease screening are presented in Table 4. Due to rainfall being well below average throughout the wet season (54% of average monthly rainfall in February/March/April/May) disease severity was much less than is usually the case. Consequently the very susceptible control variety 'Williams' had very little disease and contributed also to insufficient disease inoculum pressure particularly in some parts of the trial block. The average LER of the different varieties varied from 0.64 to 0.88 leaves per week but there was no particular relationship between YLS and LER. The overall disease reaction rating takes into account how the new varieties compared to the check varieties and the categorisation of these check varieties in previous studies (Daniells et al., 1996; Daniells and Bryde, 1999). Not surprisingly most of the varieties were very susceptible to yellow Sigatoka since they belonged to the Cavendish and Gros Michel subgroups. 'Hom Thong Mokho', which in more recent times has been allocated to the Rio subgroup, was less susceptible than those in the Gros Michel subgroup.

Table 5
Agronomic characteristics of varieties for the plant crop and first ratoon at South Johnstone Research Station (17°S).

Plant Crop

Variety	Bunch Weight (kg)	Days Planting to Harvest	Bunch wt/year (kg/year)	Fruit 22–26 cm (wt %)	Fruit 20–22 cm (wt %)	Bunch Filling Duration (Days)	Total Finger Number/ Bunch	Hand 3 Finger Diameter (cm)	Pseudostem Height (cm)	Pseudostem Circum. (cm)	Following Sucker Height (cm)
'Williams'	29.7 b	283 a	38.3 d	59.5 b	27.4 bc	89 a	133 b	3.45 a	295 a	62.3 a	194 a
'Gros Michel'	27.8 b	377 c	27.2 ab	53.2 ab	33.0 c	125 c	123 b	3.61 ab	435 d	75.2 c	301 bc
'Highgate'	34.9 c	405 d	31.5 c	55.0 b	28.5 bc	137 c	206 d	3.49 ab	331 b	80.3 d	194 a
'HTM'[a]	21.2 a	325 b	23.8 a	39.4 a	38.9 c	106 b	88 a	3.58 ab	366 c	66.2 b	285 b
'IBP 5–61'	34.7 c	399 cd	31.8 c	87.8 c	12.2 a	127 c	152 c	3.56 ab	480 e	84.3 e	374 c
'IBP 12'[b]	30.8 bc	389 cd	28.9 bc	56.7 b	35.1 c	128 c	131 b	3.56 ab	468 e	79.0 d	329 bc
'IBP 5-B'	31.3 bc	394 cd	29.0 bc	79.8 c	18.3 ab	126 c	135 bc	3.67 b	471 e	81.5 de	333 bc
95% LSD	4.63	28.0	4.23	14.99	14.42	16.96	18.1	0.181	27.3	3.15	73.4

First Ratoon

Variety	Bunch Weight (kg)	Days Planting to Harvest	Bunch wt/year (kg/ year)	Fruit 22–26 cm (wt %)	Fruit 20–22 cm (wt %)	Bunch Filling Duration (Days)	Total Finger Number/ Bunch	Hand 3 Finger Diameter (cm)	Pseudostem Height (cm)	Pseudostem Circum. (cm)	Following Sucker Height (cm)	Cumulative Yield (P + R1) kg/ plant/yr
'Williams'	41.8 c	553 a	56.9 c	48.0 bc	32.3 a	81 a	211 d	3.53 b	337 a	76.8 a	215 a	47.2 a
'Gros Michel'	33.3 bc	668 bc	41.8 b	25.2 ab	30.4 a	105 ab	167 bc	3.46 b	527 d	88.3 b	365 b	33.6 b
'Highgate'	31.3 ab	780 d	30.0 a	11.7 a	30.0 a	140 c	197 cd	3.26 a	377 b	96.8 c	213 a	31.0 b
'HTM'[a]	25.8 ab	597 ab	36.2 ab	65.0 c	24.5 a	89 a	121 a	3.55 b	433 c	77.2 a	350 b	28.9 b
'IBP 5–61'	26.2 ab	745 cd	29.5 a	22.7 ab	31.0 a	121 bc	138 ab	3.51 b	538 d	89.5 b	368 b	29.9 b
'IBP 5-B'	22.5 a	746 cd	38.1 ab	0.0 a	27.4 a	123 bc	130 a	3.46 b	548 d	89.6 b	414 b	26.6 b
95% LSD	9.35	86.3	9.64	32.9	29.5 a	26.5	31.6	0.118	34.8	4.49	96.9	7.79

[a] Hom Thong Mokho'.
[b] No first ratoon data was available for IBP 12 due to severe wind damage. Values in a column followed by the same letter are not significantly different ($P > 0.05$).

3.3. Agronomic assessment

In the plant crop at South Johnstone both 'Highgate' and 'IBP 5–61' had significantly heavier bunches than the industry standard, 'Williams'. 'Gros Michel', 'IBP 12' and 'IBP 5-B' were not significantly different to 'Williams' and 'Hom Thong Mokho' had significantly lighter bunches (Table 5). However, 'Williams' had by far the shortest duration to harvest and so was the highest yielding (bunch weight/unit time). 'Hom Thong Mokho' was the lowest yielding. In the first ratoon 'Williams' had by far the heaviest bunch weight and was harvested nearly four months earlier. Thus its yield far exceeded the other varieties. 'Highgate' performed poorly in ratoon 1 with several plants having severe choke throat and associated smaller bunches as a result. When yield of plant and ratoon crops was combined the Gros Michel subgroup of cultivars yielded 75% or less compared to 'Williams'.

Fruit of Cavendish type bananas which is between 20 and 26 cm in length receives a premium price in the marketplace with 22–26 cm preferred. In the plant crop the Cuban accessions 'IBP 5–61' and 'IBP 5-B' were the best with virtually all the fruit in the required band and most in the 22–26 cm category.

In the first ratoon the quicker cycling cultivars ('Williams' and 'Hom Thong Mokho') had the best results. This was partly related to their bunch filling occurring during summer when temperatures were more favourable for finger length development.

In the subtropics, 'Hom Thong Mokho' produced bunches with an average plant crop weight of 19.0 kg, while 'Lady Finger' and 'Williams' produced bunch sizes of 20.6 kg and 30.7 kg, respectively. However harvest dates for 'Hom Thong Mokho', on average, were six months longer compared to 'Lady Finger' and three months longer compared to 'Williams' (data not shown).

'Williams' was the shortest in stature whereas the Gros Michel varieties were intermediate to very tall (Table 5). Bunch losses due to wind damage at South Johnstone occurred for 'IBP12' (90%), 'Gros Michel' (40%), 'Highgate' (40%), 'IBP5-B' (40%), 'IBP5-61' (30%) and 'Hom Thong Mokho' (10%). These losses mostly resulted from strong winds on several occasions during the first half of 2014. 'Williams' was unaffected in the first ratoon. The bunch/yield data in Table 5 does not include these plants that were blown over whilst immature.

4. Discussion

Genetic resistance is the best form of plant protection from disease and the resistance of 'Hom Thong Mokho' to Fusarium wilt seen in the Duranbah trial (Table 3) came as a surprise as it is well known that Gros Michel cultivars are susceptible to *Foc*R1 (Stover and Simmonds, 1987). While 'Hom Thong Mokho', or 'Kluai Hom Thong' as it is known in Thailand, is a popular dessert banana and has an established export market (Valmayor et al., 1990a, 1990b; Daniells, 2009), recent molecular studies indicate it does not belong to the Gros Michel subgroup of AAA bananas (Jaroslav Dolezel pers. comm. 2015). Using microsatellite markers it has been possible to effectively genotype bananas (Christelová et al., 2011) and 'Hom Thong Mokho' can be placed within or near the AAA, Rio subgroup of bananas. It would be interesting to know if other members of this subgroup, such as 'Leite', show a similar resistance to *Foc*R1.

Apart from *Foc*R1 resistance, 'Hom Thong Mokho' also cycles faster and is significantly shorter than the standard 'Gros Michel' (Table 5), and although growth slowed appreciably in the subtropics and chilling injury to leaves and petioles was apparent at the Duranbah site where temperatures reached 2.7 °C, there was less damage and growth retardation compared to the other Gros Michel types. Like 'Gros Michel', 'Hom Thong Mokho' has attractive yellow fruit and a sweet, pleasant flavour which consistently placed it at or near the top in informal taste panels (data not shown). In terms of yellow Sigatoka it was significantly less susceptible than Williams and the Gros Michel group (Table 4).

The reaction of the IBP accessions went against expectations and showed a very susceptible reaction to *Foc*R1 (Table 3). Although 'IBP 5-B', 'IBP 5–61' and 'IBP 12' were reported to be resistant in Cuba they succumbed very quickly to *Foc*R1 (VCG 0124) and performed poorly in the cold conditions experienced at the subtropical site at Duranbah.

Mean minimum temperatures in the coldest month of August were 9.0 °C in 2012 and 9.7 °C in 2013. Moore et al. (1993) believe that cold winter temperatures in the subtropics can predispose plants to infection to *Foc*, and together with 'Cocos' and 'Highgate', the IBP accessions were severely affected by Fusarium wilt through the winter. However, they also succumbed to disease when challenged with *Foc*R1 in the tropics. Thus these results indicate that the Cuban Gros Michel accessions are susceptible to VCG 0124 Race 1 of Fusarium wilt, contrary to a previous report (Bermúdez et al., 2002). It is possible that the Cuban selections respond differently to the 2 different Race 1 strains (VCG 01210 and 0124).

With regard to their agronomic performance in the tropics, the IBP and semi-dwarf Gros Michel accessions performed as expected with lower yields compared to the industry standard Williams (Table 5). However, if the losses sustained in these small plot trials due to blowdowns are indicative of what would happen with commercial plantings in north Queensland, then it could be expected that they would be difficult to produce profitably.

Up until the early 1960s 'Gros Michel' was still being grown internationally for the world export market and today it still is a very popular variety in parts of Latin America and Asia (Daniells, 2009). The reason for this is its sweetness and excellent flavour while it ripens to an attractive yellow colour year round at ambient temperatures in the tropics with a longer shelf life than Cavendish. However, like 'Lady Finger', which has an established market in Australia, 'Gros Michel' has lower yield than Cavendish and the height of the plant at bunch harvest makes management considerably more difficult. It is also susceptible to *Foc*R1. However, production of Gros Michel fruit for an established market could still be possible if productive semi-dwarf varieties were available and were grown on production sites free of *Foc* using disease-free tissue cultured planting material with quarantine enforced to prevent introduction of contaminated soil and water.

Almost surprisingly 'Highgate' has shown resistance to *Foc*R1 in the tropics unlike 'Gros Michel' and the IBP accessions. We understand that whatever resistance 'Highgate' has to *Foc* has facilitated its use as a female parent by conventional breeding programs over many years despite the widespread presence of the pathogen in locations used for this purpose (Juan-Fernando Aguilar pers. comm. 2014).

When considering a Gros Michel type for the tropics in the absence of *Foc*R1, 'Highgate' offers the best prospects of the six Gros Michel varieties evaluated because of yield and ease of management, even though 'choke throat' was observed in the ratoon crop during what was an exceptionally cold winter. However, of further interest is 'Hom Thong Mokho', while not technically a Gros Michel variety although it is marketed as such in Asia, it has some attractive characteristics, not the least of which is its partial resistance to *Foc*R1. Its susceptibility and poor performance in the subtropics probably precludes it as a commercial variety, but the more favourable agronomic performance in warmer environments warrant further trials to determine its suitability for both producers and consumers alike.

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