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Estimating heterosis and heterobeltiosis in phenological and vegetative traits and correlations in *Musa* diploid x diploid crosses

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ABSTRACT: This study was conducted to determine the extent of heterosis and heterobeltiosis in phenological and vegetative traits in *Musa* diploid by diploid crosses. The experimental design was RCB with two replications of 6 plants per genotype. Planting was done in alleys of multispecies hedgerows in an area of 2,880 m^2 at a spacing of 3 m x 2 m. The study was conducted at the International Institute of Tropical Agriculture (IITA) High Rainfall Station, Onne, Rivers State, Nigeria for 3 years. Six female diploid banana and plantain clones (maternal/ seed parents) were crossed with a single diploid male plantain accession, TMP2x 2829-62 (paternal/pollen parent). The resulting diploid F_1 embryos were cultured *in vitro* for 6 weeks and their seedlings along with the parental clones, vegetatively propagated from the parents of each genotype, were planted in the field. Data collected included days to flowering, time to fruit filling, plant height, plant girth, and height of next tallest sucker. Data subjected to ANOVA in RCB was tested at 5% level of significance. Heterosis (Ht) and heterobeltiosis (Hbt) were estimated. The degree of heterosis and heterobeltiosis differed for different traits, different crosses and genotype. Overall, 66.7% of the progenies showed heterosis and heterobeltiosis for days to flowering and time to fruit filling; 66.7% exhibited heterosis and 50% heterobeltiosis for plant height; 33% heterosis and heterobeltiosis for plant girth and 16.7% heterosis and heterobeltiosis for height of next tallest sucker. Correlations between the levels of heterosis for different traits between the progeny and the female parents were generally weak except for time to fruit filling (r = 0.816) which showed a significant correlation. Heterosis and heterobeltiosis occur in phenological and vegetative traits in diploid x diploid crosses indicating their importance in further possibilities for breeding.

Keywords: Diploids, embryo culture, *Musa spp*, phenology, progeny.

INTRODUCTION

Plant breeding seeks to improve varieties so as to increase their yield and the quality of their breeding traits (Tomkowiak *et al*., 2019). For most plantain and banana breeding programs the primary objectives include the early maturation and uniform production of large bunches that meet the regional qualitative and quantitative demands of farmers and consumers (Cauthen *et al*., 2013; Tenkouano *et al*., 2019). Brown *et al*., 2017 outlined these demands to consist of superior bunch quality with high number of hands and fingers, increased fruit length and girth, high suckering ability, short stature, large stem girth and enhanced root systems that provide effective soil anchorage and efficient uptake of water and minerals, photosynthetic efficiency and rapid cycling. They emphasized that the relative importance of these objectives to the breeder varies across geographic regions, among subgroups of banana and plantain, and depended on consumer preferences (Cauthen *et al*., 2013;

Brown *et al*., 2017). In most of these breeding programmes, the improved performances have depended on the production of hybrids which have exhibited hybrid vigour or heterosis in several significant traits culminating in superior performance of F_1 hybrids as compared to the parents (Bansal *et al*., 2012; Tenkouano *et al*., 2019). Breeding of F_1 hybrid cultivars based on heterosis is used in many crops (Cheng *et al*., 2007; Groszmann *et al.,* 2014; Zhen *et al.,* 2017). Heterosis is a fundamental issue in plant breeding and designates the improved vigour of F_1 hybrids in comparison to their parental homozygous lines especially in the performance of certain traits. Heterosis can be manifested in morphological or physiological traits (Hoecker *et al*., 2006; Rahul, 2017) as well as in earlier maturity of F_1 hybrids than either parent (Riddle and Birchler, 2008). By capitalizing on heterosis or heterobeltiosis the time taken to produce superior cultivars in *Musa* may be shortened. This can be achieved when parents that produce hybrids with high levels of heterosis/heterobeltiosis for desired traits are used in crosses (Batte 2019). Heterosis has been reported for various agronomic traits but most have concentrated on yield and yield related traits, whilst phenological and vegetative traits have received relatively little attention. Heterosis is agronomically important because superior performance can appear as biomass, yield, and abiotic and biotic stress tolerance. Long ago, Shull (1908) defined heterosis as “the interpretation of increased vigour, size, fruitfulness, speed of development, resistance to disease and to insect pests, or to climatic rigours of any kind manifested by crossbred organisms as compared with corresponding inbreds,” Ever since its recognition in the early 20th century (East, 1908; Shull, 1908), heterosis has been exploited systematically in breeding of crops and is considered a major asset to meeting world food needs (Duvick 1999; Tushemereirwe *et al*., 2015). Soehendi and Srinives (2005), stated that the exploitation of heterosis to raise productivity in grain legumes, as in any other crop, depends on three major factors: (a) the magnitude of heterosis; (b) feasibility of large-scale production of hybrid seeds; and (c) type of gene action involved. Heterosis is a highly complex phenomenon and different hypotheses and genetic basis have been suggested to explain the reasons for heterosis, however, its physiological, biochemical, genetic and molecular mechanisms are still not clearly understood and new facts are still being uncovered about how heterosis is generated (Stuber *et al*., 1992; Virmani *et al*., 2004; Groszmann *et al*., 2013; Fujimoto *et al*., 2018). Thus, it appears that heterosis cannot be explained by any single hypothesis, and the causes of heterosis depend on the species, mode of reproduction, genetic distance of parents, traits being investigated, developmental stage of the plant, parental combination and prevailing environmental conditions among others (Hale *et al*., 2007; Li *et al.,* 2008; Kawamura *et al*., 2016; Lariepe *et al*., 2017; Su *et al*., 2017; Kaushik *et al*., 2018; Li *et al*., 2018). To date the most prevailing genetic theories include dominance (Davenport, 1908; Bruce, 1910; Jones, 1917, Garcia *et al*., 2008; Li *et al*., 2008), overdominance (Hull, 1945; Crow, 1948; Semel *et al*., 2006; Li *et al*., 2008; Shang *et al*., 2016; Fujimoto *et al*., 2018), and epistasis (Powers, 1944; Williams, 1959; Melchinger, 2007; Groszmann *et al*., 2013; Jiang *et al*., 2017; Lauss *et al*., 2018). Others have reported that additive effects, over-dominance, epistasis and environmental interactions all contribute to heterosis (Liang *et al*., 2015; Shang *et al*., 2016; Li *et al*., 2018). At the organelle level, increased efficiency in mitochondrial oxidative photophosphorylation of ATP has been claimed by some as another mechanism for hybrid vigour (McDaniel and Sarkissian, 1968; Srivastava, 1981). However early biometric studies on nuclear–cytoplasmic interactions tried to find evidence to support this conjecture with minimal success (Beavis *et al.,* 1987; Asmussen *et al.,* 1989) and there are no molecular data to support the concept of nuclear-cytoplasmic heterotic complementation (Reif *et al*., 2005). Song and Mesing (2003) on the other hand opined that heterosis could be a consequence of differences in the structure of the genome, especially in the distribution and presence of certain genes from a given gene family in crossed inbred lines. They found that a specific region of the genome of two crossed inbred corn lines, which were subsequently sequenced and mapped showing the presence of genes from a given gene family in it were significantly different. Genes that were present in one line were absent in the other, although phenotypic symptoms of their expression were visible in the other line. This is evidence that genes from the same gene family that produce similar phenotypic effects were located in different parts of the genome in each of the tested lines. Later, Fiévet *et al*., (2018) declared that heterosis is a systemic property emerging from non-linear genotype-phenotype relationships. Among the reasons for the rapid acceptance of hybrid corn despite farmers having to purchase new seeds each planting season was due not only to increased yield, but also to uniformity in growth and flowering, which allowed machine harvesting (Crow, 1948; Duvick, 2001). Valizadeh *et al*. (2017) and Batte *et al*. (2020) stated that hybrid vigour or heterosis (Ht) is the superiority of the F_1 hybrid over its parental mean (mid-parent value) while heterobeltiosis (Hbt) is the superiority of the F_1 hybrid over its better parent. Earlier, Springer and Stupar (2007) in their review article declared that though mid-parent heterosis is scientifically interesting, it is of relatively little economic importance and that better parent heterosis (heterobeltiosis) is the underlying rationale for the widespread use of hybrids in many agricultural species. Better-parent heterosis (heterobeltiosis) is of interest from an agronomic and a breeding point of view, because its amount relative to the performance of the better parent is crucial for the decision of whether or not to embark on a hybrid breeding program. Batte (2019), working with East

African highland bananas reported that significant progressive heterobeltiosis for bunch weight was found in all the NARITA hybrids that were mostly secondary triploids ensuing from the 4x × 2x crosses. Half of the NARITA hybrids however had negative heterobeltiosis for plant stature. He pointed out that by capitalizing on heterosis or heterobeltiosis the time taken to produce superior cultivars may be shortened and this can be achieved when parents that produce hybrids with high levels of heterosis/heterobeltiosis for desired traits are used in crossing blocks. Wilson *et al*., (1999) had earlier reported a 17% heterobeltiosis in triploid hybrids and as much as 60% to 261% heterobeltiosis in tetraploid hybrids for bunch weight. They also found that plant height was reduced in tetraploid and triploid hybrids derived from ‘Obino L’Ewai’ than from ‘Bobby Tannap’. Tenkouano *et al.,* (1998) had posited earlier that incorporation of useful genes in diploid males of *Musa* is much easier than in polyploidy parents indicating that diploids are vital to genetic improvement of *Musa* and suggested that crossing diploid males with higher ploidy level females, gives a higher probability of recovering hybrid offspring that show heterosis for the desired traits. Some researchers (Fu *et al*., 2014) have pointed out some challenges that exist in that not every cross exhibits strong heterosis especially when few heterotic loci, or low genetic diversity, exist in parent lines, emphasizing the need to select diverse lines enriched with heterotic loci. Also negative heterotic loci may occur simultaneously in the F_1 generation and must be removed in subsequent generations without compromising the degree of positive heterosis. In addition although the degree of heterosis tends to increase with increasing genetic diversity of the parents, this also increases the likelihood of meiotic abnormalities, such as poor chromosome pairing. Several early studies on heterosis concentrated almost solely on finding heterosis in terms of yield being the predominant trait of economic interest (Goldman, 1998; Coors and Pandey, 1999; Duvick, 2001). More recently, interest has increasingly shifted to identifying heterosis for multiple phenotypic traits instead of just yield *per se* and their relationships with yield in order to find out the extent to which improving specific traits of interest can result in higher yields (Flint-Garcia *et al.,* 2009; Rahul, 2017; Kanfany *et al*., 2018; Wolko *et al*., 2019; Batte *et al*., 2020). This study set out to investigate the extent of heterosis and heterobeltiosis in two phenological traits and three vegetative traits in diploid x diploid *Musa* crosses and their relationships with each other.

MATERIALS AND METHODS

Site description

This study was carried out at the International Institute of Tropical Agriculture (IITA) High Rainfall Station, Onne (4°51’N, 7° 03’E, 10 m above sea level), in Rivers State, South-South Nigeria. The rainfall pattern is monomodal, distributed over a 10 month period from February through December, with an annual average of 2400 mm. 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 and 27°C, respectively, while solar radiation/sunshine lasts an average of 4 hours daily (Ortiz *et al.,* 1997). The soil is derived from coastal sediments of the Niger Delta, freely drained and acidic (pH 4.3), and made up of mainly Kaolinite. Onne soils are also high in phosphorus 60 mg kg^{-1}, manganese 0.2 mmol kg^{-1}, but low in nitrogen (Swennen *et al*., 1995).

Experimental materials and experimental design

The progeny was obtained by hand pollinating female (maternal/ seed parents) - 3 diploid banana TMB2x 8084-2; TMB2x 8532-1; TMB2x 9839-3 and 3 diploid plantain TMP2x 1448-1; TMP2x 2625-5 and TMP2x 2829-62 clones with a single diploid plantain accession, TMP2x 2829-62 as male (paternal/ pollen parent) (Wilson and Tenkouano, 2019) giving a total of 6 crosses. At fruit maturity, seeds were extracted from the ripened bunches and the embryos excised and cultured *in vitro* for 6 weeks. The resulting diploid (2x) progeny seedlings were transferred to the nursery. Two-month old seedlings of these along with the parental clones (vegetatively propagated from parents) of each genotype were planted in the field. Thus, a total of 6 diploid parental clones, and 6 diploid progeny were planted in the field. The experimental design was a randomised complete block design with two replications of 6 plants per genotype. Planting was done in alleys of multispecies hedgerows in an area of 2,880 m^2 at a spacing of 3 m x 2 m (Ortiz 1995; Tenkouano *et al.,* 2010). Fertilizer was applied at the rate of 300 kg N and 450 kg K per hectare, split into 6 applications (Ortiz and Vuylsteke, 1995). Weeds were controlled with Paraquat (150ml Gramoxone^{TM} in 20L water), and applied when necessary.

Data collection and statistical analyses

Data on five traits distributed across Phenological traits - Days to flowering, time to fruit filling and Vegetative traits - Plant height, plant girth, and height of next tallest sucker all at flowering was recorded.

Days to flowering

The number of days to flowering was obtained by counting the number of days from planting or sucker emergence to the appearance of inflorescence.

Time to fruit filling

Calculated as the number of days between the date of emergence of inflorescence to the date the bunch was harvested, a time when at least a finger from the first two proximal hands had shown sign of ripening (yellowing.

Plant height

Using a metric rule, plant height was measured from soil level to the junction of the last fully expanded leaves where the inflorescence emerged.

Plant girth

Using a metric tape, the circumference of the pseudostem was measured at 100 cm from the ground.

Height of next tallest sucker

Measured as described for plant height.

All data were subjected to the analysis of variance in a randomized complete block design using the General Linear Model (GLM) of Statistical Analysis Software (SAS) version 9.1 to test for significance at 5% level of significance. If a measured trait was significant, the means were separated by the least significant difference (LSD) test.

For each trait measured, heterosis (Ht) was determined as percentage increase (+) or decrease (-) exhibited by the progeny in comparison with mid-parent values (Virmani *et al*., 1997; Hallauer *et al.*, 2010; Zhai *et al*., 2013):

MPH (FI-MP/MP)*100

Where: F1 is the performance of the hybrid, and MP is the average performance of the two parents.

While heterobeltiosis (Hbt) was calculated as percent increase (+) or decrease (-) exhibited by the progeny in comparison with the better parent values (Virmani *et al*., 1997; Hallauer *et al.*, 2010; Zhai *et al*., 2013):

BPH (FI-BP/BP)*100

Where F1 is the performance of the hybrid, and BP is the best performance of the parent

RESULTS

Phenological traits

Analysis of variance (ANOVA) showed that there were significant differences (p=0.05) in the phenological traits among genotypes. With respect to the time taken to flower, the progeny from the TMP2x 1448 x TMP2x 2829-62 cross flowered significantly (p=0.05) earlier than its female parent but not significantly earlier than the male parent (Figure 1). Progeny of the TMP2x 2829-62 x TMP2x 2829-62 cross flowered later than both parents but not significantly. Generally, there were no significant differences in the number of days to flowering between the other progenies and their parents. In only one instance, the cross TMB2x 9839-3 x TMP2x 2829-62 the male plantain parent flowered later than both the female banana parent and the progeny. The time taken to fruit filling by both parents and their progenies is presented in Figure 2. The progeny of the TMP2x 2829-62 x TMP2x 2829-62 cross showed significantly (p=0.05) earlier time to fruit filling of 3 weeks than its parents. It also exhibited significant earlier fruit filling than other female parents ranging from 21 days earlier than TMP2x 2625-5, one of the female plantain parents to 45 days earlier than TMB2x 9839-3 one of the female banana parents. Compared to other progenies it had a shorter time to fruit filling than other progenies ranging from 18 days to 37days earlier. There were significant differences between the progenies of the TMB2x 8084-2 x TMP2x 2829-62 cross and the TMB2x 8532-1 x TMP2x 2829-62 cross and their female banana parents. There were no significant differences between the progeny of the cross between TMP2x 1448-1 x TMP2x 2829-62 and its parents. Most of the other progenies had earlier fruit filling than their female parents. The progeny from the TMB2x 9839-3 x TMP2x 2829-62 cross had a significantly longer time to fruit filling (133 days) than its male plantain parent (116days).

Vegetative traits

The female banana parent, TMB2x 9839-3, was significantly (p=0.05) shorter than the progeny of the TMB2x 9839-3 x TMP2x 2829-62 cross and its male plantain parent (Figure 3). In terms of plant height, there were no significant differences between the progenies of all other crosses and their parents. The progeny of the cross TMB2x 9839-3 x TMP2x 2829-62.had significantly (p=0.05) higher plant girth than its female banana parent (Figure 4) whereas progenies of the crosses between TMB2x 8084-2 x TMP2x 2829-62 and TMB2x 8532-1 x TMP2x 2829-62 had smaller plant girths than their parents though not significantly different. There were no significant differences in the heights of the next tallest sucker (following sucker) between the parents and their progenies (Figure 5).

Heterosis and heterobeltiosis in phenological and vegetative traits

The degree of heterosis and heterobeltiosis varied considerably with the different traits (Table 1). The

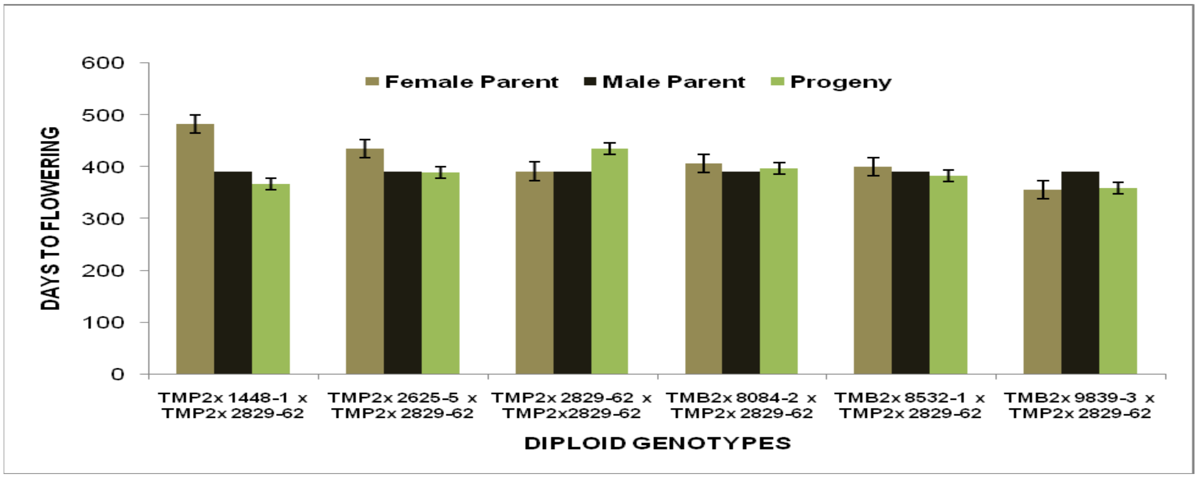

Figure 1. Effects of *Musa* diploid x diploid crosses on days to flowering.

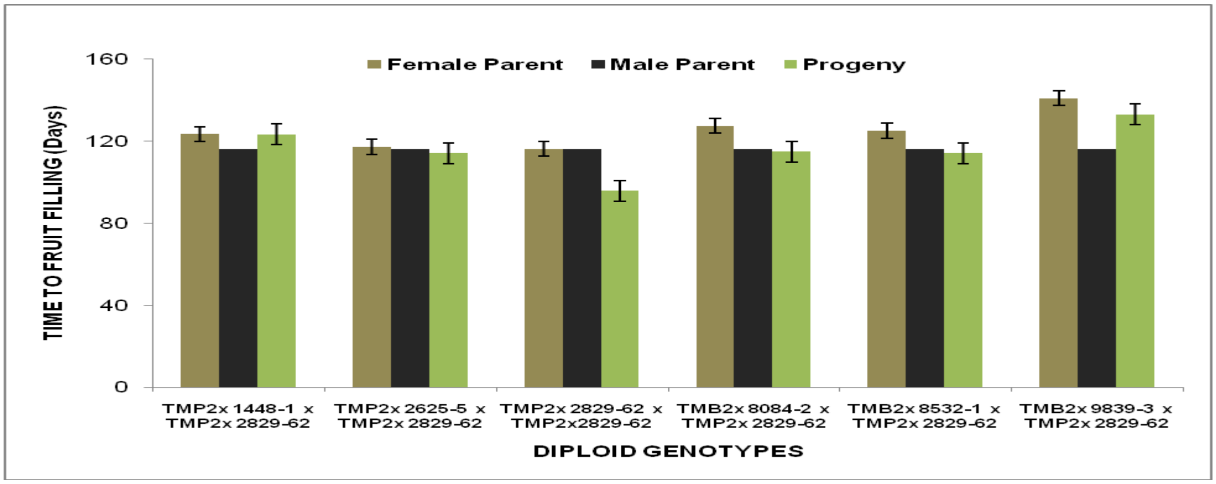

Figure 2. Effects of *Musa* diploid x diploid crosses on time to fruit filling.

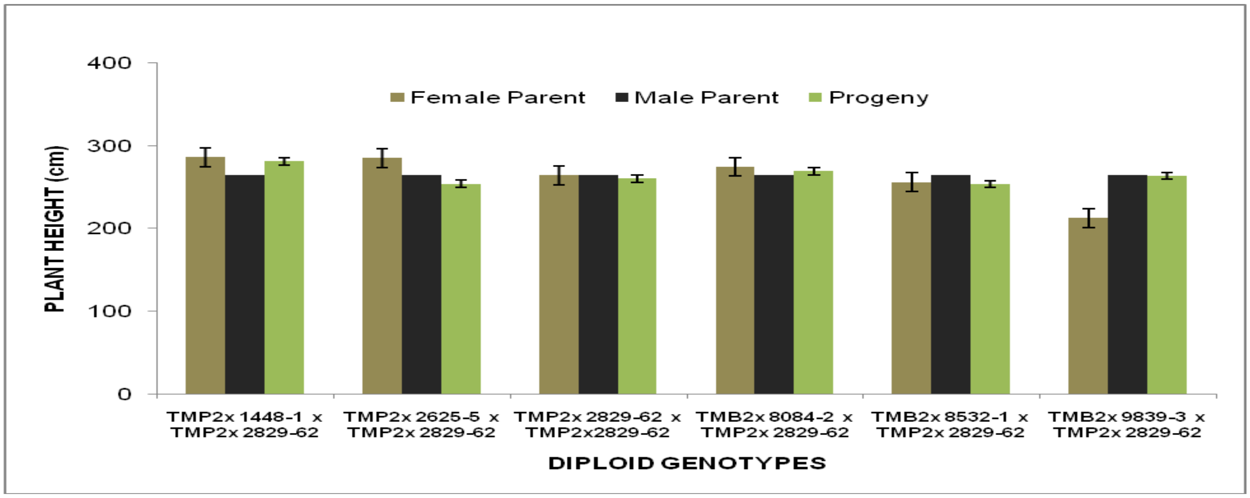

Figure 3. Effects of *Musa* diploid x diploid crosses on plant height.

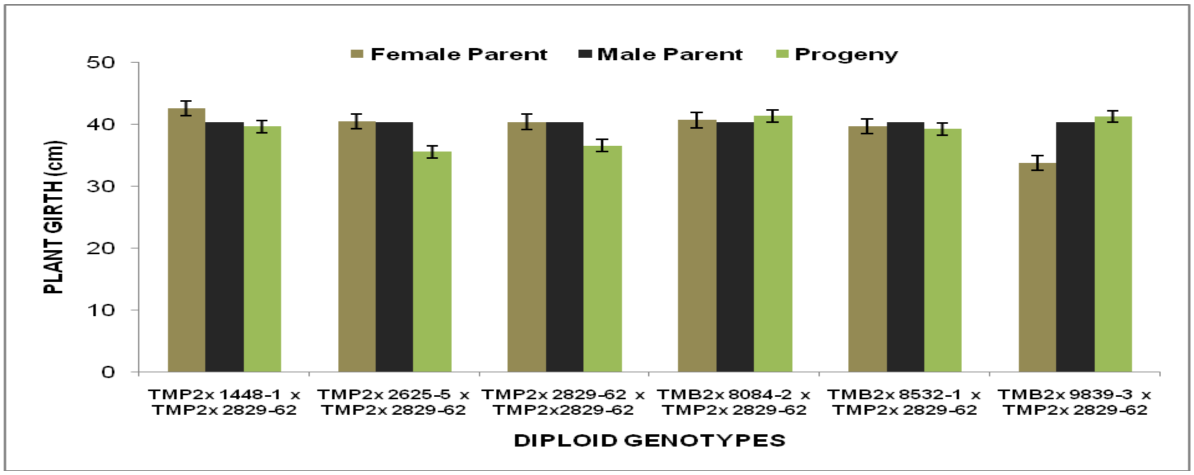

Figure 4. Effects of *Musa* diploid x diploid crosses on plant girth.

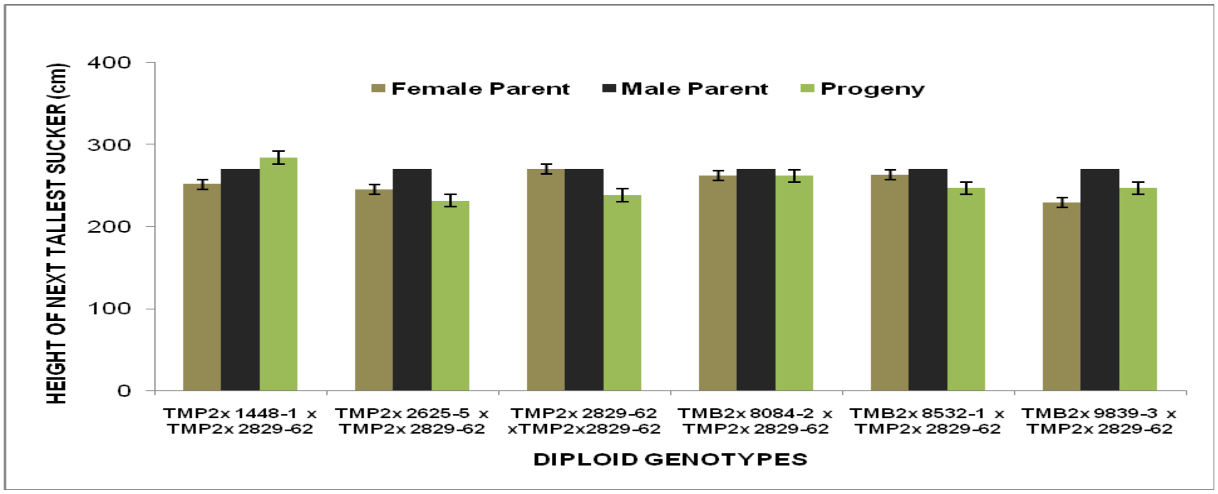

Figure 5. Effects of *Musa* diploid x diploid crosses on height of next tallest sucker.

progeny of the TMP2x 1448-1 x TMP2x 2829-62 cross had significant and the highest level of heterosis (-16.6%) and heterobeltiosis (-6.38%) of all the crosses for days to flowering (Table 1). Other progenies showed varying degrees of heterosis and heterobeltiosis for days to flowering. With respect to fruit filling, the progeny of TMP2x 2829-62 x TMP2x 2829-62 showed the highest level of heterosis and heterobeltiosis (-17.63%) for time to fruit filling and the lowest for days to flowering compared to all other progenies. For this cross TMP2x 2829-62 (female) x TMP2x 2829-62 (male) there was no better parent, therefore heterosis and heterobeltiosis were the same. Other progenies that showed notable heterosis and heterobeltiosis for time to fruit filling were progenies from the TMB2x 8084-2 x TMP2x 2829-62 cross and the cross TMB2x 8532-1 x TMP2x 2829-62. Progeny from the cross TMB2x 9839-3 x TMP2x 2829-62 had the lowest level of heterosis and heterobeltiosis for this trait. The progenies of the crosses TMP2x 2625-5 X TMP2x 2829-62 and TMB2x 8532-1 x TMP2x 2829-62 exhibited heterosis and heterobeltiosis for plant height (Table 1). The progeny of the TMP2x 1448-1 x TMP2x 2829-62 cross showed the highest level of heterosis and heterobeltiosis of all the crosses for height of next tallest sucker. The progeny of TMB2x 9839-3 x TMP2x 2829-62 cross had the highest heterobeltiosis and heterosis in plant girth of all the crosses.

Correlations

There was a highly significant negative correlation ($p = 0.05$)

Table 1. Heterosis *(Ht) and Heterobeltiosis **(Hbt) in phenological and vegetative traits in *Musa* Diploid x Diploid crosses.

Diploid x Diploid Crosses	**Ht (%) / **Hbt (%)	Days to flowering	Time to fruit filling (days)	Plant height (cm)	Plant girth (cm)	Height of next tallest sucker (cm)
TMP2x 1448-1 x TMP2x 2829-62	Ht	-16.16	2.84	6.18	-4.34	8.91
	Hbt	-6.38	6.02	6.43	-6.81	5.26
TMP2x 2625-5 x TMP2x 2829-62	Ht	-0.66	-2.23	-7.46	-11.99	-10.05
	Hbt	-5.94	-1.81	-3.79	-12.10	-14.15
TMP2x 2829-62 x TMP2x 2829-62	Ht	10.97	-17.63	-1.48	-9.41	-11.74
	Hbt	10.97	-17.63	-1.48	-9.41	-11.74
TMB2x 8084-2 x TMP2x 2829-62	Ht	1.28	-5.66	-0.09	2.10	-1.67
	Hbt	-0.61	-1.12	1.89	1.72	-3.00
TMB2x 8532-1 x TMP2x 2829-62	Ht	-2.32	-5.42	-2.40	-1.87	-7.46
	Hbt	-3.36	-1.81	-3.90	-1.01	-8.56
TMB2x 9839-3 x TMP2x 2829-62	Ht	-3.95	3.54	10.68	11.32	-1.18
	Hbt	0.93	14.53	24.14	22.19	-8.52

† For Days to flowering, Time to fruit filling and Plant height, the lower values are indicative of manifestation of heterosis and heterobeltiosis. ‡ For the cross TMP2x 2829-62 (female) x TMP2x 2829-62 (male) there was no better parent, therefore heterosis and heterobeltiosis were the same.

Table 2. Correlation coefficients between phenological and vegetative traits in Diploid x Diploid crosses of *Musa.*

Traits	Days to flowering	Time to fruit filling	Plant height	Plant girth	Height of next tallest sucker
Time to fruit filling	-0.966**				
Plant height	-0.321	0.356			
Plant girth	-0.554	0.647	0.508		
Height of next tallest sucker	-0.431	0.395	0.929**	0.594	

between days to flowering and time to fruit filling (r = -0.966**) and a highly significant and positive correlation between plant height and height of next tallest sucker (r = 0.929**) (Table 2). Correlations between other phenological and vegetative traits were not significant. Correlations between the levels of heterosis for different traits between the progeny and the female parents were generally weak; days to flowering (r = -0.134); plant height (r = 0.224); plant girth (r = -0.374); and height of next tallest sucker (r = 0.032) except for time to fruit filling (r = 0.816) which showed significant correlation suggesting perhaps that the genetic basis of heterosis is trait-dependent.

DISCUSSION

Not many studies have been reported on the phenomenon of heterosis and heterobeltiosis in *Musa* relative to cereals and legumes considering the importance of bananas and plantains; and fewer still have been on their phenological and vegetative traits. Most studies have centred more on the heterosis and heterobeltiosis of the yield components and yield, disease and pest resistance of *Musa* (Wilson and Tenkouano, 1998; Wilson *et al*., 1999; Bakry *et al*., 2009; Kabiita, 2014; Batte, 2019; Batte *et al*., 2020). In this study, whereas some traits showed considerable amount of heterosis and even heterobeltiosis, the degree of heterosis and heterobeltiosis however differed for different traits. Heterosis and heterobeltiosis for phenological traits were manifested in earliness of the progenies to achieve flowering and fruit filling. However shorter stature in terms of plant height is indicative of heterosis and heterobeltiosis and thicker plant girth is indicative of heterosis and heterobeltiosis in *Musa*. Time taken to flowering as well as flowering synchrony between male and female parents are important phenological traits in Musa breeding because they influence pollination success and seed set (Wilson and Tenkouano, 2019a; Wilson *et al*., 2020) of plantain and banana. Moreover, synchrony in flowering of female parents whose flowering duration is often less than a week, and male parents is critical for fertilization to generate new hybrid genotypes with desired agronomic performance. This is because recent studies indicate that open pollination using appropriate mating designs and hand pollination in plantain and banana are not significantly different eliminating the once exclusive practice of hand pollination and its attendant expense, drudgery, labour and time constraints (Wilson and Tenkouano 2019b). Earlier, Wilson *et al.* (1999) had reported that heterosis for yield in tetraploid and triploid hybrids was associated with reduced time to flowering and faster sucker growth. The time taken to fruit filling is a critical character because it determines fruit maturity and earliness to market for farmers. Farmers who are able to get produce to market early, before there is a glut with the laws of demand and supply will obviously benefit from higher prices. Heterosis and heterobeltiosis for phenological traits were manifested in earliness of the progenies to achieve flowering and fruit filling. Lariepe *et al*. (2012) reported significant heterosis in earliness for silking date of maize varying from -10% to -14.5%. Therefore, diploids that exhibit earliness in flowering and fruiting will make good potential parent materials in *Musa* breeding programmes.

Generally, in terms of plant height and plant girth there were no significant differences between the progenies of most of the crosses and their parents a finding similar to that reported by Kabiita (2014) in banana and in rice by Yu *et al*. (2020). Identification of parental combinations that produce high progeny performance with heterosis in desired traits is one of the critical steps in the utilization of heterosis for breeding. For plantains and bananas, plant height and girth are important because tall plants with slim girths are more prone to lodging by wind and breakage under the weight of bunches (Brown *et al.,* 2017). However, although taller plants get more sunlight for photosynthesis they are also more difficult to harvest and require longer and more expensive stakes to keep them upright. Therefore, in selecting best performing progenies moderately tall plants with thick girths are preferred (Batte *et al.,* 2020). For the following traits therefore: days to flowering, time to fruit filling) and plant height, the lower heterosis and heterobeltiosis values are indicative of positive manifestation of heterosis and heterobeltiosis, whereas for plant girth and height of next tallest sucker the higher values are indicative of heterosis and heterobeltiosis. While in some instances some progenies do show heterosis in all traits (Cardoso *et al*., 2014), several studies in maize have demonstrated that highly heterotic progenies do not consistently have high levels of heterosis for all traits measured (Auger *et al*., 2005; Riddle and Birchler, 2008; Flint-Garcia *et al*., 2009). In fact, it is possible to identify maize hybrids with very high levels of heterosis for plant height but almost no heterosis for plant yield, and vice versa declared Flint-Garcia *et al*. (2009). In this study, there was a highly significant negative correlation (p=0.05) between days to flowering and time to fruit filling (r=-0.966**) and a highly significant and positive correlation between plant height and height of next tallest sucker (r=0.929**). Correlations between other phenological and vegetative traits were not significant. Correlations between the levels of heterosis for different traits between the progeny and the female parents were generally weak; days to flowering (r=-0.134); plant height (r=0.224); plant girth (r=-0.374); and height of next tallest sucker (r=0.032) except for time to fruit filling (r=0.816) which showed significant correlation suggesting perhaps that the genetic basis of heterosis is trait-dependent (Flint-Garcia *et al*., 2009). Schnable and Springer (2013) had stated earlier, that generally, levels of heterosis for different traits are not well correlated unless the traits have a physiological relationship to each other

Conclusion

The results suggest that heterosis and heterobeltiosis do occur in phenological and vegetative traits when diploid x diploid crosses are made between male plantain parents and female plantain and banana parents; indicating that selection of diploid parents that show heterotic effects in important phenological and vegetative traits offer further possibilities for breeding since plantains and bananas are vegetatively propagated and the effect of heterobeltiosis will not be lost over time. The cross of the diploid female banana and diploid male plantain TMB2x8532-1 x TMP2x 2829-62 and the cross of the diploid female plantain and diploid male plantain TMP2x 2625-5 x TMP2x 2829-62 both gave the overall average best heterobeltiosis and are recommended for progressing genetic gain in such diploid diploid crosses in any *Musa* breeding programme.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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