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Full Length Research Paper

Correlation and heritability analysis in breeding of camu-camu [*Myrciaria dubia* (Kunth) McVaugh]

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Between 2002 and 2011 in Peru and Brazil, there have been made studies of correlation and heritability in search of tools for genetic improvement of camu-camu. This work is intended to systematize successful information aiming at the consolidation of criteria for the selection of higher plants. The author evaluated basic collections, progenies and clones existing in experimental centers belonging to INIA (Instituto Nacional de Innovación Agraria), IIAP (Instituto de Investigaciones de la Amazonia Peruana) and INPA (Instituto Nacional de Pesquisas da Amazonia). The length of petiole (LP) has an intermediate heritability (in the broad sense) of $h^2g = 0.42$ and correlation coefficients of $r^2 = 0.37$ for fruit yield and $r^2 = 0.54$ for fruit weight. Basal branch number (NRB) also shows levels of heritability average (in the strict sense): $h^2a = 0.45$ and $h^2g = 0.33$ in the broad sense. NRB in turn significantly correlated with fruit yield (FY): $r^2 = 0.43$; fruit weight (FW): $r^2 = 0.38$ and ascorbic acid (AA): $r^2 = -0.30$. The values of pH and soluble solids (degrees Brix) of the pulp showed a high correlation with AA ($r^2 = 0.85$ and $r^2 = 0.94$, respectively). It is emphasized that the parameters, number of basal branches, petiole length and fruit weight that present a relatively high correlation with fruit yield also have an intermediate level of heritability, which qualifies them as important tools for the selection of superior plants of camu-camu.

Key words: Camu-camu, correlation, heritability, breeding.

INTRODUCTION

Evaluation of genetic material accumulates abundant information regarding the genetic and environmental response expressed in plant. In the case of camu-camu, genetic improvement work has been going on for over three decades in two Amazonian areas of Peru and Brazil. Among many other parameters, in several studies, correlation and heritability indexes were calculated. In 13 progenies from the areas of Roraima, Rondonia and Amazonas (Brazil), Abtibol (2002) found negative correlation between the parameters, pluvial precipitation and flowering. Likewise, positive correlation was found between the parameters, vitamin C and pH versus soluble solids; diameter of fruit versus length of fruit; fruit yield, weight of pulp and seed weight versus number of fruits. In 12 progenies coming from Uatumã River (Brazil), positive correlation was found between leaf diameter versus leaf length; yield of fruit versus weight of pulp; yield of fruit versus weight of seed; weight of pulp versus weight of seed; weight of pulp versus number of fruits; weight of seeds versus number of fruits; pH versus number of seeds per fruit. Negative correlation was found between vitamin C content and number of seeds per fruit (Malveira, 2002). INIA and IIAP (Peru) have conducted several heritability studies with clones and progenies. Relatively high levels of heritability were detected for number of basal branches and petiole length Pinedo, P.M. et al. (2011). In this paper, the results of trials of correlation and heritability have been analyzed, in order to help the selection and improvement of camu-camu.

METHODOLOGY

Studies were performed in germplasm evaluation plots in three government agencies: National Institute for Agrarian Innovation (INIA), Peruvian Amazonian Research Institute (IIAP) and Instituto Nacional de Pesquisas da Amazonia (INPA). The basic collections

and genetic testing were installed both in highland areas and in floodable areas. In the basic collections, the arrangement of the plants was not adjusted to a statistical model and were installed both in rows as in randomized way, with variable number of plants (10 to 20) per family. Genetic tests are comparative studies of progenies and clones with 1 to 9 plants per experimental unit, arranged in randomized complete block design with 3 to 4 repetitions. The two groups of clones evaluated were propagated by woody cuttings and air layering.

The studies incorporated in this report are 70% conducted in IIAP by the author on genetic material from Loreto-Peru and 30% are studies conducted in Brazil (Uatumã River and other rivers)

The main parameters evaluated were: plant height, plant diameter, number of basal branches, basal stem diameter, leaf length, petiole length, yield of fruit, number of flowers, number of fruit harvested, number of seeds, weight of fruits, brix grades, pH and content of ascorbic acid. The correlation analysis was done using SPSS-15 and indices of heritability were calculated using SELEGEN-REML/BLUP Program (Genetics Selecao System and Computerized Estatistico) (Vilela, 2007).

RESULTS

Table 1 shows the results of correlation analysis of vegetative and reproductive parameters, and chemicals with three parameters important for their commercial value: fruit yield, fruit weight and ascorbic acid content.

Among the parameters of reproductive organs remarkable for its high correlation with the yield of fruit, the followings keys are considered: average number of seeds and average weight of fruit with $r^2 = 0.35$ and $r^2 = 0.47$, respectively (Paredes, 2011).

Of the four calculations of correlation made between yield fruit and fruit weight, two are propagated by sexual seed and the other two are groups of clones (propagated by asexual methods). In the first two (Pinedo, et al. (2009); Malveira, 2002), which collections were by sexual propagation, negative values of $r^2 = -0.294$ and $r^2 = -0.334$ were found. These negative correlation values are corroborated by the indices which are also negative between fruit yield versus fruit diameter and length of fruit (Malveira, 2002; Abtibol, 2002). However, in the two clonal collections, correlation values were both positive ($r^2 = 0.161$ and $r^2 = 0.472$). Obviously, the selection level of the materials in the case of clones was much higher compared to the sexually propagated collections. The selection process tends to exclude plants with small fruits, which could explain these conflicting results between materials with different levels of selection. Regardless of the fruit weight, there is a very clear correlation between highly positive fruit yield and number of harvested fruits, consistently found in two studies Pinedo, et al. (2011); Wall, 2011), with very high correlation coefficients of $r^2 = 0.933$, $r^2 = 0.992$ and $r^2 = 0.947$, respectively.

Also interesting is the finding of positive correlation of intermediate value between fruit yield and ascorbic acid ($r^2 = 0.259$) (Paredes, 2011), and the correlation of fruit yield with weight of fruit. In this case, we would have linking of high commercial interest parameters such as fruit yield, ascorbic acid content and average weight of fruit.

Table 1 also shows that the parameters total basal diameter, width of leaf and petiole length kept a relatively high level of correlation with content of ascorbic acid, having values of $r^2 = 0.207$; $r^2 = 0.464$ and $r^2 = 0.521$, respectively Pinedo, et al. (2011). Regarding reproductive organs, total number of seeds shows positive correlation with content of ascorbic acid ($r^2 = 0.377$) (Abtibol, 2002) and negative for the same correlation ($r^2 = - 0640$) (Malveira, 2002), indicating once again contradictory results in different genetic materials. The content of ascorbic acid in Table 1 is positively correlated with fruit weight ($r^2 = 0.259$) (Paredes, 2011). With respect to chemical parameters, Abtibol (2002) found very high levels of correlation of degrees brix ($r^2 = 0.940$) and pH ($r^2 = 0.851$) versus the level of ascorbic acid.

In Table 2, we present a summary of heritability analysis performed between 2006 and 2011 on two groups of 5 and 37 clones and a group of 108 sexually propagated progenies. So heritability rates for the clones were calculated in the broad sense ($h^2g = H^2$) and the progenies in the strict sense (or additive genetic variance).

DISCUSSION

The important parameters based on their positive correlation with fruit yield are considered as priority; they are: number of seeds ($r^2 = 0.352$) (Pinedo, et al. (2011) and weight of fruit ($r^2 = 0.472$) (Paredes, 2011). However, for weight of fruit, negative values of correlation were obtained: $r^2 = -0294$ (Pinedo, 2007) and $r^2 = -0334$ (Malveira, 2002). These contradictory results could be due to the propagation method (sexual for progenies and vegetative for clones) and because the genetic material tested comes from geographically distant populations.

Vilela (2002) proposes a classification for heritability in strict sense (h^2a) as follows: Low = $0.01 \leq h^2a \leq 0.15$; medium or moderate = $0.15 < h^2a < 0.50$ and high = $h^2a > 0.50$. According to this classification, levels of heritability for all parameters evaluated in this study did not reach level high. The parameters with higher levels of heritability are: number of basal branches (h2a = 0.450) and petiole length ($h^2g = 0.425$), both classified as mild or moderate level. Also the interesting parameters fruit yield and fruit weight present moderate levels of heritability ($h^2g = 0.264$ and 0.287, respectively) (Pinedo, et al. (2011).

The parameters with a remarkable correlation with fruit yield, and with relatively high heritability are: number of basal branches, length of petiole and weight of fruit. However, for the case of the parameter fruit weight, the correlation may be positive or negative. The parameter, petiole length also has a great potential for selection of fruits high weight by its good correlation and heritability.

Table 1. Summary of correlations with three main parameters of the camu-camu.

Parameter	Correlation coefficient (r^2)		
	Fruit yield	**Fruit weight**	**Ascorbic acid**
Parameters of the plants and the vegetative organs (stem and leaf)			
Plant height	0.142(*) Pinedo et al.(2011) 0.62(**) Oliva (2002)	0.001 Pinedo et al. (2011)	
Crown diameter	0.247(**) Pinedo et al.(2011) 0.73 (**) Oliva (2002)	0.031 Pinedo et al.(2011)	
Number of basal branches	-0.035 Pinedo et al. (2011) 0.430 Pinedo (2010)	0.063 Pinedo et al. (2011) 0.385 Pinedo (2010) 0.171(*) Pinedo (2010)	-0.30 Pinedo (2010) -0.013 Pinedo (2010)
Average basal diameter	-0.035 Pinedo et al. (2011) 0.430 Pinedo (2010) -0.31 Pinedo (2010)	0.018 Pinedo (2010) 0.171(*) Pinedo (2010)	0.243 Pinedo (2010) 0.107 Pinedo (2010)
Total basal diameter	0.309(**) Pinedo (2010)	0.309(**) Pinedo (2010)	0.207(*) Paredes (2011)
Leaf length	0.020 Pinedo (2010) 0.045 Pinedo (2010)	0.171 Pinedo (2010) -0.002 Pinedo (2010)	0.055 Pinedo (2010) 0.075 Pinedo (2010)
Leaf width	-0.110 Pinedo (2010) 0.031 Pinedo (2010)	0.073 Pinedo (2010) -0.054 Pinedo (2010)	0.088 Pinedo (2010) 0.464(**) Paredes (2011)
Petiole length	0.37 Pinedo (2010) 0.150 Pinedo (2010)	0.543 Pinedo (2010) -0.13 Pinedo (2010)	0.053 Pinedo (2010) 0.521(**) Paredes (2011)
Parameters of reproductive organs (flower and fruit)			
Fruit yield		-0.17 Paredes (2011) 0.161 Pinedo (2010) 0.472(**) Paredes (2011)	-0.047Pinedo (2010) 0.362 Malveira (2002) -0.265 Abtibol (2002) 0.228(**) Paredes (2011)
Number of flowers	0.059 Pinedo et al. (2011) 0.044 Pinedo (2010)	-0.17 Paredes (2011) 0.131 Pinedo (2010)	-0.032 Paredes (2011) 0.152 Paredes (2011)
Number of green fruits	0.179(*) Paredes (2011) -0.002 Paredes (2011) 0.981(**) Malveira (2002) 0.947(**) Paredes (2011)	-0.15 Paredes (2011) 0.053 Paredes (2011)	-0.066 Paredes (2011) 0.111 Paredes (2011) 0.274 Malveira (2002) -0.243 Abtibol (2002)
Total number of seeds	0.420(**) Pinedo et al.(2011) 0.347(**) Paredes (2011) -0.315 Abtibol (2002)	-0.118 Pinedo, et al. (2011) 0.647(**) Paredes (2011)	0.377 Abtibol (2002) 0.262(**) Pinedo et al. (2011) -0.64 Malveira (2002)
Average number of seeds	0.352(**) Paredes (2011)	0.663(**) Paredes (2011)	0.261(**) Paredes (2011)
Shell weight	0.357(**) Pinedo,et al.(2011)	-0.064 Pinedo, et al. (2011)	
Weight of pulp	0.296(**) Pinedo et al.(2011) 0.990(**) Malveira (2002)	0.047 Pinedo et al. (2011)	0.290 Malveira (2002)

Table 1. Continued.

Seed weight	0.318(**) Pinedo et al. (2011) 0.976(**) Malveira (2002) 0.990(**) Abtibol (2002)	-0.12 Pinedo, et al. (2011)	0.366 Malveira (2002) 0.255 Abtibol (2002)
Fruit diameter	-0.334 Malveira (2002) -0.453 Abtibol (2002)		-0.417 Malveira (2002) -0.302 Abtibol (2002)
Fruit length	-0.311 Malveira (2002) -0.433 Abtibol (2002)		-0.360 Malveira (2002) -0.299 Abtibol (2002)
Percentage of shell	0.393(**) Paredes (2011)	0.623(**) Paredes (2011)	0.123 Paredes (2011)
Percentage of seed	0.380(**) Paredes (2011)	0.646(**) Paredes (2011)	0.197(*) Paredes (2011)
Percentage of pulp	0.445(**) Paredes (2011)	0.641(**) Paredes (2011)	0.208(*) Paredes (2011)
Fruit weight	-0.294(**)Pinedo et al. (2011) 0.161 Pinedo (2010) 0.472(**) Paredes (2011) -0.334 Malveira (2002)		-0.032 Pinedo (2010) 0.259(**) Paredes (2011)
Parameters of chemical analysis of pulp			
Brix	0.064 Pinedo et al. (2011) -0.190 Malveira (2002) -0.339 Abtibol (2002)	-0.223(*) Pinedo et al.(2011)	0.149 Malveira (2002) 0.940(**) Abtibol (2002)
pH	-0.082 Pinedo et al. (2011) 0.320 Malveira (2002) -0.364 Abtibol (2002)	-0.006 Pinedo et al. (2011)	-0.200 Malveira (2002) 0.851(**) Abtibol (2002)
Ascorbic acid content	0.228(**) Paredes (2011)	0.259(**) Paredes (2011)	

The heritability of the character content of ascorbic acid was relatively low ($h^2g = 0.0025$) (Pinedo, 2010).

Marked differences were observed in the degree of heritability between progenies and clones. The values of: basal diameter, number of basal branches and height of plant for clones used to be smaller than that of progenies. This difference could be explained by the propagation method since the vegetative propagation could influence such parameters, unlike the sexual propagation in progenies that maintain a natural scheme less influenced by environmental factors.

The heritability of the character ascorbic acid was very low ($h^2g = 0.0025$) (Pinedo, 2010). This result confirms a significant influence of environmental factors on the ascorbic acid level of the pulp, which was observed by Yuyama et al. (2002), who for the same plant in its natural environment record very different values of ascorbic acid from one year to another in apparent correlation with the level of flooding of the river. The flooding of the river is associated with the level of sedimentation and this in turn affects soil nutrient levels. Pinedo et al. (2010) also found a significant difference between ascorbic acid levels by hour of harvest, which would be indicative of a correlation between evapotranspiration and content of the acid in the pulp.

Conclusions

The study showed a level of contradiction between the values of correlation and heritability according to the region of origin or method of propagation (depending progenies or clones), which makes difficult a comprehensive analysis of the observed results.

The main parameters correlated with greater consistency with fruit yield are height of plant, diameter of plant, number of basal branches, diameter basal, length of petiole, total number of seeds and fruit weight.

The parameters, petiole length, fruit yield, total number of seeds, degrees Brix and ascorbic acid showed intermediate level of correlation with fruit weight.

The content of ascorbic acid showed intermediate

Table 2. Levels of heritability (h2) for 14 paramaters of the camu-camu.

Parameter	h^2	Author	Trial	Type of heritability
Total basal diameter	0.161 ± 0.093	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
	0.240	Pinedo et al. (2011)	Comp. 108 clones	h^2a = in the strict sense
Average basal diameter	0.236 ± 0.113	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
	0.004 ± 0.040	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Number of basal branches	0.217 ± 0.108	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
	0.450(**)	Pinedo et al. (2011)	Comp. 108 clones	h^2a = in the strict sense
	0.334 ± 0.366	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Plant height	0.123 ± 0.081	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
	0.200	Pinedo et al. (2011)	Comp. 108 clones	h^2a = in the strict sense
Crown diameter	0.197 ± 0.103	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
	0.300(*)	Pinedo (2009)	Comp. 108 clones	h^2a = in the strict sense
Number of twigs	0.169 ± 0.096	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
Number of flowers	0.128 ± 0.083	Pinedo et al. (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
Number of fruits	0.171 ± 0.262	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Fruit weight	0.287 ± 0.339	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Fruit yield	0.264 ± 0.325	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Ascorbic acid	0.0025 ± 0.032	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
Leaf length	0.134 ± 0.231	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
	0.008 ± 0.021	Paredes (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
Leaf width	0.062 ± 0.158	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
	0.326 ± 0.133	Paredes (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense
Petiole length	0.425 ± 0.412	Pinedo (2010)	Comp. 5 clones	$h^2g = H^2$ in the broad sense
	0.008 ± 0.021	Paredes (2011)	Comp. 37 clones	$h^2g = H^2$ in the broad sense

correlation with number of basal branches, basal average diameter, leaf width, petiole length, yield of fruit, total number of seeds and weight of fruits. Degrees Brix and pH have achieved a high level of correlation with content of ascorbic acid.

Parameters, number of basal branches and petiole length showed higher level of heritability. In second term are considered: plant diameter, fruit weight and fruit yield.

The parameters that combine an interesting level of correlation with priority characters with an intermediate level of heritability are: number of basal branches (for progenies), petiole length (for clones) and weight of fruit (for clones). The parameter, petiole length could also serve for selection of fruits with high weight because it combines good levels of correlation and heritability. The parameter of high commercial interest, ascorbic acid content showed a very low level of heritability (h^2g = 0.0025) for five evaluated clones.

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