Heterosis for number of fruits and seed yields in jatropha (Jatropha curcas L.)

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Abstract. Jatropha production is still low, therefore development of high-yielding varieties by hybridization is needed. This study aimed to determine heterosis and heterobeltiosis in jatropha and estimate the mode of gene action. The hybridizations were carried out between two improved population and one provenance, well known as high yield genotypes as female parents, and 18 provenances indicating high oil content as male parents at Karangploso Experimental Station, Malang, East Java in 2010. In 2011, F1 seeds were planted in Asembagus Experimental Station, Situbondo, East Java and then were selected with criteria high fruit number and seed yield. The selected F1 were clonally multiplied using stem cutting and were planted in 2012 for evaluation purposes. The results showed that the heterosis and heterobeltiosis values from hybrid jatropha were varied. The crossing between HS49 X SP65, HS49 X SP54, HS49 X SP103, IP3P X SP7, IP3A X SP65 and IP3A X SP 89 demonstrated high significant positive heterosis and heterobeltiosis values. These hybrids could be used as materials for developing high-yielding varieties. The potency ratio of jatropha hybrid was found positively overdominance gene action which could be useful information for future jatropha breeding program.

Keywords: hybridization, gene action, mid parent, better parent.

1. Introduction

Jatropha (Jatropha curcas L.) seeds contain oil that has been found to more suitable for producing biodiesel compared to other oil seeds. Jatropha yield, however, is still relatively low due to the limited superior varieties available[1]. Producing improved varieties of jatropha with higher yield could be obtained by hybridizing different parents which is known as heterosis. Heterosis is a natural phenomenon whereby progeny of genetically diverse individuals show increased vigor than their parents [2]. Heterosis can be expressed as mid-parent, better parent, and standard heterosis[3]. Notably, heterosis has been used to improve many crop species such as chili [4], tomato [5,6], and oat [7]. The positive and negative heterosis for seed yield from 6 x 6 half-diallel cross in jatropha has been reported[3], whereas three crossing combinations in jatropha accessions produced a high heterosis effect for oil production [8].

Heterosis can increase yield, plant height, number of leaves/plant, leaf area/plant, number of pods/plant, pod length, number of seeds/pod, 100-seed weight, yield/plant, chemical components, and resistance to disease of mungbean [9]. Yield character is commonly influenced by many genes,
therefore, the yield of hybrid progeny will be higher than the parent [8]. Jatropha is known as a perennial plant that exhibits facultative cross-pollination as the mating pattern. Based on the previous studies in other perennial cross-pollination crops, such as cassava[10] and castor plant[11], it is expected that the use of hybrid vigour in Jatropha could enhance its productivity. The study of hybrid vigour could also be used to determine the mode of gene action in specific character. The type of gene action is calculated using potence ratio that could also show the effect of gene action from the parents to the progeny [12]. This study aimed to determine the level of mid-parent and better parent heterosis from several crossing combinations in jatropha and estimate the mode of gene action affecting fruit number and seed yield of jatropha hybrid.

2. Materials and Methods
Hybridization activities were carried out in Karangploso Experimental Station, Malang, East Java from January to December 2010. Two improved populations, one provenance of jatropha known as high yield genotype were used as female parents and 18 provenances of high oil contents were used as male parents. In 2011, the F1 seeds were then planted in Asembagus Experimental Station, Situbondo, East Java and then were selected with criteria of high fruit number and seed yield. The crossing combinations scheme were shown in Table 1.

The most potential F1 hybrids produced were clonally multiplied by stem cutting and then planted at 2mx2m spacing in 2012 for further evaluations. Each hybrid consisted of 25 plants. The fruit numbers and seed yields of the first and second year’s generated plants were observed in two consecutive years (2012, 2013). The values of mid-parent heterosis (H) and better-parent heterosis (heterobeltiosis-Hb) were calculated by following formulas:

\[
\%H = \frac{(F1 - MP)\times 100}{MP}
\]

\[
\%Hb = \frac{(F1 - BP)\times 100}{BP}
\]

Mid-parent value means \((P1+P2)/2\); P1 and P2 are the mean values of parent 1 and 2; F1 is the mean value of hybrid progeny; Better-parent is the mean value of the better parent (showing the more desirable value of the trait in a cross).

The data heterosis significance of different characters was analyzed using the following formulas [1, 5].

\[
t - test for \ H = \frac{F1 - MP}{SH}
\]

\[
t - test for \ Hb = \frac{F1 - BP}{SHb}
\]

Sh and SHb are the standard error of estimates of H and Hb.

The potence ratio \((h)\) to estimate the dominant effect of gene action were calculated using the following formula[13]:

\[
h = \frac{F1 - MP}{BP - MP}
\]

The level of dominance determined the potence ratio \((h)\) were classified as follow [13]:

\(h = 0\), there is no dominance gene action (additive)
h = 1 or h = -1, there is positively or negatively completely dominance
0<h<1, incomplete positively dominance
-1<h<0, incomplete negatively dominance
h>1 or h>-1, positive or negative over-dominance.

Table 1. Crossing combination among Jatropha genotypes.

| No. | Crossing Combination | Female parent | Male parent | Female parent | Male parent | Female parent | Male parent |
|-----|----------------------|---------------|-------------|---------------|-------------|---------------|-------------|
| 1.  | HS49 SP4 SP7 SP4     | SP4           | SP7         | SP4           | SP4         |
| 2.  | SP10 IP3P SP37       | SP10          | IP3P        | SP37          | SP37        |
| 3.  | SP19 SP65 SP65       | SP19          | SP65        | SP65          | SP65        |
| 4.  | SP33 SP103 IP3A SP89| SP33          | SP103       | IP3A          | SP89        |
| 5.  | SP37 SP104 HS1       | SP37          | SP104       | HS1           | HS1         |
| 6.  | SP65 HS61            | SP65          | HS61        |               |             |
| 7.  | SP54 JATIM 33        | SP54          | JATIM 33    |               |             |
| 8.  | SP103                | SP103         |            |               |             |
| 9.  | HS1                  | HS1           |            |               |             |
| 10. | HS48                 | HS48          |            |               |             |

3. Results and Discussion
The heterosis over mid-parent and better parent (heterobeltiosis) for fruit number of jatropha varied on all cross combinations (Table 1). The value of heterosis and heterobeltiosis of the fruit number from crossing of HS49 as female parent and ten male parents of jathropha showed that the heterosis value ranged from 1.74% to 188 % in the first year and -2.28% to 118.64 % in the second year. The heterobeltiosis value obtained ranged from 6.65% to 90.17% in first year and -17.51% to 118.12 % in second year. The positive significant heterosis was exhibited by five crosses in the first year, whereas in the second year almost all crosses showed significantly heterosis. The positive significant heterobeltiosis was shown for the number of fruit per plant by five crosses in the first year and eight crosses in the second year. It is notable that the highest significant heterosis and heterobeltiosis were identified in cross of HS49 X SP65 (Table 2).

The heterosis and heterobeltiosis values of fruit number per plant from cross between IP3P as female parent revealed the highest significant different for fruit number/plant from the cross of IP3P X SP7. The crossing between IP3P x SP104 exhibited significant negative heterobeltiosis indicating that the progeny had lower fruit number compared to the SP104 parent. The heterosis and heterobeltiosis of fruit number per plant in crossing between IP3A as female parent and SP65 male parent resulted the highest significant positive heterosis and heterobeltiosis.

The seed yield of the heterosis and heterobeltiosis jatropha from all crosses combinations in the first and second year are shown in Tables 3. Almost all crosses showed significantly positive heterosis, of which the cross of IP3P X SP65 produced the high heterosis and heterobeltiosis values. The hybrids that have positive heterosis with high value are important in jatropha breeding to create high yielding varieties [3]. This study results are relevant with previous studies that Crossing of different jatropha genotypes produced high heterosis values on the seed yield character reported in Thailand [1, 14]. The variation in the heterosis and heterobeltiosis values is probably affected by the genetic distance between parents, traits, and environment factor [2].
### Table 2: Heterosis and heterobeltiosis of fruit number per plant observed

| Crossing     | Heterosis          |       | Heterobeltiosis |       |
|--------------|--------------------|-------|-----------------|-------|
|              | 1st year           | 2nd year | 1st year | 2nd year |
| HS49XSP4     | 53.23***           | 86.46**| 37.81*        | 64.36**|
| HS49XSP10    | 22.24**            | 58.18**| 16.42ns       | 45.61**|
| HS49XSP19    | 48.74ns            | 96.78**| 43.88ns       | 71.18**|
| HS49XSP33    | 4.25ns             | 83.61**| -6.65ns       | 78.51**|
| HS49XSP37    | 67.21**            | 118.64**| 50.09**       | 89.81**|
| HS49XSP65    | 188.21**           | 297.99**| 85.13**       | 118.12**|
| HS49XSP54    | 41.44ns            | 65.05**| 37.81*        | 64.37**|
| HS49XSP103   | 113.26**           | 53.12**| 90.17**       | 36.71**|
| HS49XHS1     | 1.74ns             | -2.28ns| 0.70ns        | -17.51ns|
| HS49XHS48    | 13.11ns            | 14.67* | -0.52ns       | 4.24ns |
| IP3PXSP7     | 217.28**           | 783.45**| 122.08**      | 444.91**|
| IP3PXSP37    | 27.27**            | 206.89**| 1.39ns        | 109.19**|
| IP3PXSP65    | 59.67ns            | 126.51**| 51.31ns       | 51.13* |
| IP3PXSP103   | 89.25**            | 128.75**| 80.60**       | 51.33* |
| IP3PXSP104   | -0.52ns            | -12.77ns| -16.06ns      | -47.19**|
| IP3AXSP4     | 6.92ns             | 28.38**| -22.85**      | 0.74ns |
| IP3AXSP33    | 0.51ns             | 37.86**| -27.05**      | 24.62**|
| IP3AXSP65    | 146.71**           | 359.24**| 86.64**       | 159.19**|
| IP3AXSP89    | 87.26**            | 83.37**| 50.79**       | 45.77**|
| IP3AXHS1     | 4.37ns             | -35.03**| -19.45**      | -43.85**|
| IP3A X HS61  | 25.53ns            | 55.57**| 23.94**       | 21.29ns|
| IP3A X       | JATIM33            | 2.77ns | 14.79ns       | -3.87ns|

- ** significance at 0.01
- * significance at 0.05
- ns non significance

The potence ratio could be used to estimate the mode of gene action [13]. The potence ratio of the fruit number and seed yield in F1 hybrids of jatropha indicated the presence of various degrees of dominance effect (Table 9, 10, 11). In crossing combination where the female parent was HS 49, the most mode of gene action in the hybrid was positively overdominance. The same results were also reported in maize hybrid [15]. In the case of jatropha plant studied, the crossing of IP3P and IP3A female parents showed no dominance mode of gene action. Only one negatively overdominance gene action was found from HS49 X SP33 hybridization. Negative values of potence ratio indicated the presence of various degrees of recessiveness, *i.e.* partial- to under-recessiveness[16]. Clearly that overdominance is an intra-allelic interaction in which presence of multiple alleles lead to greater performance than homozygosity for either allelic state [15], as demonstrated in this study.

The correlation analysis between heterosis of fruit number per plant with seed yield, and correlation between heterobeltiosis of fruit number per plant and seed yield on the first and second years suggested the successful crosses in this study (Table 5). On the first year, there was a significant positive correlation between heterosis and between heterobeltiosis of fruit number per plant and seed yield. This result indicated that a pair of parents which have high value of heterosis on fruit number per plant also have high value of heterosis on seed yield, similarly to heterobeltiosis. Therefore, parental selection to produce hybrids with high seed yield can be done based on heterosis and/or heterobeltiosis of fruit number per plant. The positive correlation between heterosis and between heterobeltiosis for fruit
number with seed yield on Jatropha is probably caused by significantly positive correlation between both characters. The previous experiment found the value of significantly positive correlation of phenotypically and genotypically between fruit number per plant and seed yield i.e. 0.98 and 0.98 respectively [17]. According to [18], genetic aspect, there is a correlation between one character to another as a result of pleiotropy and/or linkage between both characters. On second year, correlation among the same characters as performed on the first year, as not significant. Interaction among characters is likely to contribute this heterosis and heterobeltiosis, therefore further studies on correlation on the two between seed yield and other characters on Jatropha is still required.

**Table 3.** Heterosis and heterobeltiosis of seed yield

| Crossing   | Heterosis |          |          | Heterobeltiosis |          |
|------------|-----------|----------|----------|-----------------|----------|
|            | 1st year  | 2nd year | 1st year | 2nd year        |          |
| HS49XSP4   | 59.25**   | 83.58**  | 43.95**  | 71.68**         |          |
| HS49XSP10  | 26.89**   | 60.95**  | 24.65**  | 47.99**         |          |
| HS49XSP19  | 60.93*    | 90.09**  | 54.74**  | 75.87**         |          |
| HS49XSP33  | 25.32*    | 109.65** | 15.65ns  | 101.68**        |          |
| HS49XSP37  | 83.75**   | 118.86** | 68.59**  | 107.19**        |          |
| HS49XSP65  | 234.21    | 266.03** | 116.95** | 103.45**        |          |
| HS49XSP54  | 104.87**  | 103.69** | 37.58*   | 41.80**         |          |
| HS49XSP103 | 113.26**  | 47.06**  | 99.07**  | 31.88**         |          |
| HS49XHS1   | 6.92ns    | -16.79** | 5.97ns   | -27.94**        |          |
| HS49X HS48 | 27.61**   | 7.75ns   | 18.16*   | -5.89ns         |          |
| IP3P XSP7  | 32.01*    | 244.75** | 2.96ns   | 140.69**        |          |
| IP3P XSP37 | 78.84*    | 155.72** | 61.72ns  | 82.48**         |          |
| IP3P XSP65 | 264.87**  | 768.89** | 163.04** | 461.53**        |          |
| IP3P XSP103| 112.23**  | 132.89** | 88.75**  | 51.71**         |          |
| IP3P XSP104| 17.79ns   | 4.68ns   | 0.12ns   | -35.18**        |          |
| IP3A XSP4  | 40.21**   | 55.87**  | -5.12ns  | 17.86*          |          |
| IP3A XSP33 | 18.54ns   | 721.51** | -18.79*  | 572.49**        |          |
| IP3A XSP65 | 205.89**  | 432.27** | 157.23** | 216.60**        |          |
| IP3A XSP89 | 113.04**  | 98.07**  | 56.04**  | 48.21**         |          |
| IP3A X HS1 | 12.31ns   | -22.22** | -18.83** | -44.43**        |          |
| IP3A X HS61| 54.56**   | -57.93** | 35.95*   | -75.51**        |          |
| IP3A X     | 18.75ns   | -19.74ns | -540ns   | 7.49ns          |          |

* = significance at 0.05
** = significance at 0.01
ns = non significance
Table 4. Potence ratio and mode of gene action of fruit number per plant and seed yield from crossings between HS49 female parent and ten male parents of jatropha

| Crossing   | Fruit number per plant | Seed yield |
|------------|------------------------|------------|
|            | Potence ratio          | Gene action | Potence ratio | Gene action |
| HS49XSP4   | 5.57                   | Positively overdominance | 4.76 | Positively overdominance |
| HS49XSP10  | 4.45                   | Positively overdominance | 14.98 | Positively overdominance |
| HS49XSP19  | 14.41                  | Positively overdominance | 14.86 | Positively overdominance |
| HS49XSP33  | 0.36                   | incomplete positive | -5.05 | Negatively overdominance |
| HS49XSP37  | 5.89                   | Positively overdominance | 9.31 | Positively overdominance |
| HS49XSP65  | 3.38                   | Positively overdominance | 4.33 | Positively overdominance |
| HS49XSP54  | 0.67                   | incomplete positive | 2.14 | Positively overdominance |
| HS49XSP103 | 9.33                   | Positively overdominance | 15.88 | Positively overdominance |
| HS49XHS48  | 1.68                   | Positively overdominance | 7.69 | Positively overdominance |
| HS49XSP104 | 0.96                   | completely positive | 3.45 | Positively overdominance |
| IP3P XSP7  | 1.01                   | complete positive | 1.00 | complete positive |
| IP3P XSP37 | 10.79                  | Positively overdominance | 7.44 | Positively overdominance |
| IP3P XSP65 | 5.07                   | Positively overdominance | 6.84 | Positively overdominance |
| IP3P XSP103| 18.65                  | Positively overdominance | 9.02 | Positively overdominance |
| IP3P XSP104| 0.0                    | Additive (no dominance) | 1.00 | complete positive |
| IP3A XSP4  | 0.18                   | incomplete positively | 0.84 | incomplete positively |
| IP3A XSP33 | 0.0                    | Additive (no dominance) | 0.4 | incomplete positively |
| IP3A XSP65 | 4.56                   | Positively overdominance | 10.88 | Positively overdominance |
| IP3A XSP89 | 3.6                    | Positively overdominance | 3.09 | Positively overdominance |
| IP3A X HS1 | 0.14                   | incomplete positively | 0.32 | incomplete positively |
| IP3A X HS61| 19.89                  | Positively overdominance | 0.73 | incomplete positively |
| IP3A X JATIM33 | 0.40             | incomplete positively | 0.73 | incomplete positively |

Table 5. Correlation between heterosis and between heterobeltiosis for fruit number per plant and seed yield of Jatropha

| Time of observation | Coefficient correlation |
|---------------------|-------------------------|
|                     | Heterosis               | Heterobeltiosis |
| On 1st year         | 0.57 **                 | 0.41 *         |
| On 2nd year         | 0.31 ns                 | 0.22 ns        |

* ** significant at level 1 % and 5 %
** not significant
4. Conclusion
In this study, jatropha hybrids produced varied heterosis and heterobeltiosis values. Six crosses of jatropha combined parents showed high significantly positive heterosis and heterobeltiosis values. These six hybrids (HS49XSP65, HS49XSP54, HS49XSP103, IP3PXSP7, IP3AXSP65 and IP3AXSP89) could be utilized as genetic materials for improving high-yielding varieties. The positive overdominance gene action was demonstrated by potence ratio of jatropha hybrids that could be exploited in future jatropha breeding program.

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