Analysis on genetic variability and heritability of fruit characters in *Citrullus lanatus* (Thunb.) Matsumura and Nakai (Cucurbitaceae) cultivars.

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**Key words:** Bebu, Wéwlé small seeds, heterosis, heritability

1 **SUMMARY**

Offspring performances coming from crosses between two *Citrullus lanatus* (Bebu and Wéwlé small seeds (WSS) cultivars) were performed to evaluate various components of variation, heritability and genetic advance of fruit characters. Parents (Bebu and WSS), F₁, F₂ and BC₁ hybrids were sowed in the same environment at two locations: Manfla (savannah) and Research Station of Nangui Abrogoua University (forest). Means of different parameters varied according to locations, with statistically significant performance observed in savannah (Manfla) than forest (Abidjan), and large variability was found between fruits of parental and hybrid F₁, BC₁ and F₂ families. Parental and F₁ individuals were homogenous while F₂ and BC₁ generations were heterogeneous. The early cultivar Bebu yields few big fruits per plant than the late cultivar WSS. Fruit maturity period and number of hybrids F₁, BC₁ and F₂ families were intermediate to those parents. Heterosis was observed in F₁ fruit size. Percentage heterosis according to mid-parent average was negative for fruit maturity period and fruit number but positive for fruit size characters. Percentage heterosis according to better parent average was negative for fruit maturity period and fruit number but positive for fruit size. The genotype, phenotypic and additive variance was larger than the environmental variance in the majority of the families at both locations. This involved high broad and narrow-sense heritability for all characters. In conclusion, this study showed a homogeneity between parental and F₁ genotype but a heterogeneity between BC₁ and F₂ one. In addition, heterosis was observed in F₁ fruit size and high heritability was observed for all characters.

2 **INTRODUCTION**

The world population is expected to reach 8 billion by 2030 (FAO, 2002). In order to answer this higher demand for food by the expanding population, high yield can be achieved by improving cultural practices and by developing genetically improved cultivars (Achu et al., 2006). High-yielding cultivars, precision-farming systems, increased use of chemicals for fertilization and weed and disease control, and proper training of the local farmers allowed a significant change in agriculture (Gusmini and Wehrer, 2005). Consequently, crop yield has increased and many crops are now successfully cultivated worldwide. In Côte
d'Ivoire, breeding programs concerning some industrial crops such as coffee, cocoa, rubber, oil palm trees were performed, relegating to the background the main traditional food crops. Despite their agronomic, cultural and culinary importance, these plants lack attention from research and development so that they are categorized as orphan crops (IPGRI, 2002). This is the case of oleaginous cucurbits known as "pistachio" in Côte d'Ivoire. Pistachios contained five species of Cucurbitaceae including Citrullus lanatus, which is the most cultivated (Zoro Bi et al., 2003). Citrullus lanatus is cultivated in a wide range of tropical, semi tropical and dry regions of the world. It is originally found in Southern Africa (Razaviand Milani, 2006). Plants have a non-climbing creeping habit and deeply-cut lobed leaves and must be grown at a wide spacing because of their long, trailing vines. Flowers are viable for only one day (Whener, 2008a). The staminate flowers are precocious (27 to 29 days after seedling, emerging from the middle of the stem with long peduncles. The female flowers emerge one week later (34 to 37 days after seedling), and emerge at the apices of the stems, with short, fat peduncles, followed by an inferior ovary (Gusmini, 2003; Adjoumani, et al., 2012). Depending on the cultivar, fruits are produced in different sizes: small, medium, and large, different shapes: round and oval or elongate (Gusmini, 2003).The seed have an important role in the people diet because of its full nutritious particles and its general and common usage as roasted seeds, seed oil, or medicine for decreasing the blood pressure. Seeds averagely consist of 31.9% protein, 4.4% carbohydrates, 57.1% fat, 8.2% fibre, 6.2% ash130 mg calcium, 456 mg phosphorus, 7.5 mg Iron. The plants are classified into two groups according to morphologic and agronomic evaluation of C. lanatus cultivars in Côte d'Ivoire. The first group is characterized by glossy seeds with a tapered proximal extremity. It includes two cultivars (Wlewlé small and medium seed). In contrast, the second group with two cultivars (Bbnu and Wlewlé large seed) have seeds with flat ovoid shape, rugged and thick ends (Adjoumani et al., 2012). Low yields were recorded during the different campaigns although these traditional cultivars were well adapted to climatic and ecological conditions (Koffi et al., 2009). Earlier efforts, in Citrullus breeding, consisted to the development of new cultivars of different types with good agronomic traits (early maturity, big fruit and seed, large fruit and seed number). However, breeding programs are bound to the knowledge of key traits, genetic systems controlling their inheritance, and genetic and environmental factors that influence their expressions (Chandrababu and Sharma, 1999). It requires stages of selection for parents and progenies. The selection criteria of elite plants and progenies, depends on the variability in the base population and the relative magnitude of the genetic components determining the phenotypic expression of the traits. Individual plant selection can be effective only if the variables under selection have high heritability values (Gatti et al, 2005; Akbar et al., 2008). Heritability of a character describes the extent to which it is transmitted from one generation to the next one. Thus, knowledge of heritability of a trait guides a plant breeder to predict behaviour of succeeding generations and helps to predict the response to selection. High genetic advance coupled with high heritability estimates offer a most suitable condition for selection (Akbar et al., 2008; Waqar-Ul-Haq, 2008). Inbreeding has been used in plant breeding programs to fix favourable genotypes of agricultural interest (Allard, 1978), to separate favourable genotypes and to reduce the percentage of heterozygote in the population (Jansen & Jansen, 1990). However, inbreeding reduces population fitness, increases the genetic variance between families and reduces it within families, with a progressive increase in the additive variance at the expense of dominance in totally homozygote lines (Ceballos, 1998). Heterosis refers to the increased yield and overall performance of F₁ hybrids derived from the cross of two inbred lines. Higher levels of heterosis are more likely when the parents carry a high frequency of
dominant alleles or when over dominance gene action is present (AVRDC, 2007). In *Citrullus lanatus*, heterosis, as well as general (GCA) and specific (SCA) combining ability, received much attention. Overall, the presence of heterosis in watermelon, and the importance of direction of the crosses and GCA in the choice of parents for hybrid production, was confirmed. Earliness, yield and fruit quality are some of the most frequent traits influenced by heterosis (Gusmini and Wehner, 2004, Gvozdanovic-Varga et al., 2011). Breeding of watermelon is largely conducted outside Africa, in particular in the United States (Mujaju, 2009). In *C. lanatus*, the genetics of plant maturity and fruit characters have not been studied in Côte d’Ivoire and there is little published information available to help *C. lanatus* breeders in the choice of the proper breeding. The objectives of this study was to compare the performances of the progenies obtained from crosses between *Bebu* and *WSS small seeds* and to estimate the magnitude of the various components of variation, heritability and genetic advance of plant maturity and fruit characters.

### 3 MATERIALS AND METHODS

#### 3.1 Materials: At the end of diversity study between Ivorian *C. lanatus* cultivars, results had shown that *Bebu* and *WSS small seeds* (*W33*) were genetically more distant and possessed several contrasted agronomic characters. *Bebu* plants were precocious and yielded big fruit, which contained few big seeds. *W33* plants were late maturity and yielded small fruits with a great number of small seeds (Adjoumani et al., 2011). Both cultivars were used to conduct this experiment. Seeds of these cultivars were provided from four successive self-pollination experiments that had been conserved in genetic laboratory of Nangui Abrogoua University under introduction number (NI) NI 121 for *Bebu* cultivar and NI 113 for *W33* cultivar. *Bebu* and *WSS* were crossed and three generations (*F₁*, *F₂* and *BC₁*) were produced. Experiment material was composed of parental seeds (*Bebu* and *W33*) and hybrids seeds (*F₁*, *F₂* and *BC₁*).

#### 3.2 Methods: F1, F2, BC₁ and BC₁w hybrids had been obtained previously after two crop seasons. The first field test was conducted from March to June 2009 at Research Station of Nangui Abrogoua University. It had permitted to obtain *F₁* seeds. This generation comes from reciprocal crosses between *Bebu* and *W33* cultivars (*Bebu* x *W33* and *W33* x *Bebu*). Seeds from three fruits from each cross had been selected to generate *F₁* plants. *F₁w* and *F₁h* were families developed from respective crosses *WSS* x *Bebu* and *Bebu* x *WSS*. The second test was conducted from August to November 2009 at the same Research Station. During this test, parental, *F₁h* and *F₁w* seeds were both sowed on the same parcel to have *F₂h*, *F₂w*, *BC₁h* and *BC₁w* seeds. From *F₁h* and *F₁w* plants, self-pollination was performed to produce respectively *F₂h* and *F₂w* plants. Crosses between *F₁w* plants and each parent produced *BC₁h* and *BC₁w* plants (respectively backcross on *Bebu* and *W33*). When hybrids seeds were found, the whole generation (parental and hybrids) seeds were sowed from March to June 2010 in the same environment at two different agro- ecologically locations: Manfia (savannah) and Research Station of Nangui Abrogoua University (forest). Manfia is a village closest to Goihitafla city in the district of Zuenoula (District of Marahoué). It is localized center-west of Côte d’Ivoire precisely between latitude 7°00 N and 7°26 N and longitudes 6°00 W et 6°30 W (Kouassi et Zoro Bi, 2009). The Research Station of Nangui Abrogoua University is inside Nangui Abrogoua University of Abidjan. This University is located in Lagoon District in southern Côte d’lvoire (48410 N, 48000 W) (Zoro et al., 2006). In both location each field was 6300 m² (105 m x 60 m) and contained 32 rows distant each over from 3 m. the number of rows for each field was 2 for each parental line, 3 for each *F₁* family, 6 for each back cross (*BC₁*) and *F₂* family. Two to three seeds of each family were sowed per hole, with an intra-row spacing of 2
Ten days after sowing, seedlings were separated and the most vigorous one were let in place. In each location, individual number in family was 30, 60, 180 and 180 respectively for parent, F1, BC1 and F2. Regular weeding of the fields had been made during plant vegetative cycle. Any fertilization, fungicide and insecticide contribution had been applied in the fields. At the harvest characterized by total plant drying, 3 fruits per plant were selected to evaluate fruit parameters. Five parameters were evaluated during this study:

**Fruit maturity period:** it had been determined by counting days between sowing and the fruit harvest characterized by total plant drying

**Fruit number per plant:** fruit number per plant was determined by simple fruit counting on each plant

**Fruit mass per plant:** each fruit was weighed with an electronic balance (Kain HD5K3; sensibility 5g). Fruit mass per plant corresponds to average of 3 fruit mass per plant

**Fruit diameter per plant:** diametric lateral opposite board after fruit median section was measured with “pied à coulisse”. Fruit diameter (DFr) per plant corresponds to average of 3 fruit diameter per plant

**Fruit volume (VFr) per plant:** fruits of *C. lanatus* cultivars are supposed spherical. Their volume are evaluated like spherical volume as follow: 

\[ V_{Fr} = \frac{4}{3}\pi r^3, \text{ where } r = DFr/2 \]

### 3.3 Statistical analysis:

Coefficient of variation (CV) was used to study variability between individuals in the same family. It corresponds to relation between standard error (σ) and average (x)

\[ CV = \frac{\sigma}{x} \times 100 \]

- If \( CV < 25 \% \), individuals in the same family are homogeneous or similar
- If \( CV \geq 25 \% \), individuals in the same family are heterogeneous or different

Parental and hybrid performances were first evaluated by comparing, for each trait, different families by using two ways of analysis of variance [ANOVA 2: families (parents, F10,F15, F20,F25, BC1b and BC15)] using SAS software (SAS, 2006).

This test evaluated variability between families, the main effects of location on family production and the interaction between families and locations. Then, the measurements of variance from parents and offsprings were used to estimate environmental, genetic and additive variances. The variance of the F2 provides an estimate of phenotypic variance, whereas the mean variance of the non-segregating generations (parents and F1) gives an estimate of environmental effects (Wright, 1968). The additive variance is derived from subtracting the variances of the backcrosses from twice the phenotypic (F2) variance as an extension of the single locus model under the hypothesis of absence of linkage and genetic-by-environment interactions (Warner, 1952). Phenotypic (\( \sigma^2P \)), environmental (\( \sigma^2E \)), genotypic (\( \sigma^2G \)) and additive (\( \sigma^2A \)) variance effects were estimated from generation variances as follows (Warner, 1952; Wright, 1968):

\[
\sigma^2(P) = \sigma^2(F_2) \\
\sigma^2(E) = \frac{\sigma^2(P_a) + \sigma^2(P_b) + 2\sigma^2(F_2)}{4} \\
\sigma^2(G) = \sigma^2(P) - \sigma^2(E) \\
\sigma^2(A) = 2\sigma^2(F_2) - [\sigma^2(BC1P_a) + \sigma^2(BC1P_b)]
\]

The broad (H\(^2\)) and narrow-sense (h\(^2\)) heritability can then be respectively calculated from the available estimates of genetic, additive, and phenotypic variances.

\[
H^2 = \frac{\sigma^2(G)}{\sigma^2(P)} = \frac{\sigma^2(F_2) - \sigma^2(F_2)}{\sigma^2(F_2)} \\
h^2 = \frac{\sigma^2(A)}{\sigma^2(P)}
\]

The predicted gain from selection (Gs) was evaluated according to Kumar (2009).

\[ Gs = kh^2 \sqrt{\sigma^2(F_2)} \]

k = differential selection which varied with selection intensity (k = 2.063, 1,755 and 1,555 respectively at 5%, 10% or 15% intensity on normal distribution table (Nanson, 1967).

Breeding value of the studied material was demonstrated via the analyses of heterosis and
combining abilities in the F₁ generation (Nya and Eka, 2010). Percentage heterosis according to mid-parent (MPH) and better parent heterosis (BPH) was calculated using the formula by Gusmini and Wehner (2004) as follows.

\[
MPH = \frac{(F_1 - MP) \times 100}{MP} \\
BPH = \frac{(F_1 - BP) \times 100}{BP}
\]

Where \( F_1 \): mean of F₁ family, MP: mean of mid-parent (two parents) and BP: mean of best parent.

4 RESULTS

4.1 Locations and Families effects:
According to two ways analysis of variance, experimental site influenced significantly families’ performances (\( P < 0.05 \)). Means of different parameters varied according to locations with higher performance observed in savannah (Manfla) than forest (Abidjan). In addition, for a given site, performance differed from families whatever character (\( P < 0.001 \)). However, no location-family interaction was observed. Savannah was more favourable to these families than the forest and large variability was observed between parental and hybrid F₁, BC₁ and F₂ families (Table 1).

<table>
<thead>
<tr>
<th>Traits</th>
<th>location</th>
<th>Family</th>
<th>Interaction location-family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit maturity period (das)</td>
<td>37.15</td>
<td>110.89***</td>
<td>1.69***</td>
</tr>
<tr>
<td>Fruit number per plant</td>
<td>2.11**</td>
<td>62.89***</td>
<td>1.44***</td>
</tr>
<tr>
<td>Fruit mass (g)</td>
<td>7.45*</td>
<td>59.07***</td>
<td>0.11**</td>
</tr>
<tr>
<td>Fruit diameter (cm)</td>
<td>8.40**</td>
<td>61.50***</td>
<td>0.20**</td>
</tr>
<tr>
<td>Fruit volume (cm³)</td>
<td>34.36***</td>
<td>60.84***</td>
<td>0.67**</td>
</tr>
</tbody>
</table>

ns: no significant *: significant at 5% **: significant at 1% ***: significant at 0.1% das: days after sowing

4.2 Variability inside each family:
Coefficient of variation (CV) of each trait was evaluated according to families (Table 2). These coefficients of variation were inferior to 25% in parental and F₁ families for all traits. The individuals of these parental and F₁ population were homogeneous. However, except fruit maturity period, the coefficient of variation was higher than 25% for fruit characters in F₂, BC₁, and BC₁w families. There is a large heterogeneity inside these F₂ and BC₁ generations.

4.3 Variability between families: Genetic variability between families had been examined and results details had been consigned on table 3.

4.3.1 Fruit maturity period: fruit maturity period varied significantly (\( P < 0.001 \)) between families on the both locations (table 3). Bebu cultivar was precocious while WSSS cultivar was late. Bebu's fruits reached maturity stage 80 days after sowing while those of WSSS can be harvested 104 to 108 days after sowing according to location. The fruit maturity period of hybrid F₁, BC₁, and F₂ were intermediate to those of parents. In addition, crossway had not significant effect on the fruit maturity period of F₁ and F₂. Therefore, fruits of F₁w and F₁b families can be harvested respectively 92 and 96 days after sowing. Average of F₁ families corresponded to geometric average from both parent. Semi-dominance effect exists between early and late fruit maturity. Fruits from F₂w and F₂b families can be harvested earlier than F₁ families since fruit maturity were produced around 90 days after sowing. However, hybrid BC₁ fruit maturity period depends on cross direction. There is maternal effect for this generation because BC₁ fruit maturity, were near to that one which is used as female plant.
during the cross. So, fruits of BC<sub>1h</sub> family can be harvested 10 days after those of *Bebu* and around 21 days before WSS. Fruits of BC<sub>1w</sub> family can be harvested 10 days before those of WSS and around 14 days after *Bebu*.

### Table 2: Coefficients of variation of each fruit character on the both experiment

<table>
<thead>
<tr>
<th>Traits</th>
<th>Locations</th>
<th>Bebu</th>
<th>BC&lt;sub&gt;1h&lt;/sub&gt;</th>
<th>F&lt;sub&gt;1h&lt;/sub&gt;</th>
<th>F&lt;sub&gt;1w&lt;/sub&gt;</th>
<th>F&lt;sub&gt;2b&lt;/sub&gt;</th>
<th>F&lt;sub&gt;2w&lt;/sub&gt;</th>
<th>BC&lt;sub&gt;1w&lt;/sub&gt;</th>
<th>WSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit maturity period (das)</td>
<td>Abidjan</td>
<td>4.48</td>
<td>6.28</td>
<td>3.11</td>
<td>4.62</td>
<td>12.15</td>
<td>11.82</td>
<td>7.00</td>
<td>4.63</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>4.65</td>
<td>7.02</td>
<td>2.42</td>
<td>4.69</td>
<td>9.33</td>
<td>8.92</td>
<td>7.69</td>
<td>0.45</td>
</tr>
<tr>
<td>Fruit number per plant</td>
<td>Abidjan</td>
<td>20.44</td>
<td>72.48</td>
<td>22.12</td>
<td>22.35</td>
<td>44.49</td>
<td>47.22</td>
<td>80.07</td>
<td>22.93</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>19.59</td>
<td>64.85</td>
<td>24.54</td>
<td>22.47</td>
<td>29.31</td>
<td>48.42</td>
<td>70.29</td>
<td>24.83</td>
</tr>
<tr>
<td>Fruit mass (g)</td>
<td>Abidjan</td>
<td>15.36</td>
<td>20.07</td>
<td>23.36</td>
<td>9.20</td>
<td>31.68</td>
<td>37.49</td>
<td>24.81</td>
<td>10.45</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>17.95</td>
<td>29.72</td>
<td>22.52</td>
<td>9.00</td>
<td>40.75</td>
<td>35.57</td>
<td>28.65</td>
<td>17.18</td>
</tr>
<tr>
<td>Fruit diameter (cm)</td>
<td>Abidjan</td>
<td>4.94</td>
<td>30.14</td>
<td>7.50</td>
<td>4.20</td>
<td>30.06</td>
<td>32.82</td>
<td>28.97</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>5.92</td>
<td>29.58</td>
<td>7.68</td>
<td>6.02</td>
<td>34.00</td>
<td>31.60</td>
<td>28.71</td>
<td>5.33</td>
</tr>
<tr>
<td>Fruit volume (cm&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>Abidjan</td>
<td>9.78</td>
<td>29.63</td>
<td>21.64</td>
<td>22.96</td>
<td>31.58</td>
<td>38.89</td>
<td>25.60</td>
<td>7.65</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>17.25</td>
<td>29.73</td>
<td>19.88</td>
<td>16.73</td>
<td>40.68</td>
<td>34.75</td>
<td>25.28</td>
<td>17.17</td>
</tr>
</tbody>
</table>

**Notes:** DAS = days after sowing, WSS = *W. Sessilis*, BC<sub>1h</sub>: F<sub>1h</sub> × *Bebu*, BC<sub>1w</sub>: F<sub>1w</sub> × *Bebu*, BC<sub>2h</sub>: F<sub>2h</sub> × *Bebu*, BC<sub>2w</sub>: F<sub>2w</sub> × *Bebu*, BC<sub>1h</sub>: BC<sub>1w</sub>: back cross on *W. Sessilis*, BC<sub>2h</sub>: BC<sub>2w</sub>: back cross on *Bebu*, F<sub>1h</sub>: F<sub>1w</sub>: F<sub>2h</sub>: F<sub>2w</sub>: F<sub>1h</sub> from *W. Sessilis* crossed with *Bebu*, F<sub>1w</sub>: F<sub>2w</sub>: F<sub>1w</sub> from *W. Sessilis* crossed with *Bebu*, F<sub>2w</sub>: F<sub>2w</sub> from self-pollination of F<sub>1w</sub> individuals, F<sub>2w</sub>: F<sub>2w</sub> from self-pollination of F<sub>1w</sub> individuals.

#### 4.3.2 Fruit number per plant:

Fruit number from each plant differed significantly among families at both sites (*P* < 0.001). WSS plant yielded more fruits than plants of other families with approximately 11 fruits per plant (table 3). *Bebu* and BC<sub>1</sub> plants yielded less fruits with respectively 3 to 5 fruits per plant. The number of fruits produced by F<sub>1</sub> and F<sub>2</sub> plants was intermediate to those of parents. F<sub>1</sub> plants yielded 6 to 7 fruits per plant according habit. This average of F<sub>1</sub> families corresponded to geometric average from both parent. So, semi-dominance effect exists between more and less fruit characters. According to environmental site, each F<sub>2</sub> plant yields on the average 7 to 9 fruits. Cross-way had not significantly effect on the number of fruits yielded by hybrids F<sub>1</sub>, BC<sub>1</sub> and F<sub>2</sub>.

#### 4.3.3 Fruit mass:

Fruit mass varied significantly (*P* < 0.001) between families in the both locations (table 3). Fruits of *Bebu* cultivar were heavier than other families’ fruits with magnitude slightly superior to 1100 g. Fruits of *W. Sessilis* cultivar were higher and weighted less than 750g. Heterosis effect was observed for this trait because F<sub>1</sub> fruit mass magnitude was higher than *Bebu*, the best parent for this character. Fruit mass of F<sub>1</sub> weighted more than 1200 g against 1100 g for *Bebu*’s fruits. Cross-way had no effect on fruit mass yielded in F<sub>1</sub> because fruits yielded on F<sub>1w</sub> and F<sub>1h</sub> families had statistically the same mass average. Fruit mass average from BC<sub>1</sub> and F<sub>2</sub> was intermediate to parental fruit mass average. There is maternal effect for this generation because fruit mass of BC<sub>1</sub> and F<sub>2</sub> families was closest to female plant during the cross. Thus, fruits from BC<sub>1h</sub> and F<sub>1h</sub> families on the one hand and BC<sub>1w</sub> and F<sub>2w</sub> families on the other hand, had approximately the same mass and their fruit mass was closest to respectively *Bebu* and *W. Sessilis*. According to habit, fruits from BC<sub>1h</sub> and F<sub>1h</sub> families weighted between 950 to 1000 g (next to 1100 g from *Bebu*) while those from BC<sub>1w</sub> and F<sub>2w</sub> families varied from 816 to 903 g (next to 750 g from *W. Sessilis*). Cross-way had no significant effect on fruit mass of F<sub>1</sub> hybrids but it influenced BC<sub>1</sub> and F<sub>2</sub> fruit mass with high magnitude observed when *Bebu* was considered as maternal plant during crosses.

#### 4.3.4 Fruit size:

Various fruit size was observed (*P* < 0.001) between families on both locations (table 3). *Bebu* plants yielded big fruits with approximately 13 cm and 1100 cm<sup>3</sup> for respectively diameter and volume traits. In contrast, *W. Sessilis* plants yielded small fruits with...
respectively a diameter and a volume close to 11 cm and 730 cm³. Heterosis effect was observed for fruit size because fruits of F₁ were bigger than Bebu and WSS fruits (Fig. 1). F₁ plants yielded big fruits with volume varying from 1173.44 to 1358.11 cm³. Cross direction had no effect on fruit size in F₁. Fruits yielded from BC₁ and F₂ families had intermediate mean size. Cross direction influenced significantly fruit size on these families. Fruits from BC₁ were bigger during the backcross, when Bebu cultivar was used as female (BC₁<sub>f</sub>) and smaller when WSS was used as female (BC₁<sub>₁</sub>) (Figure 2). Likewise, fruits from F₂ were bigger when before self pollination in F₁ families, Bebu cultivar had been used as female (F₂<sub>_f</sub>) and smaller when WSS had been used as female (F₂<sub>_₁</sub>) (Fig. 3). These results showed existence of maternal effect in these generations for these traits.

4.4 Genetic effect

4.4.1 Heterosis effect: Percentage heterosis according to mid-parent average (MPH) is negative for number of fruits and positive for all other traits (Table 4). Percentage heterosis according to better parent average (BPH) was negative for fruit maturity and number. The F₁ hybrid had 8.75 to 13.41 % less fruit maturity and 37.48 to 39.55% less fruit number per plant than WSS, the best parent for these characters. However, BHP was positive for the traits relative to fruit size. The fruit diameter of the F₁ hybrid was more 17.26 to 23.40 % than Bebu one. Concerning the fruit mass, it was more 65.81 to 74.74 % than Bebu, the best parent for these fruit size traits.
**Figure 1**: Parent (Bebu and WSS) and F₁ hybrid fruits illustrating heterosis in *C. lanatus* cultivars

**Figure 2**: Fruits yielded on BC₁w (left) and BC₁b (right) families

**Figure 3**: Fruits yielded on F₂w (left) and F₂b (right) families

**Figure 4**: Fruits variability yielded on F₂
Table 3: Variability between families according characters

<table>
<thead>
<tr>
<th>Traits</th>
<th>locations</th>
<th>Bebu</th>
<th>BC1b</th>
<th>F1b</th>
<th>F1w</th>
<th>F2b</th>
<th>F2w</th>
<th>BC1w</th>
<th>WSS</th>
<th>Statistical test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit maturity period (das)</td>
<td>Abidjan</td>
<td>78.04±</td>
<td>87.45±</td>
<td>92.52±</td>
<td>95.13±</td>
<td>90.14±</td>
<td>90.79±</td>
<td>103.70±</td>
<td>104.25±</td>
<td>124.4</td>
</tr>
<tr>
<td></td>
<td>Manfla</td>
<td>79.91±</td>
<td>88.56±</td>
<td>93.08±</td>
<td>95.54±</td>
<td>90.23±</td>
<td>91.08±</td>
<td>105.78±</td>
<td>107.50±</td>
<td>32.53</td>
</tr>
<tr>
<td>Fruit number per plant</td>
<td>Abidjan</td>
<td>3.1±</td>
<td>3.74±</td>
<td>6.41±</td>
<td>6.44±</td>
<td>7.51±</td>
<td>8.47±</td>
<td>4.00±</td>
<td>4.62±</td>
<td>22.37</td>
</tr>
<tr>
<td></td>
<td>Manfla</td>
<td>3.35±</td>
<td>3.81±</td>
<td>6.71±</td>
<td>6.78±</td>
<td>8.19±</td>
<td>8.89±</td>
<td>4.30±</td>
<td>4.83±</td>
<td>45.67</td>
</tr>
<tr>
<td>Fruit mass (g)</td>
<td>Abidjan</td>
<td>1123.03±</td>
<td>996.12±</td>
<td>1258.74±</td>
<td>1208.97±</td>
<td>956.63±</td>
<td>885.87±</td>
<td>816.23±</td>
<td>729.11±</td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td>Manfla</td>
<td>1146.6±</td>
<td>998.90±</td>
<td>1275.60±</td>
<td>1243.40±</td>
<td>973.92±</td>
<td>902.61±</td>
<td>834.50±</td>
<td>744.87±</td>
<td>28.9</td>
</tr>
<tr>
<td>Fruit diameter (cm)</td>
<td>Abidjan</td>
<td>12.80±</td>
<td>12.27±</td>
<td>13.13±</td>
<td>12.99±</td>
<td>11.99±</td>
<td>11.46±</td>
<td>11.18±</td>
<td>10.64±</td>
<td>29.61</td>
</tr>
<tr>
<td></td>
<td>Manfla</td>
<td>13.01±</td>
<td>12.33±</td>
<td>13.13±</td>
<td>13.04±</td>
<td>12.12±</td>
<td>11.85±</td>
<td>11.53±</td>
<td>11.12±</td>
<td>35.00</td>
</tr>
<tr>
<td>Fruit volume (cm³)</td>
<td>Abidjan</td>
<td>1054.71±</td>
<td>972.73±</td>
<td>1187.61±</td>
<td>1173.44±</td>
<td>932.41±</td>
<td>848.71±</td>
<td>790.17±</td>
<td>689.81±</td>
<td>30.32</td>
</tr>
<tr>
<td></td>
<td>Manfla</td>
<td>1214.93±</td>
<td>1079.16±</td>
<td>1358.11±</td>
<td>1346.69±</td>
<td>1023.81±</td>
<td>871.84±</td>
<td>871.84±</td>
<td>777.18±</td>
<td>32.91</td>
</tr>
</tbody>
</table>

Das: days after sowing, WSS: Welwè Small Seed, BC1a: back cross on WSS cultivar, BC1b: back cross on Bebu cultivar, F1b: F1 from Welwè × Bebu cross, F1w: F1 from Bebu × Welwè cross, F2s: F2 from self-pollination of F1w individuals, F2w: F2 from self-pollination of F1b individuals. *Equal letters correspond to statistically equal means, based upon one way of analysis of variance.
Table 4: Mean and Percentage heterosis according mid-parent (MPH) and better parent heterosis (BPH) for the studied fruit traits

<table>
<thead>
<tr>
<th>Families</th>
<th>Fruit maturity period</th>
<th>Fruit number per plant</th>
<th>Fruit mass</th>
<th>Fruit diameter</th>
<th>Fruit volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manfl</td>
<td>Abidjan</td>
<td>Manfl</td>
<td>Abidjan</td>
<td>Manfl</td>
</tr>
<tr>
<td>Bebu</td>
<td>79.91</td>
<td>78.04</td>
<td>3.35</td>
<td>3.1</td>
<td>1146.6</td>
</tr>
<tr>
<td>W3S</td>
<td>107.5</td>
<td>104.25</td>
<td>11.1</td>
<td>10.3</td>
<td>744.87</td>
</tr>
<tr>
<td>Bebu and W3S</td>
<td>92.70</td>
<td>91.14</td>
<td>7.22</td>
<td>6.7</td>
<td>945.73</td>
</tr>
<tr>
<td>F1w</td>
<td></td>
<td></td>
<td>95.54</td>
<td>95.13</td>
<td>6.78</td>
</tr>
<tr>
<td>MPH (%)</td>
<td>01.96</td>
<td>04.37</td>
<td>-06.16</td>
<td>-03.90</td>
<td>31.474</td>
</tr>
<tr>
<td>BPH (%)</td>
<td>-11.12</td>
<td>-08.74</td>
<td>-38.92</td>
<td>-37.48</td>
<td>66.93</td>
</tr>
<tr>
<td>F1h</td>
<td>93.08</td>
<td>92.52</td>
<td>6.71</td>
<td>6.41</td>
<td>1275.69</td>
</tr>
<tr>
<td>MPH (%)</td>
<td>0.40</td>
<td>1.51</td>
<td>-7.13</td>
<td>-4.33</td>
<td>34.89</td>
</tr>
<tr>
<td>BPH (%)</td>
<td>-13.41</td>
<td>-11.25</td>
<td>-39.55</td>
<td>-37.78</td>
<td>71.26</td>
</tr>
</tbody>
</table>

W3S: Wlêwlê Small Seed, F1w: F1 from Wlêwlê♀ × Bebu♂ cross, F1h: F1 from Bebu♀ × Wlêwlê♂ cross, MPH: percentage heterosis according mid-parent, BPH: percentage heterosis according better parent.

Percentage heterosis according mid-parent (MPH) and better parent heterosis (BPH) was calculated using the formula by Gusmini and Wehener (2004) as follows.

$$MPH = \frac{(MF1 - MP) \times 100}{MP}$$

$$BPH = \frac{(MF1 - BP) \times 100}{BP}$$

Where MF1: mean of F1 family, MP: mean of mid-parent (two parents) and BP: mean of best parent.
4.5 Phenotypic variance: Phenotypic variances varied according to locations, families and characters (Table 5). Phenotypic variances were higher in Manfla than Abidjan for parents, F₁ and BC₁ families for all fruit traits. In contrast for the F₂ family, this parameter was higher on Abidjan location than Manfla one. This indicated that parents, F₁ and BC₁ were more heterogeneous on Manfla location than Abidjan while F₂ family was more heterogeneous in Abidjan location than Manfla. Values of phenotypic variances were also high for fruit mass and volume for all families on the both locations. Fruits recorded on the both locations were heterogeneous. Among families, parents and F₁ hybrids had low phenotypic variances while F₂ and BC₁ had high phenotypic variances. Parents and F₁ hybrids were more homogeneous than F₂ and BC₁, thus indicating a great phenotypic variability of F₂ (Fig. 3 and 4) and BC₁ (Figure 2) in our experiment. Among parent, fruit were more heterogeneous in Bebu than W’3’3 while fruit number and days to harvest were more homogenous in Bebu than W’3’3.

4.6 Variance, heritability and genetic gain estimation: the genotypic σ², phenotypicσ²p, environmental σ²e and additive σ²A variances, broad (H²) and narrow (h²) sense of heritability and genetic gain of characters were grouped in table 6. The genotypic, phenotypic and additive variance was higher than the environmental variance in the majority of the families at both locations. This involved high broad (H² ≥ 0,50) and narrow-sense heritability (h² ≥ 0,50) for all traits. More than 50 % of variation observed between individuals and families were imputable to genetic effect. In addition, fruit number had higher heritability in Manfla location than Abidjan location while all other characters had higher heritability in Abidjan location than Manfla. Genetic gain was high for fruit mass and volume and for days to harvest.

Table 5: Phenotypic variances by generation for C. lanatus cultivars families tested for days to harvest and fruit characters

<table>
<thead>
<tr>
<th>Location</th>
<th>Population</th>
<th>Fruit maturity period (das)</th>
<th>Fruit number per plant</th>
<th>Fruit mass (g)</th>
<th>Fruit diameter (cm)</th>
<th>Fruit volume(cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manfla (Abidjan)</td>
<td>Bebu</td>
<td>12.90 (13.04)</td>
<td>0.69 (0.52)</td>
<td>38793.86 (13775.05)</td>
<td>0.52 (0.25)</td>
<td>43506.88 (5518.53)</td>
</tr>
<tr>
<td>W’3’3</td>
<td>25.00 (21.78)</td>
<td>4.73 (4.43)</td>
<td>17874.33 (12547.15)</td>
<td>0.43 (0.28)</td>
<td>17980.46 (4553.84)</td>
<td></td>
</tr>
<tr>
<td>BC₁₀</td>
<td>38.64 (33.79)</td>
<td>8.10 (7.35)</td>
<td>88153.81 (83856.06)</td>
<td>1.40 (1.55)</td>
<td>102922.43 (83095.03)</td>
<td></td>
</tr>
<tr>
<td>BC₁₀w</td>
<td>66.11 (52.64)</td>
<td>11.52 (13.69)</td>
<td>57151.52 (41022.69)</td>
<td>1.01 (1.00)</td>
<td>78578.21 (70922.19)</td>
<td></td>
</tr>
<tr>
<td>F₂₀</td>
<td>89.05 (115.10)</td>
<td>18.53 (16.00)</td>
<td>103075.51 (110295.45)</td>
<td>1.89 (2.16)</td>
<td>106082.74 (108931.35)</td>
<td></td>
</tr>
<tr>
<td>F₁₀w</td>
<td>20.07 (19.32)</td>
<td>2.32 (2.07)</td>
<td>13251.43 (12365.89)</td>
<td>0.62 (0.30)</td>
<td>50737.84 (42621.22)</td>
<td></td>
</tr>
</tbody>
</table>

das: days after seeding, W’3’3: Wlew’k Small Seed, BC₁₀: back cross on W’3’3 cultivar, BC₁₀w: back cross on Bebu cultivar, F₁₀: F₁ from Wlew’k × Bebu, F₂₀: F₂ from self-pollination of F₁₀w individuals

4350
Table 6: Variance, heritability and genetic gain to selection estimates for families for each character

<table>
<thead>
<tr>
<th>Locations</th>
<th>Traits</th>
<th>Variances</th>
<th>heritability</th>
<th>genetic advance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\sigma_P^2$</td>
<td>$\sigma_E^2$</td>
<td>$\sigma_G^2$</td>
</tr>
<tr>
<td>Manfla</td>
<td>Fruit maturity period (days)</td>
<td>89.04 (115.10)</td>
<td>19.51 (18.37)</td>
<td>69.54 (96.73)</td>
</tr>
<tr>
<td></td>
<td>Fruit number per plant</td>
<td>18.53 (16.00)</td>
<td>2.51 (3.52)</td>
<td>17.21 (12.48)</td>
</tr>
<tr>
<td></td>
<td>Fruit mass (g)</td>
<td>103075.51 (110295.45)</td>
<td>20426.76 (12763.49)</td>
<td>82648.75 (97531.96)</td>
</tr>
<tr>
<td></td>
<td>Fruit diameter (cm)</td>
<td>1.89 (2.16)</td>
<td>0.55 (0.28)</td>
<td>1.38 (1.88)</td>
</tr>
<tr>
<td></td>
<td>Fruit volume (cm³)</td>
<td>106082.74 (108931.35)</td>
<td>40740.76 (39078.71)</td>
<td>65341.98 (69852.65)</td>
</tr>
</tbody>
</table>

Phenotypic ($\sigma_P^2$), environmental ($\sigma_E^2$), genotypic ($\sigma_G^2$), additive ($\sigma_A^2$) variance effects, heritability and genetic advance of each character were estimated from generation variances as follows (Warner, 1952; Wright, 1968): $\sigma_P^2 = \sigma_E^2 + \sigma_G^2 + \sigma_A^2$, $\sigma_E^2 = \frac{\sigma_A^2}{k}$,

$k = selection differential which varied with selection intensity (K = 2.063, 1,755 and 1,555 respectively at 5%, 10% or 15% intensity on normal distribution table (Nanson, 1967).
5 DISCUSSION

Cross direction. Variability of segregating offspring, heritability and genetic gain of days to harvest and fruits characters were evaluated in two cultivars of C. lanatus. Among results, location effect on offspring performance was observed. Offspring performances were higher when they were grown in savannah (Manfla) than forest (Abidjan). Savannah could be more favourable for C. lanatus cultivars and their offsprings than forest. This result may be related to rainfall difference between both locations. In fact, rain was regular and abundant in forest than savannah. These abundant rains involved high humidity that was mentioned to be unfavourable to Citrullus lanatus crop as observed by Wehner (2008b). Cross direction did not affect F$_1$ performance but it affected significantly BC$_1$ and F$_2$ fruit size where maternal effect had been observed. Therefore, fruits from F$_{2m}$ and BC$_{1b}$ were big as fruits yielded by Bebu while those from F$_{2w}$ and BC$_{1w}$ were small as their WSS maternal parents. These results suggested cross direction importance in C. lanatus genetic breeding. Variability in qualitative and quantitative character expression according to cross direction had already been observed in C. lanatus (Gusmini et al., 2004). Variability inside families throughout coefficient of variation showed homogeneity inside parental and F$_1$ families. Individuals of these families were practically similar whatever characters and cross direction. Fruits were yielded at the same period and fruit size and number were similar in these families. This result could be probably bound to multiple self-fecundations, which had increased homozygosity race involving pure genotype in these families according to Mendel laws (Vedele et Loudet, 2001). Gusmini et Wehner (2008) had also mentioned possibility to observe hybrid homogeneity in C. lanatus after hybridization. However, high phenotypic variability had been observed inside BC$_1$ and particularly F$_2$. This variability could justify segregation characters produced in parents and could show existence of phenotypic divergence between them. These phenotypic divergences observed in parents were appeared in their offsprings according to Mendel laws (characters disjunction). Difference between BC$_1$ and F$_2$ families was the evidence that some individuals could be identical to one of both parents while others were recombinant showing at different proportions both parents characters (Vedele et Loudet, 2001). Gusmini et al. (2004) had also observed segregation characters during crosses between two C. lanatus cultivars: Charleston Gray 3 PI 560006 and Calbourn Gray 3PI 490383w. These segregation characters justified also high variability between families, which showed difference between parents and their offspring on the one hand, and between offspring on the other hand. For many characters, intermediate forms were obtained. Fulks et al. (1979) and Zamir (2001) had also observed intermediate form during crosses between C. lanatus and his ancestor C. colocynthis. However, heterosis effects were observed for fruit size (fruit mass, diameter and volume). Means of F$_1$ families were superior to those of parents for these characters involving high percentage heterosis according to mid-parent and better parent. This higher level of heterosis arises from the fact that both cultivars (Bebu and F3S3) were genetically different (Adjoumani et al., 2012). Cross breeding tends to cause more gene pairs to be heterozygous (the offspring receives different genes from its parents). This arises from the fact that different offsprings tend to have high frequencies of different genes. Consequently, more heterozygocity and heterosis were produced. Heterozygocity and heterosis will result in better performance if there is non-additive gene action (dominance and epistasis) and the recessive allele results in inferior performance (AVRDC, 2007). Other researches such as Brar and Sidhu (1977), Brar and Sukhija (1977) and Gusmini and Wehner (2005), had mentioned high heterosis phenomenon in C. lanatus for different agronomic traits. This can contribute to increase production in some cultivars. In addition, maternal effects have been found in back cross families. Phenotypes of Back
cross offsprings were influenced by that of its mother independently of the direct effects of the genes that it inherits. Therefore, back cross realized on W’S’S offsprings were similar to W’S’S individuals and back cross on Bebu offspring were similar to Bebu individuals. Phenotypic similarity between these hybrids and their maternal parent suggest existence of more number of parental genes than F1 hybrid genes during back cross in characters expression evaluated. Maternal effects may be more caused by genes inherited from mother than the environment effect in the experiences (Wilson et al., 2004). Previous studies have demonstrated maternal effect in C. lanatus (Henderson et al., 1998). Heritability varied according to environment and parameters as had revealed by Bodzon (2004), Akbar et al. (2008) and Waqar-Ul-Haq et al. (2008). All characters evaluated, had shown high broad and narrow-sense heritability whatever experimental environment. High heritability indicates less environmental influence in the observed variation because genetic and additive variances were largely higher to environmental variances (Eid, 2009; Ogbonna and Obi, 2010). It also indicates the extent of genetic control for expression of a particular trait and the reliability of phenotype in predicting its breeding value (Chopra, 2000; Tazeen et al., 2009). Here, more than 50 % of variations observed between individuals and families were related to genetic effect or variability. All of these characters must be exactly transmitted from a generation to another one whatever environmental conditions. This high heritability confirmed agronomical and morphological differences between selected parents (Bebu and W’S’S) as had mentioned by Singh and Westermann, 2002. In addition, high heritability went with high selection gain for fruit size (fruit mass and volume) on the both site. Similar observation had been mentioned by Gusmini (2005) and Kumar (2009) on fruit size and number. In breeding program, selections must be done according to these characters to sample individuals possessing big fruits.

6 REFERENCES


Ogbonna PE and Obi IU: 2010. Variability of yield and yield components in “Egusi”
melon. *African Crop Science Journal* 18: 107-113