Flowering and Seed Set In a 4x-2x *Musa* Polycross Mating Scheme

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Abstract- **This experiment was conducted to evaluate relationship between flowering of tetraploid maternal (seed) parents and diploid paternal (pollen) parents and the effects on seed set in a polycross mating scheme. The two experimental polycross blocks consisted of four maternal tetraploid plantain hybrids TMPx 2796-5, TMPx 5511-2, TMPx 1658-4 and TMPx 7152-2, and three paternal diploid hybrids TMP2x 2829-62 (plantain), and TMB2x 5105-1 and SH 3362 (bananas). Experimental design was an RCB replicated 2 times. Data collected included time to flowering (TTF), duration of flowering (DOF), synchrony /flowering overlap of paternal and maternal parents, number of bunches and number of seeds of maternal parents over 3 crop cycles. Data were subjected to analysis of variance (ANOVA) and significant effects were tested at $P \geq 0.05$. Means were compared using LSD at ($P \geq 0.05$). Correlation analysis was used to estimate relationships. There was floral synchrony between some paternal and some maternal parents in the plant crop; in ratoon 1, and in ratoon 2. Flowering overlap occurred between SH3326 plant crop and one maternal parent of ratoon 1. Generally, seed set was highest in ratoon 1 and lowest in ratoon 2. Cumulatively TMPx 2796-5 had significantly ($P > 0.05$) the highest number of seeds set followed by TMPx 1658-4 with TMPx 7152-2 having the lowest. Significant positive correlations occurred in TTF between maternal TMPx 2796-5 and paternal TMP2 x 2829-62 in ratoon 1; and between TMPx 7152-2 and TMP2x 2829-62 and also between TMPx 7152-2 and SH 3362 in ratoon 2. There was positive significant correlation between TTF of maternal parent TMPx 7152-2 and seed set in ratoon 1. There was positive significant correlation between TTF of paternal TMP2x 2829-62 and seed set of TMPx 7152-2 and between paternal TMB2x 5105-1 and seed set of TMPx 2796-5**

Keywords **Floral synchrony, Seed set, pollination, decentralisation, bananas, plantains, flowering phenology**

I. INTRODUCTION

Production of enough viable synthetic secondary triploid seeds in *Musa* by breeders will provide a giant practical leap towards easing and accelerating decentralisation of *Musa* breeding, the evaluation and location trials for varietal releases, on-farm testing and selection, as well as plant introductions. These synthetic hybrid seeds will reduce the labour and cost of producing segregating progenies, shipping and post-entry costs, and reduce delay in plant quarantine operations. In addition, seeds can be transported effectively and efficiently in seed packets for direct seed germination in the field further reducing handling costs [1]. All of these benefits require that cost effective and efficient methods for maximum hybrid seed production by *Musa* breeders be found. Open pollination for crop improvement and breeding as against the once exclusive laborious, costly and time consuming practice of hand pollination, is becoming more common and more efficient. This is because more information is becoming available and various mating designs and schemes are increasingly being explored, modified and exploited to achieve breeders' goals. Such mating designs include the Polycross, Bi-parental mating, Top cross, North Carolina (I, II, III), Diallels (I, II, III, IV) and Line X tester design, nested mating and neighbour-restricted designs among others [2] [3] [4]). The term "polycross" is used to designate the pollination system based on natural random inter-mating of diverse genotypes grown together in isolated blocks. The polycross is especially useful and cost effective for designing mating trials. It has been utilized long ago to efficiently enhance intermating between tetraploid and diploid accessions and synthesize triploids in grasses [5] [6]. More recently it has been exploited for improvement of economic traits in sugarcane [7]; for cassava improvement [8]; for forward selection in *Pinus pinaster* Ait the maritime pine [9] and for population improvement and variety development in yam [10]. Our *Musa* polycross consists of a systematic arrangement of several improved 4x *Musa* maternal /seed and 2x paternal /pollen parents with enhanced resistance to several biotic and abiotic agents thus providing a mechanism for simultaneous introgression of desirable genes into the breeding populations. The resulting progenies constitute genetically diverse synthetic hybrid populations, predominately triploids when the maternal /seed parents are tetraploid and the paternal /pollen parents are diploid. Diploid parents produce more pollen than polyploid cultivars or hybrids [11] [12] [13] and are therefore preferred as male /pollen parents. Seed yield is influenced by time of pollination, environmental conditions, genetic variation in female fertility, differences observed among pollinations made between the basal and distal hand, and variation associated with the relative contributions of the *acuminata* and *balbisiana* genomes [14]. Reference [14] declared that valuable hybridisation in *Musa* is possible with judicious selection of male and female parents and that edible AA diploids have been used both as male and female parents. He stated that the AA cultivar Pisang Lilin is a particularly good male parent (50% male fertile) and has produced many viable diploids when crossed with other edible diploids but is a poor female parent, although [15] declared that even if seeds are obtained, the seed yield of hybrids in *Musa* breeding programs is usually low and germination is poor. Research at IITA has confirmed that triploid (3x) and diploid (2x) crosses resulted in poor seed set per bunch [1]. This complicates breeding efforts and increases the amount of resources and prolongs time required to develop superior varieties resistant to multiple biotic and abiotic agents [16]. Crosses between primary tetraploid (4x) and diploid (2x) hybrids however produced large amounts of secondary triploid hybrid seeds, particularly under open pollination regimes [17]. The tetraploid hybrids are both female and male fertile and this often reduces fruit quality due to the presence of seeds in the pulp. However, this characteristic of the tetraploid hybrids facilitates the production of large number of seeds when they are crossed with other accessions. To restore seedlessness, crosses are made between the primary 4x and 2x hybrids to produce secondary 3x hybrids. They affirmed that a large fraction of the seeds obtained are normal botanical seeds that can be germinated directly in the soil, thereby reducing the need for *in vitro* germination of seedlings and allowing for field testing of large numbers of progenies. However, the genetic quality of these hybrid seeds is dependent on (a) pollen shedding and female receptivity coinciding; (b) the compatibility between mating parents and (c) low or insignificant natural self-pollination [18[[19] [20]). Analysis of combining ability in 4x-2x crosses revealed that some traits were primarily inherited from the male (2x) or female (4x) parents, a finding of practical importance for parental selection in 4x-2x cross-breeding [21] [22]. In order to maximize seed yield from such crosses, floral synchrony between both parents is desirable as plants may suffer from reduced pollination because of complete mismatches in flowering between both parents and, thus, may set less fruits and/or seeds than those developed when most flowers are receptive [23]. This is because flowering phenology, or the period of time when plant species flower, influences when reproductive structures interact with resources for fruit and seed development [24] [25] [26]. There is also the possibility of temporal mismatch between the availability of the most effective pollinators and the onset of flowering. Moreover, it is possible that the presence, abundance and composition of pollinator species which fluctuates temporally [27] [28] may also affect pollination and resultant seed set [23]. It is imperative therefore that data on phenology, the flowering time of potential maternal/ seed and paternal /pollen parents in any open pollination scheme be available to provide breeders with the best matches and enable them adjust or stagger planting in order to achieve optimal floral synchrony or overlap of flowering in crossing parents. In their study on sugar cane [7] concluded that prior understanding of the flowering pattern of the genotypes was critical if desired mating success is to be achieved. Others had also earlier reported that even small shifts in flowering time could have consequences for plant reproductive success [29]. Individuals of a plant species like *Musa* with hermaphrodite flowers tend not to experience autogamous self-pollination because of dichogamy - separation in maturation time of stigma and pollen to avoid autogamous self-pollination, which leads to maximum seed setting but minimum genetic variation in their offspring. But other maternal /seed parents may pollinate each other in the absence of pollen from the designated paternal /pollen parents. Thus asynchrony between male and female flowering, have been reported to affect seed production [23] [30]. Such complications suggest the need to explore how time of flowering influences pollination success and seed set in *Musa*. Phenology of *Musa* species and floral synchrony has not received the detailed attention required so far and therefore a comprehensive knowledge of flowering phenology, fruiting pattern and seed set is critical for successful open pollination in *Musa* breeding. This study was therefore conducted to evaluate the relationship between flowering of tetraploid maternal/ seed parents and diploid paternal /pollen parents and whether this affects seed set in a polycross mating scheme. It will also provide valuable information on the reliability of the polycross scheme in seed production for breeding improvement in bananas and plantains.

II. MATERIALS AND METHODS

This study was carried out at the International Institute of Tropical Agriculture (IITA) High Rainfall Station, Onne (4°51'N, 7° 03'E, 10m above sea level), in Rivers State, south-south Nigeria for a period of 30months. The station is located in the rainforest characterized by an Ultisol/Acrisol (U.S. Department of Agriculture- USDA Taxonomy/ World Reference Base) derived from coastal sediments. The soil is a deep freely drained Typic Paleudult of loamy and siliceous iso-hyperthermic origin. The surface soils (0 - 15cm) are well drained and high in phosphorus 60mg/kg, organic matter 1.85 %, but are low in total nitrogen 0.18% and also acidic with a pH of 4.6. Other nutrients are potassium 0.28 me/100g and magnesium 0.36me/100g. The rainfall pattern is monomodal, distributed over a 10month period from February through December, with an annual average of 2400mm. Relative humidity remains high all year round with mean values of 78% in February, increasing to 89% in the months of July and September. The mean annual minimum and maximum temperatures are 25^0C and 27^0C, respectively, while solar radiation / sunshine lasts an average of 4hours daily [31]

Experimental Materials

Four tetraploid plantain hybrids were used as female or maternal/ seed parents (TMPx 1658-4, TMPx 2796-5, TMPx 7152-2 and TMPx 5511-2). One diploid plantain (TMP2x 2829-2) hybrid, and 2 diploid banana (TMB2x 15101-2 and SH 3362) hybrids were used as male or paternal/ pollen parents. The flowering patterns of paternal and maternal parents and the seed sets of maternal parents were studied in a random mating polycross scheme.

Treatments and Experimental Design

Two polycross blocks were established, each covering 620m^2 located in the south and east extremes of the 100-hectare station. The polycross blocks were isolated from all plantain and banana fields by a distance of 270m (more than the 200m isolation distance of *Musa*) and these crossing blocks were further surrounded by West African triploid male-sterile AAB plantain cultivars (Obino l'ewai and Bobby Tannap), respectively. Two-month old seedlings were transplanted from the nursery to the polycross blocks. The experimental polycross blocks - PC1 consisted of two primary tetraploid plantain hybrids TMPx 2796-5 and TMPx 5511-2 as female or maternal/ seed parents while PC2 comprised another two primary tetraploid plantain hybrids TMPx 1658-4 and TMPx 7152-2 also as female or maternal/ seed parents, all replicated at 12 plants per clone. Each crossing block had 31 plants of each of the three male / paternal diploid hybrid parents TMP2x 2829-62 (plantain), and the banana hybrids TMB2x 5105-1 and SH 3362. Plant spacing was 3m x 2m (giving a plant population of 1,667 plants per hectare) with male and female parents arranged according to a checkerboard layout in which each female plant was surrounded by systematically disposed male plants. A ratio of one female to eight male plants was imposed to improve floral synchrony and optimize pollination. After the plant crop was established, the next 2 followers or daughter plants were selected to continue the next cycle of production as ratoons 1 and 2 and other suckers were thinned out. The plants were grown for three consecutive crop cycles - plant crop, first ratoon (ratoon 1) and second ratoon (ratoon 2).

Data Collection and Statistical Analyses

Flowering

Flowering parameters were measured for the maternal /seed parents and the paternal /pollen parents in each crop cycle as follows: (i) onset of flowering i.e. time to flowering or anthesis; (TTF) (ii) duration of flowering (DOF) i.e. date of first flower opening and last flower dying; and (iii) synchrony /flowering overlap of paternal (pollen parent) and maternal (seed) parents. At the floral stage, flower bracts enlarge and differentiate into female (pistillate) flowers and male (staminate) flowers. During anthesis, time to flowering (TTF) was recorded in days after planting (this gave better precision than weeks after planting) as the date of opening of the pistillate flowers for the maternal /seed parents. For the paternal/ pollen parents, the date of opening of the staminate flowers was also documented. The duration of flowering (DOF) was also recorded for both maternal /seed parents and paternal/ pollen parents over the 3 crop cycles.

Number and percentage of bunches: At maturity, (this varied from 90-120days following flower emergence for the various maternal/ seed parents), the number of fruit bunches and the percentage of bunches per plot of the maternal/ seed parents was recorded in each of the 3 crop cycles.

Seed set: At maturity the fruit bunches of the maternal/ seed parents were harvested, ripened, and the seeds extracted, washed and air-dried. Well-formed hard seeds were counted for each maternal parent and the total number of seeds produced calculated for each crop cycle.

Data analysis

Time to flowering (TTF) and duration of flowering (DOF) of maternal /seed and paternal /pollen parents, number of bunches and seed set were subjected to analysis of variance (ANOVA) using the GLM procedure of Statistical Analyses Software (SAS) version 9.1 [32] and any effects found to be significant were tested at a significance level of 5% while means were compared using LSD at (P > 0.05). Correlation analysis (P > 0.05) and P > 0.01) was used to estimate the relationship between the time to flowering of the maternal (seed) parents and the paternal (pollen) parents. In addition, the relationship between the time to flowering of the maternal (seed) parents and seed set as well as the relationship between the time to flowering of the paternal (pollen) parents and seed set were also examined.

III. RESULTS AND DISCUSSION

Time to Flowering

The time to flowering (TTF) or anthesis of maternal /seed parents and paternal/ pollen parents in each of the crop cycles and the percentage change in TTF between successive crop cycles are presented in Table 1. On average for maternal /seed parents, TTF was 331days after planting (DAP) in the plant crop, 479DAP in ratoon 1 and 823DAP in ratoon 2. There were significant differences (P > 0.05) in time to flowering (TTF) in the 3 crop cycles among maternal /seed parents. Time to flowering (TTF) increased significantly and progressively among maternal /seed parents from the plant crop to ratoon 1 by as much as 34% to 63% and from ratoon 1 to ratoon 2 by as much as 61% to 77% (Table 1). There were also significant differences (P > 0.05) in TTF of maternal /seed parents in each crop cycle. Earliest flowering maternal /seed parent in the plant crop was TMPx 7152-2 (297DAP) which flowered significantly (P > 0.05) earlier than others. In ratoon 1, TMPx 1658-4 (459DAP) flowered significantly (P > 0.05) earlier than others while in ratoon 2 TMPx 2796-5 (771DAP) flowered significantly (P > 0.05) earlier than others.

TABLE 1: TIME TO FLOWERING (TTF) OF MATERNAL /SEED PARENTS IN EACH CROP CYCLE AND PERCENTAGE CHANGE IN TTF BETWEEN SUCCESSIVE CROP CYCLES

Crop Cycle	Maternal / Seed Parents (Tetraploids)			
	TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
Plant crop	358DAP*^{b}	333DAP ^{b}	297DAP ^{a}	334DAP ^{b}
Ratoon 1	479DAP ^{cd}	495DAP ^{d}	484DAP ^{cd}	459DAP ^{c}
% change between crop cycles	(34%)	(49%)	(63%)	(37%)
Ratoon 2	771DAP ^{e}	878DAP ^{g}	827DAP ^{f}	814DAP ^{f}
% change between crop cycles	(61%)	(77%)	(71%)	(77%)

DAP* = *Days after planting*

Figures in brackets show the % change in time to flowering between preceding crop and the next

Figures with the same alphabets are not significantly different at P > 0.05 (LSD)

For paternal /pollen parents, on average, time to flowering (TTF) was 384DAP in the plant crop, 574DAP in ratoon 1 and 789DAP in ratoon 2 (Table 2) showing that there were significant differences (*P* > 0.05) in time to flowering (TTF) in the 3 crop cycles. Time to flowering increased significantly and progressively from the plant crop to ratoon 1 by as much as 39% to 76% and from ratoon 1 to ratoon 2 by as much as 26% to 45%. As in maternal seed parents, there were also significant differences (*P* > 0.05) in TTF of paternal /pollen parents in each crop cycle. Earliest flowering paternal /pollen parent was TMB2x 5105-1 (311DAP) in the plant crop which flowered significantly (*P* > 0.05) earlier than others; TMP2x 2829-62 (471DAP) flowered significantly (*P* > 0.05) earlier than others in ratoon 1 and again (685DAP) in ratoon 2. Consistently, SH 3362, was the last to flower in each crop cycle.

TABLE 2: TIME TO FLOWERING (TTF) OF PATERNAL /POLLEN PARENTS IN EACH CROP CYCLE AND PERCENTAGE CHANGE IN TTF BETWEEN SUCCESSIVE CROP CYCLES

Crop Cycle	Paternal /Pollen Parents (Diploids)		
	TMP2x 2829-62	TMB2x 5105-1	SH 3362
Plant crop	339DAP*[a]	311DAP[a]	497DAP[b]
Ratoon 1	472DAP[b]	548DAP[c]	716DAP[d]
% change between crop cycles	(39%)	(76%)	(44%)
Ratoon 2	686DAP[d]	795DAP[e]	888DAP[f]
% change between crop cycles	(45%)	(45%)	(26%)

DAP* = *Days after planting*

Figures in brackets show the % change in time to flowering between preceding crop and the next

Figures with the same alphabets are not significantly different at P > 0.05 (LSD)

Duration of Flowering

The duration of flowering (DOF) in maternal / seed parents and paternal /pollen parents in each of the crop cycles and the percentage change in DOF between successive crop cycles are shown in Table 3. Maternal /seed parents flowered for an average of 4.75days in the plant crop; 5days in ratoon 1 and 5days in ratoon 2 approximating overall 5days each over the 3 crop cycles. Thus while there was considerable variation in time to flowering (TTF) among maternal /seed parents in all crop cycles, duration of flowering (DOF) was significantly different (*P* > 0.05) only in the plant crop. Comparatively DOF was relatively more uniform and did not change by more than 25% between the plant crop and ratoon 1, while there were no changes in DOF between ratoon 1 and ratoon 2. Thus there were no significant (*P* < 0.05) interaction effects between duration of flowering and crop cycle among maternal /seed parents, meaning that duration of flowering did not differ significantly during the crop cycles.

TABLE 3: DURATION OF FLOWERING (DOF) OF MATERNAL /SEED PARENTS IN EACH CROP CYCLE AND PERCENTAGE CHANGE IN DOF BETWEEN SUCCESSIVE CROP CYCLES

Crop Cycle	Maternal / Seed Parents (Tetraploids)			
	TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
Plant crop	4days[a]	6days[c]	5days[b]	4days[a]
Ratoon 1	5days[b]	5days[b]	5days[b]	5days[b]
% change between crop cycles	(25%)	(25%)	(0%)	(25%)
Ratoon 2	5days[b]	5days[b]	5days[b]	5days[b]
% change between crop cycles	(0%)	(0%)	(0%)	(0%)

Figures in brackets show the % change in duration of flowering between preceding crop and the next

Figures with the same alphabets are not significantly different at P > 0.05 (LSD)

Among the paternal /pollen parents, TMP2x 2829-62 had consistently and significantly (*P* > 0.05) the shortest duration of flowering (DOF) in each crop cycle approximating 34days, while TMB2x 5105-1 had significantly (*P* > 0.05) the longest DOF averaging 64days in each crop cycle (Table 4). The Honduran banana SH 3362, a diploid banana and an introduction from Honduras in Central America, a leading banana producer and exporter had an average 49days DOF. Thus, whereas it consistently flowered later than the other 2 paternal/ pollen parents its DOF was midway between both.

TABLE 4: DURATION OF FLOWERING (DOF) OF PATERNAL /POLLEN PARENTS IN EACH CROP CYCLE AND PERCENTAGE CHANGE IN DOF BETWEEN SUCCESSIVE CROP CYCLES

Crop Cycle	Paternal /Pollen Parents (Diploids)		
	TMP2x 2829-62	TMB2x 5105-1	SH 3362
Plant crop	34days[a]	66days[b]	52days[c]
Ratoon 1	35days[a]	63days[b]	50days[cd]
% change between crop cycles	(2.9%)	(- 4.6%)	(- 3.9%)
Ratoon 2	34days[a]	62days[b]	46days[d]
% change between crop cycles	(- 2.9%)	(- 1.6%)	(- 8%)

Figures in brackets show the % change in duration of flowering between preceding crop and the next

Figures with the same alphabets are not significantly different at P > 0.05 (LSD)

Synchrony / overlap between maternal and paternal flowering activities

In Table 5, the time to flowering (TTF) and duration of flowering (DOF) in both maternal /seed parents and paternal /pollen parents and the possible temporal alignment (synchrony) and overlap of both activities in the two groups of parents during the 3 crop cycles (Plant crop, Ratoon 1 and Ratoon 2) are compared. In the plant crop, there was floral synchrony between 2 paternal /pollen parents and 1 or 3 maternal /seed parents as follows:

(a) Paternal /pollen parent TMP2x 2829-62 (339DAP /34days) with one Maternal /seed parent TMPx 1658-4 (358DAP /4days); and (b) Paternal /pollen parent TMB2x 5105-1 (311DAP /66days) with 3 Maternal /seed parents TMPx 2796-5 (358DAP /4days); TMPx 5511-2 (333DAP /6days), and TMPx 1658-4 (334DAP /4days). The implication of course is that the synthetic hybrid seeds produced in the plant crop will probably have TMB2x 5105-1 and to a lesser degree TMP2x 2829-62 as pollen parents. In ratoon 1, floral synchrony occurred between one paternal /pollen parent and 3 maternal /seed parents from the same crop cycle viz TMP2x 2829-62 (472DAP /35days) with TMPx 2796-5 (479DAP /5days), TMPx 5511-2 (495DAP /5days) and TMPx 7152-2 (484DAP /5days). In addition, there was flowering overlap between the Honduran banana paternal /pollen parent SH3326 (497DAP /52days) from the earlier plant crop cycle with one maternal/ seed parent TMPx 5511-2 (495DAP /5days) of ratoon 1. This would suggest that TMP2x 2829-62 could be the male progenitor of most of the synthetic hybrid seeds produced in ratoon 1 and to a lesser degree SH3326. In the last crop cycle ratoon 2, there was floral synchrony between 1 paternal /pollen parent and 2 maternal /seed parents, that is, paternal /pollen parent TMB2x 5105-1 (795DAP /62days) with maternal/ seed parents TMPx 7152-2 (827DAP /5days) and TMPx 1658-4 (814DAP /5days) indicating a high likelihood of TMB2x 5105-1 being the pollen parent of the synthetic hybrid seeds produced in ratoon 2. Thus apart from the possible contribution of pollen by SH3362 in ratoon 1 to one maternal/ seed parent, TMB2x 5105-1 would appear to be the dominant pollen contributor in the plant crop and ratoon 2; while TMP2x 2829-62 was dominant in ratoon 1 and to a lesser degree in the plant crop. Thus floral synchrony of parents could be critical for making decisions about parent selection for mating design establishments such as the polycross [33] if the synthetic hybrid seeds with the desired genetic traits are to be obtained.

TABLE 5: TIME TO FLOWERING OF PATERNAL /POLLEN PARENTS AND MATERNAL /SEED PARENTS SHOWING POSSIBLE SYNCHRONY AND OVERLAP BETWEEN THEM IN EACH OF THE 3 CROP CYCLES

PLANT CROP					
Paternal Parents (Diploids)	TTF (DOF)	Maternal / Seed Parents (Tetraploids)			
		TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
		TTF (DOF) 358DAP (4days)	TTF (DOF) 333DAP (6days)	TTF (DOF) 297DAP (5days)	TTF (DOF) 334DAP (4days)
TMP2x 2829-62	339DAP (34days)	S	NIL	NIL	NIL
TMB2x 5105-1	311DAP (66days)	S	S	NIL	S
SH 3362	497DAP (52days)	NIL	NIL	NIL	NIL
RATOON 1					
Paternal Parents (Diploids)	TTF (DOF)	Maternal / Seed Parents (Tetraploids)			
		TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
		TTF (DOF) 479DAP (5days)	TTF (DOF) 495DAP (5days)	TTF (DOF) 484DAP (5days)	TTF (DOF) 459DAP (5days)
TMP2x 2829-62	472DAP (35days)	S	S O	S	NIL
TMB2x 5105-1	548DAP (63days)	NIL	NIL	NIL	NIL
SH 3362	716DAP (50days)	NIL	NIL	NIL	NIL
RATOON 2					
Paternal Parents (Diploids)	TTF (DOF)	Maternal / Seed Parents (Tetraploids)			
		TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
		TTF (DOF) 771DAP (5days)	TTF (DOF) 878DAP (5days)	TTF (DOF) 827DAP (5days)	TTF (DOF) 814DAP (5days)
TMP2x 2829-62	686DAP (34days)	NIL	NIL	NIL	NIL
TMB2x 5105-1	795DAP (62days)	NIL	NIL	S	S
SH 3362	888DAP (46days)	NIL	NIL	NIL	NIL

TTF = *Time to Flowering;* DOF = *Duration of Flowering;* DAP = *Days after Planting;*

S = *Possible floral synchrony of paternal /pollen parents & maternal /seed parents in the same crop cycle*

O = *Possible overlap in flowering of paternal /pollen parent [SH3362] & maternal /seed parents in different crop cycles (Plant crop & Ratoon 1)*

Number and percentage of bunches produced by maternal /seed parents

The number and percentage of bunches produced by the maternal /seed parents are shown in Table 6. Generally, number and percentage of bunches produced by all maternal /seed parents was highest in ratoon 1 and next highest in ratoon 2 except for TMPx 7152-2 which produced its highest bunches and percentage in the plant crop. Cumulatively over the 3 crop cycles, TMPx 7152-2 had the lowest number of bunches producing significantly ($P > 0.05$) the least bunches than others.

TABLE 6: NUMBER AND PERCENTAGE OF BUNCHES PRODUCED BY MATERNAL /SEED PARENTS PER PLOT

Crop Cycle	Number and percentage of bunches produced by maternal /seed parents per plot*							
	TMPx 2796-5		TMPx 5511-2		TMPx 7152-2		TMPx 1658-4	
	No	(%)	No.	(%)	No.	(%)	No.	(%)
Plant Crop	5	42	5	42	5	42	4	33
Ratoon 1	9	75	10	83	3	25	8	67
Ratoon 2	6	50	8	67	3	25	8	67
Total	20		23		11		20	
Mean %	56		64		31		56	

**All plots had 12 maternal /seed parents*

Seed set

The number of seeds set by each of the maternal/ seed parents and seeds per bunch over the 3 crop cycles are presented in Table 7. The highest number of seeds set was in ratoon 1 for all maternal /seed parents except for TMPx 1658-4 which had the highest seeds set in the plant crop. Seed set was lowest in ratoon 2 for all maternal parents. The variation in seed set may be related to the change in the number of female and male plants that flowered. This could also be explained by the fact that floral synchrony occurred between more parents in the plant and first ratoon crops compared to the second ratoon crop. The number of seeds set provides a measure of maternal /seed parent success. In the plant crop and ratoon 1, TMPx 2796-5 had significantly (P > 0.05) highest number of seeds followed by TMPx 1658-4. Cumulatively over the 3 crop cycles, TMPx 2796-5 had significantly (P > 0.05) the highest number of seeds set followed by TMPx 1658-4 with TMPx 7152-2 having the lowest. An efficient pollination scheme can be measured by the proportion of seed set [34] and the diversity of genes that can be incorporated into individual plants within limited time and resources. Open pollination gave higher number of seeds with well-formed embryos than did hand pollination [17]. Reference [35] also obtained higher seed set in open pollinated populations of *Helianthus* species (sunflower), compared to hand pollination. Earlier flowering could also allow for longer development time for seeds and more time within a season for offspring germination and growth. Although later reproduction may allow time for more resources to accumulate, time for seed maturation is shorter and earlier flowering plants had higher seed mass [36]

TABLE 7: NUMBER OF SEEDS SET BY MATERNAL /SEED PARENTS OVER 3 CROP CYCLES

Crop cycle	Number of Seeds			
	TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
Plant Crop	952^{a}	175^{c}	197^{c}	405^{b}
Ratoon 1	1940^{d}	559^{f}	121^{g}	652^{e}
Ratoon 2	197^{i}	224^{hi}	102^{j}	271^{h}
Total	3089	958	420	1328

Figures with the same alphabets in the same crop cycle are not significantly different at P > 0.05 (LSD)

Relationships between time to flowering (TTF) of maternal /seed parents and paternal /pollen parents

In the plant crop, a positive though not significant correlation was observed between time to flowering of the maternal parent TMPx 2796-5 and that of the paternal parent TMB2x 5105-1 (Table 8). Also SH 3362 showed similar positive correlations in TTF with 3 maternal parents TMPx 1658-4, TMPx 5511-2 and TMPx 7152-2. This indicates that the synthetic hybrids obtained in the plant crop could likely have TMB2x5105-1 and SH 3362 as their male progenitors. In ratoon 1, the paternal /pollen parent TMP2x 2829-62 had a significant (P > 0.05) and positive correlation with maternal /seed parent TMPx 2796-5 indicating the possibility of it being the male progenitor; whereas the paternal parent TMB2x 5105-1 had a significant (P > 0.05) but negative correlation with TMPx 7152-2. In ratoon 2 TMP2x 2829-62 had a significant positive correlation with TMPx 7152-2, and SH 3362 also had a significant positive correlation with TMPx 7152-2. Therefore, ideally these paternal parents would be expected to be the progenitors of the synthetic hybrids obtained from these maternal parents in ratoon 2.

TABLE 8: SIMPLE LINEAR CORRELATION VALUES SHOWING RELATIONSHIP BETWEEN TIME TO FLOWERING OF PATERNAL AND MATERNAL PARENTS IN EACH CROP CYCLE

MATERNAL (SEED) PARENTS	PATERNAL (POLLEN) PARENTS		
	PLANT CROP		
	TMP2x 2829-62	TMB2x 5105-1	SH 3362
TMPx 2796-5	-0.089	0.503	-0.621
TMPx 5511-2	-0.096	0.131	0.527
TMPx 7152-2	-0.134	-0.189	0.428
TMPx 1658-4	0.180	-0.128	0.575
	RATOON 1		
TMPx 2796-5	0.652*	-0.118	-0.258
TMPx 5511-2	0.470	0.454	0.446
TMPx 7152-2	0.353	-0.956**	-0.170
TMPx 1658-4	0.084	-0.190	-0.234
	RATOON 2		
TMPx 2796-5	0.310	-0.070	0.430
TMPx 5511-2	-0.357	0.152	0.201
TMPx 7152-2	0.990**	0.323	0.949**
TMPx 1658-4	0.003	-0.653*	0.000

** r is significant at P>0.05*

*** r is significant at P>0.01*

Relationships between time to flowering (TTF) of maternal /seed parents and seed set

Correlation analysis showed that seed set was negatively and significantly (P > 0.05) correlated with time to flowering in the maternal /seed parents TMPx 7152-2 in the plant crop but positively and significantly correlated with time to flowering in ratoon 1 (Table 9)

TABLE 9. SIMPLE LINEAR CORRELATION VALUES SHOWING RELATIONSHIP BETWEEN TIME TO FLOWERING OF MATERNAL PARENTS AND SEED SET

Time to Flowering of Maternal Parents	Seed Set of Maternal Parents			
	PLANT CROP			
	TMPx 2796-5	TMPx 5511-2	TMPx 7152-2	TMPx 1658-4
TMPx 2796-5	0.102			
TMPx 5511-2		0.406		
TMPx 7152-2			-0.774**	
TMPx 1658-4				-0.410

RATOON 1				
TMPx 2796-5	-0.296			
TMPx 5511-2		-0.523		
TMPx 7152-2			0.932**	
TMPx 1658-4				0.518
RATOON 2				
TMPx 2796-5	-0.336			
TMPx 5511-2		-0.064		
TMPx 7152-2			-0.153	
TMPx 1658-4				-0.167

* *r is significant at P>0.05*

** *r is significant at P>0.01*

Relationship between the seed set of maternal parents and time to flowering of paternal parents

Seed set of the maternal parent TMPx 7152-2 was positively and significantly (*P* > 0.05) correlated with the number of days to flowering of the paternal/pollen parent TMP2x 2829-62 in ratoon 1 (Table 10). In ratoon 2, seed set in the maternal parent TMPx 2796-5 was positively and significantly correlated with time to flowering of the paternal/pollen parent TMB2x 5105-1 whereas seed set of TMPx 7152-2 was negatively and significantly correlated with time to flowering of the paternal/pollen parent TMB2x 5105-1.

TABLE 10. SIMPLE LINEAR CORRELATION VALUES SHOWING RELATIONSHIP BETWEEN SEED SET OF MATERNAL PARENTS AND TIME TO FLOWERING OF PATERNAL PARENTS

Seed Set of Maternal (Seed) Parents	PLANT CROP		
	TMP2x 2829-62	TMB2x 5105-1	SH 3362
TMPx 2796-5	-0.449	0.320	-0.726
TMPx 5511-2	0.294	0.178	0
TMPx 7152-2	0.074	0.325	-0.454
TMPx 1658-4	0.094	-0.415	-0.358
RATOON 1			
TMPx 2796-5	-0.352	-0.069	-0.362
TMPx 5511-2	-0.497	-0.016	0
TMPx 7152-2	0.763**	-0.208	-0.419
TMPx 1658-4	-0.120	0.004	-0.306
RATOON 2			
TMPx 2796-5	-0.156	0.826**	0.200
TMPx 5511-2	-0.099	0.520	0
TMPx 7152-2	-0.293	-0.985**	-0.457
TMPx 1658-4	0.420	-0.233	-0.313

* *r is significant at P* > 0.05

** *r is significant at P>0.01*

Thus it would appear that apart from flowering synchrony between male and female parents there are other factors that play a significant role in determining seed set in *Musa* spp. Other factors that could be determinants to seed set could be the prevailing weather conditions, i.e. relative humidity, amount of solar radiation, and temperature [20]. Also genetic variations in pollen germination rate [37] or an ability to hinder other pollen by chemical interference as in Scots pine [38], high pollen production [39], pollen and pistil traits as in apricot [40] could play an important role. Pollen traits can also be influenced by pistil traits that enhance pollen competition providing an ability to sort among pollen, e.g. a long style [41], a large stigmatic surface [42] or delayed stigma receptivity and fertilization [43], competition for optimal placement on the pollinator [44] and early male flowering in dioecious species as a means to compete for access to ovules of high-quality female plants [45]. Others include pollen contribution rate, pollen-pollen interactions, genetic incompatibility between male and female gametophytes [46] [47], pollen tube growth rate, timing of pollen arrival on the stigma, etc [48]. However not only recipients, but also pollen donors can influence timing of floral receptivity, i.e. when pollination can lead to successful seed set [49]. Early fertilization leads to a female fitness cost in terms of reduced seed production and seed biomass [50], which is consistent with a sexual conflict over timing of floral receptivity [51] [52]. Thus, enhanced pollen competition involving sequential arrival of pollen from several donors appears to be negative for the female reproductive function. Early pollinated flowers are not pollen limited [50]. The underlying mechanism for the reduced seed set at early fertilization is not yet fully known or understood but could be caused by other pollen traits apart from an ability to induce stigma receptivity [48]. If both stigma and ovule receptivity is delayed, fast growing pollen tubes in unripe pistils could cause the low seed set by arriving early at the ovary. Provided that early arrival to the ovary is beneficial in terms of increased siring success despite the lowered number of sired seeds, rapid growth of pollen tubes would be the sexually antagonistic trait, as it is increasing competitive ability and causing pistil harm [48]. More research on pollen production, pollen tube growth, and embryo viability is required to better understand issues associated with poor seed production and to optimize conditions that will lead to better seed yield in *Musa* [53]. More specifically, detailed knowledge of floral biology and seed development is crucial for recovery of seeds and progeny from crosses [54].

IV. CONCLUSION

This study has shown that in any *Musa* mating design experiment, floral synchrony between male and female parents is not the sole determinant to seed set, though it is one of the important factors to be taken into consideration when choosing the parents in order to increase or maximize the potential for transferring desired traits to the emerging progenies.

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