Sustainable Integrated Management of Whiteflies through Host Plant Resistance

PROGRESS REPORT
2001 – 2002

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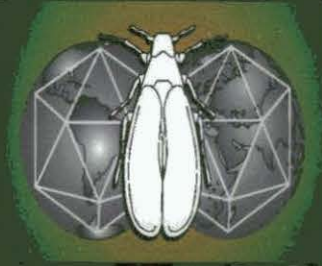
Funding Agency: MFAT, New Zealand

System-wide Programme on
Integrated Pest Management



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Collaborating Institutions: CIAT – Cali, Colombia
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Project Purpose

To reduce crop losses due to whitefly feeding damage and whitefly-transmitted viruses, and prevent further environmental degradation and food contamination due to excessive pesticide use, leading to a more productive and sustainable agricultural system.

Project Objectives

1. To identify and access exotic or novel genes and gene combinations which can contribute to germplasm enhancement for whitefly resistance in cassava.
2. To study the genetics of resistance and to map genes for whitefly resistance in cassava and develop molecular markers for their incorporation into improved African, Latin American and Asian germplasm.
3. To develop crop management options for reducing whitefly populations, and the transmission of whitefly transmitted viruses.

Project Summary

Whiteflies are major agricultural pests primarily in tropical and sub-tropical regions of the world. They are phloem feeders and cause direct damage (yield losses) by feeding on a wide range of plant hosts. In addition whiteflies are major vectors of numerous virus diseases, including the African Cassava Mosaic Disease complex (ACMD complex) that causes considerable yield losses in cassava in Africa.

Whiteflies are difficult to control and farmers in the tropics, including cassava producers, will react to whitefly attacks with the indiscriminate use of toxic pesticides to reduce whitefly populations. These excessive, ill-timed, costly applications of insecticide cocktails often result

in disturbing or destroying the existing ecological equilibrium between whiteflies and their natural enemies, as well as causing environmental pollution and threatening human health.

In traditional production systems, few options for controlling arthropod pests are available to resource limited producers. The combination of host plant resistance (HPR) combined with biological control offers farmers an effective, low costs, ecologically sound and user friendly alternative to costly, toxic pesticides. CIAT's whitefly IPM project, as part of the CGIAR System-wide Whitefly IPM Program, carries out basic and applied research in HPR and biological control as part of an integrated pest management strategy. The results of this research are presented in this Progress Report. Highlights of this research are described below.

- Studies on the identification of marker linked genes that could confer resistance to whiteflies in cassava have progressed considerably. In a cross between resistant (MEcu 72) and susceptible (MCol 2246) a batch of 343 cassava microsatellites (Simple Sequences Repeat, SSR) markers were used in the study. The oligonucleotide PCR primer pairs for the SSR markers were used to amplify the corresponding regions in the genome of both the parents and the progenie for the mapping population. The SSR markers displayed a high percentage of polymorphism, more than 60% or a total of 180 markers. This guarantees a high number of markers for the construction of a legitimate molecular genetic map. Screening of the mapping population with the polymorphic SSR is well advanced.
- Germplasm Evaluations: Nearly 3800 genotypes were field evaluated during 2001-2002 for whitefly (*A. socialis*) damage and populations. Genotypes originated from the CIAT cassava germplasm bank (2117 accessions) and open pollinate and controlled crosses, as well as wild Manihot species.
- 212 genotypes (5.6%) expressed no symptoms and 586 genotypes (15.4%) had a damage rating between 1.5 and 2.4 (see damage scale on page 9 in this report); both groups will be re-evaluated. 2508 genotypes (63.0%) had damage ratings of 4 to 6, indicating high selection pressure at the field sites. All genotypes rated above 3.5 (on a 1 to 6 scale) are considered susceptible and discarded from further evaluation.
- ICA (Colombia Institute of Agronomy) has approved the release of a whitefly resistant cultivar developed by CIAT in collaboration with CORPOICA of the Ministry of Agriculture and Rural Development (MADR). This cultivar, CORPOICA/CIAT Nataima-31 completed 3 years of evaluation at 3 field sites in the Tolima Valley. This is one of the first whitefly resistant cultivars released for a major food crop.
- The cultivar CORPOICA/CIAT-31 (CG489-31), in addition to being resistant to whiteflies, is high yielding, a desirable plant type (good stake production) and excellent cooking quality. Field trials demonstrate that the cultivar will continue to give good yields in the presence of high whitefly populations, whereas yields of local farmers varieties are reduced considerably. In addition to being a whitefly resistant variety, CORPOICA/CIAT-31 is also highly resistant to thrips and shows moderate resistance to mites.
- The sister hybrid, CG489-34, also received a very favorable evaluation in the aforementioned field trials and may also be approved for release in the near future.
- Biotype B of *Bemisia tabaci*, the potential vector of African Cassava Mosaic Disease (ACMD) in the Americas has been successfully reared on cassava in the laboratory. Occasionally observed on cassava in the field, but more commonly found colonizing field beans, laboratory experiments with the B-biotype show that it will more readily adapt to

cassava related species (*Jatropha gossypiifolia*) and poinsettia before establishing on cassava. This important discovery will aid on our preparation for evaluating the potential of ACMD or other Gemini-viruses infesting cassava.

- In our ongoing studies to identify the genetics of whitefly resistance a cross was made between the resistant cultivar MEcu 72 and the high yielding susceptible cultivar MCol 2246. Preliminary results, described in this report, indicate a high **hereditability** of whitefly resistance and very high yield potential. Numerous progeny yielded above 50 T/ha in single row yield trials. All 700 progeny from this cross have been re-planted at two sites in Colombia.
- A collaborative research project has been developed with the Natural Resources Institute (NRI) in the UK to evaluate whitefly resistant cassava genotypes from the Neotropics against the *Bemisia tabaci* whitefly species from Africa, the vector of ACMD. Whitefly resistant genotypes have already been sent from CIAT to NRI and evaluations have been initiated. Whitefly resistant germplasm, after evaluation in the UK will be introduced into Africa, probably into Uganda through a joint collaboration between NRI, IITA, NARO and CIAT.
- Surveys for cassava whiteflies and associated parasitoid species have been completed in Colombia, Venezuela and Ecuador. This three-year study shows that the greatest species richness for both whiteflies and their parasitoids was found in Colombia where 5 whitefly species were found feeding on cassava. A corresponding 11 micro-hymenopteran parasitoid species were collected from the whitefly species. Biological control is a complementary strategy with HPR, and these results provide a basis for future research in parasitoid (biological control) efficacy. Additional information on biological control of whiteflies can be found on our website: http://www.ciat.cgiar.org/ipm/index.htm
- A survey of cassava producers in Valle de Cauca and Cauca Departments indicate that farmers do not employ a uniform criteria in cassava crop management. At least 20 different varieties are grown and although a complex of arthropod pests were identified, whiteflies are considered one of the most damaging. Several pesticides are being applied for whitefly control, but only 1, Confidor (Imidacloprid), gave effective control.
- A cassava whitefly IPM strategy is being developed for the Cauca Valley and Cauca Departments. The combination of HPR and biological control, especially using entomopathogenic fungi, is the major emphasis at present. The resistant cultivar CORPOICA/CIAT-31 will be made available to cassava farmers during 2002. Planting material for distribution is now being multiplied.
- The CGIAR System-wide IPM project, of which MFAT is a contributing partner, has been assured funding by DFID for the second three-year phase of the project. This insures continuance to the activities in the project and assurance that technologies, such as whitefly resistant cassava varieties will be made available to farmers in both Latin America and Africa, as well as in Asia, if needed.
- Several additional cassava genotypes have been selected as whitefly resistant after several years of field trials. These include MPer 273, MPer 234, MBra 81 and CG 936-7. These genotypes, along with several others are being evaluated in the laboratory, under controlled conditions, to determine resistance mechanisms.
- During 2001-2002 the CIAT Cassava Germplasm Development Project continued to incorporate whitefly resistance into its breeding program. Using MEcu 72 as its primary source of resistance, cassava breeders have made crosses with regional varieties from

different agroecological zones. The goal here is to develop whitefly resistant hybrids that are adapted to a wide range of ecological conditions.

- Visit by Dr. Jeanne Jacobs, Food and Crops Institute, New Zealand. Dr. Jeanne Jacobs, a Project Collaborator, from the Food and Crops Institute, in New Zealand visited CIAT during the year being reported. Activities during the visit included field trips to the evaluation sites in Nataima, Tolima and the ones in the Valle del Cauca. She saw first hand the infestation of cassava fields by whiteflies and also discussed the scoring methodologies. Of greatest import probably was the consultation with CIAT personnel involved in the generation of the segregation data to be used in the construction of the linkage map in which she will be playing a leading role. An agreement was reached in the scoring formats so that it would suit the software to be used. In order to move rapidly also, it was decided that the screening of the mapping population with the SSR markers should be done according to the existing linkage groups of the framework map.

Present research being funded by the MFAT Cassava Host Plant Resistance Project consists of five major areas of activity:

1. Cassava germplasm evaluation to identify sources of whitefly resistance in landrace varieties from the CIAT cassava germplasm bank.
2. Identification of genomic regions responsible for the expression of whitefly resistance in cassava.
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4. Construction of a linkage map for resistance to whiteflies.
5. Development of cassava whitefly resistant hybrids for release to cassava farmers.

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Introduction

More than 1500 species of whiteflies (Hemiptera: Aleyrodidae) have been identified, primarily in the tropical and subtropical regions of the world. About 150 of these are considered as agricultural pests, damaging a wide range of hosts that include vegetables (tomatoes, broccoli, peppers), legumes (soy beans, ground nuts, alfalfa, beans), cucurbits (melons, squash, zucchini), ornamentals (poinsettia) and root crops (cassava, sweet potato).

A large complex of whitefly species are reported on cassava, the majority of these being found in the neotropics, where 11 species are reported. The most important species include *Aleurotrachelus socialis, Trialeurodes variabilis, Bemisia tuberculata, B. tabaci*[1], *B. argentifolia*[1] and *Aleurotrixus aepim. A. socialis* is the predominant species in Northern South America (Colombia, Venezuela and Ecuador) where it causes considerable crop damage. *A. socialis* is the major species causing crop damage in Brazil. Both species cause direct damage to cassava by feeding on the phloem of leaves, causing chlorosis and leaf fall, which results in crop loss. Neither species is known to transmit virus diseases.

B. tabaci has a pantropical distribution, feeding on cassava in Africa, Latin America and several countries in Asia, and is the vector of Africa Cassava Mosaic Disease (ACMD). Prior to 1990, the *B. tabaci* biotypes found in the Americas did not feed on cassava and it was therefore speculated that the absence **of ACMD in the Americas was partially due to the inability** of its vector, *B. tabaci* to colonize cassava. Since the early 1900s a new biotype (B) of *B. tabaci* has been found feeding on cassava in the Neotropics. It is considered that ACMD now posses a more serious threat to cassava production given that most traditional cultivars in the Neotropics are highly susceptible to the disease. In addition, since the *B. tabaci* biotype complex is the vector of several viruses of crops often grown in association with cassava or near it, the possibility of virus diseases moving among these crops, or the appearance of a new virus, represents a potential threat. For example ACMD in Africa is now considered to be a complex of at least five separate virus diseases that may have occurred through mutation or vectored from an associated crop. This may be the reason for recent outbreaks of ACMD in East Africa.

Bemisia afer occurs on cassava in many countries of Africa, especially East Africa (Kenya, Uganda, Tanzania, Malawi, etc.) where, until recently it was reported as a minor pest. However, more recently, it has been described as occurring in higher populations and causing crop damage. It is also suspected as being the vector of cassava brown streak virus. This species has now been reported in the Americas, attacking sweet potato in Peru. This is the first outbreak observed of *B. afer* **sens.lat.** in an agricultural situation in the Americas. *B. afer* has been recorded from numerous regions and countries including, Egypt, Greece, the Middle East, the Ethiopian region, India, Pakistan, New Guinea, Fiji, Tonga, Sudan, Sierra Leone, Nigeria, Niger, Chad, Cameroon, Congo, Zaire, Rhodesia, South Africa and Australia. It is considered a common and widespread

[1] Recent evidence suggests that *B. Tabaci* represents a species complex with numerous biotypes and two described cryptic species. The binomial *B. Tabaci* is used throughout this report in its broadest sense to include all members of the species complex unless a more specific designation is indicated.

pest species, feeding on a wide variety of plants. Recent information indicates that it has spread from Peru into Brazil; based on its history in East Africa, it is considered a potential threat to cassava in the neotropics. As an introduced pest, and in the absence of its co-evolved or major natural enemies, its rate of dissemination and population increases might be more dramatic. We will try to monitor this situation.

One of the objectives of the CIAT whitefly IPM project being finance by MFAT/NZ, has been to evaluate our resistant varieties against other species of whitefly. As stated earlier and in previous "Progress Reports," our HPR evaluations and resistant hybrid development has been for the species *Aleurotrachelus socialis*. We are now especially pleased to report that collaborative projects have been initiated to evaluate *A. socialis* resistant germplasm against other whitefly species especially *Bemisia tabaci*. A collaborative project with Natural Resources Institute (NRI), based in Chatham Maritine in the U.K., has now been started where *B. tabaci* survival and development will be evaluated on *A. socialis* resistant cultivars. Once the protocols and methodologies have been developed, a second phase of this project will be directed at evaluating resistant cultivars against the *Bemisia afer* species. NRI collaboration is important in this initiative as they can introduce the two aforementioned species into the UK for experimental purposes, something we cannot do in the Americas. MFAT funding is facilitating evaluation of *B. tabaci*, B. biotype development on whitefly resistant cultivars at CIAT, thereby allowing for comparative results between the African and Neotropic biotypes.

The ultimate goal of this work, of course, is to introduce whitefly resistant cultivars from the Neotropics into cassava breeding programs in Africa. These links have now been established with IITA and NARO researchers in Uganda. Once we have identified varieties resistant to the *B. tabaci* biotype of Africa, whitefly resistant cassava germplasm will be introduced into Africa and combined, in a germplasm improvement program, with ACMD resistant cassava varieties available and adapted to the African environment. It is expected that this exciting and novel research will ultimately reduce cassava whitefly populations and ACMD virus incidence.

Whitefly IPM: Host Plant Resistance and Biological Control

In traditional production systems, few options for controlling arthropod pests are available to resource limited farmers. Biological control and host plant resistance offer complementary tactics and strategies for reducing whitefly populations and preventing serious yield losses in cassava. Cassava is a long season crop, a functional perennial since traditional farmers seldom harvest all of the crop. Natural enemy populations may, therefore, be present throughout the entire crop cycle and can be sustained from one crop cycle to the next. In addition, large complexes of natural enemies have been found to be associated with most cassava pests. After several years of surveys of cassava fields in numerous countries in the neotropics, we have determined the extent of the natural enemy species richness associated with cassava pests, including whiteflies. The results of some of these surveys and the subsequent research are available upon request and can be found on our website at:
http://www.ciat.cgiar.org/ipm/index.htm

The CIAT cassava germplasm bank of nearly 6000 accessions of locally collected cultivars (land races) is an invaluable resource for identifying arthropod, especially whitefly resistance. These

traditional cultivars represent centuries of cassava selection and cultivation in diverse habitats by farmers over a long period in the presence of a high diversity of herbivores. The large scale screening or the evaluation of an extensive collection of cultivars, breeding materials, hybrids or selected wild or cultivated species for whitefly resistance has been limited in nearly all crops. In many cases the range of germplasm evaluated is too limited to understand or obtain the diversity of whitefly resistant genes that may be available in a given crop species.

We consider that for a crop improvement program to develop cultivars resistant to arthropod pests, and especially to whiteflies, at lest five criteria must be met:

- A germplasm bank that is representative of the crop species and that contains ample genetic diversity.
- Methodologies for mass rearing the pest.
- Methodologies for distinguishing resistant and susceptible cultivars in the field or greenhouse.
- Ample natural field populations of the pest to permit sufficient selection pressure and to be able to distinguish resistant and susceptible cultivars.
- A breeding scheme to incorporate heritable resistance into cultivars.

In the case of cassava and the whitefly HPR program all these criteria have been met. This has resulted in a growing list of cassava cultivars selected for moderate to high levels of resistance. Through a collaborative effort with CIATs Cassava Germplasm Improvement Project several high yielding, whitefly resistant hybrids have been developed. The Colombian Institute of Agronomy (ICA) of the Ministry of Agriculture and Rural, Development (MADR) has now approved the release of one of these hybrids, CG 489-31 (CORPOICA-CIAT Nataima 31), scheduled for 2002. In addition recent crosses between a resistant (MEcu 72) and high yielding susceptible cultivar (MCol 2246) has resulted in several additional whitefly resistant hybrids that are being continually evaluated.

A research project has now been initiated to evaluate wild *Manihot* species for resistance to whiteflies, as well as other arthropod pests. It is speculated that the Wild *Manihot* species (more than 100 species have been identified) may contain valuable genes for pest resistance (for example ACMD resistance presently available in cultivated cassava, *Manihot esculenta*, originated in a wild species. *M. glassiovii* CIAT's development of the cassava genome map and transformation techniques will facilitate the use of useful genes identified in wild *Manihot* species.

Activity 1. Evaluation of cassava germplasm for resistance to the whitefly, *Aleurotrachelus socialis*, in the year 2001

Rationale

The high incidence of frog-skin disease in CIAT's cassava germplasm during the 2000-2001 growing season impacted negatively on our ability to screen cassava germplasm and carry out experiments at the CIAT headquarters in Palmira. The continued build-up of the cassava frog skin disease, combined with an ever increasing whitefly populations made it impossible to objectively evaluate cassava genotypes and also to maintain the cassava germplasm bank on-station. The decision was therefore taken to suspend planting new cassava fields on-station. This therefore resulted in a 2-month period when there was no cassava being grown at CIAT. It was figured that this would reduce frog skin disease and whitefly incidence in subsequent plantings. Steps were also taken to rid the cassava germplasm of frog skin disease by using the tissue culture method to raise propagules for the accessions in the germplasm bank and for the other elite materials.

The implementation of these measures resulted in the need to identify additional sites outside of the CIAT station to maintain the cassava germplasm accessions, carry out experiments and multiply elite materials or varieties needed to maintain arthropod colonies for research purposes. The site, free of frog skin disease, chosen to plant much of these materials, was the Experimental Farm of the Universidad Nacional de Colombia, Palmira (CEUNP), located in the Candelaria Municipality, Valle del Cauca, and at CENICAÑA, Florida Municipality, Valle del Cauca. In addition, the cassava entomology section rented small parcels of land (each less than 1ha.) at two locations (approximately 7 and 25 km from CIAT, respectively) where there are very little cassava cultivation going on. This, it was hoped would lead to a reduced whiteflies infestation and also the absence of the cassava frog skin disease. This provided sites where elite genotypes for arthropod, especially whitefly, resistance could be multiplied, and from these source materials for greenhouse and field experiments.

Materials and Methods

The majority of the evaluations done for whitefly resistance during the 2000-2001 growing cycle were carried out at CEUNP and in close collaboration with the CIAT's Cassava Plant Breeding and Genetics sections. Five groups of genotypes were evaluated for *A. socialis* damage and resistance using both the host damage and pest population scoring scales (Table 1). These groups were:

1. A total of 2117 accessions from the CIAT cassava germplasm bank;
2. A group of 321 clones being progenies from controlled crosses (CW) from diverse parents including wild species;
3. A total of 606 clones obtained from Open crosses (OW);
4. A batch of 103 clones from the so-called Family K, being progenies from MNGA-2 X CM2177-2 (Cebucan) cross used to construct the cassava molecular genetic framework map; and
5. A total of 653 clones from the Observation field (CO) of the Cassava Plant Breeding Unit being evaluated for the Interandean valley ecosystems, 500 to 1200 m.a.s.l.

Over 3800 clones were therefore evaluated in 2001 at the CEUNP location. Both the damage severity and population scales were based on a 1 to 6 rating, with 1 being the absence of damage and no immature or pupae whitefly present; and a 6 rating signifying maximum damage and whitefly population (Table 1). A rating of 1 or 2 rating was considered highly resistant, 2.5 to 3.5 moderate to low levels of resistance, while a score 4 or above in either damage or population was considered susceptible. Those genotypes or cultivars that had scores of 1 to 3.5 were earmarked for re-evaluation in subsequent trials. This was informed by the fact that a low rating could indicate an "escape," in that; by chance whitefly populations were not high on a particular genotype. Often numerous evaluations (4 to 7) are required to identify a resistant genotype, when natural field infestations are used.

Table 1. Whitefly population and damage severity scoring scales for evaluating cassava germplasm for resistance to whiteflies.

Whitefly Population Scale (Nymphs and Pupae)
1 = no whitefly stages present
2 = 1-200 individuals per cassava leaf
3 = 201-500 individuals per leaf
4 = 501-2000 individuals per leaf
5 = 2001-4000 individuals per leaf
6 = > 4000 individuals per leaf
Damage Severity Scale
1 = no leaf damage
2 = young leaves still green but slightly flaccid
3 = some twisting of young leaves, slight leaf curling
4 = apical leaves curled and twisted; yellow-green mottled appearance
5 = same as 4, but with "sooty mold" and yellowing of leaves
6 = considerable leaf necrosis and defoliation, sooty mold on mid and lower leaves and young stems.

Results

Approximately 3800 cassava clones consisting of the five aforementioned groups were evaluated. The overall evaluation indicates that whitefly populations were high and resulted in significant selection pressure (Figures 1 and 2). Of these, 2508 cultivars, or 63.0% of the total germplasm evaluated had a damage rating of 4.0 to 6.0 and these were considered susceptible and therefore to be eliminated from any future need for screening or evaluation (Figure 1). At the other extreme, 212 clones (5.6%) showed no damage symptoms (score of 1), indicating possible high levels of resistance. Also, 586 clones (15.4%) had scores ranging from 1.5 to 2.5. In this case damage symptoms and whitefly stages were present but both at low levels, indicating a moderate level of resistance. These evaluations, therefore, resulted in about 21%, or 798 clones being rated below 2.5, indicating the possibility of high to moderate levels of resistance. These clones need to be reevaluated in subsequent years in order to identify the "escapes".

About 492 clones, or 13.0%, had scores ranging between 2.5 and 3.5. It is probable that these clones may have some moderate to low levels of resistance. However, many may also have considerably favorable agronomic qualities, i.e. high yield or dry matter, that could prove valuable in a breeding program in crossing them with putative parents with higher levels of resistance or yields.

Photo: **Whitefly (*A. Socialis*) damage on cassava. The two upper photos show typical leaf damage symptoms, the downward curling of young leaves and whitefly populations on the lower leaf surface. Bottom left photo shows a comparison between healthy (Resistant Variety MEcu 72) and infested leaves. Bottom right photo indicates whitefly feeding damage to upper leaves and heavy "sooty mold" presence on lower leaves.**

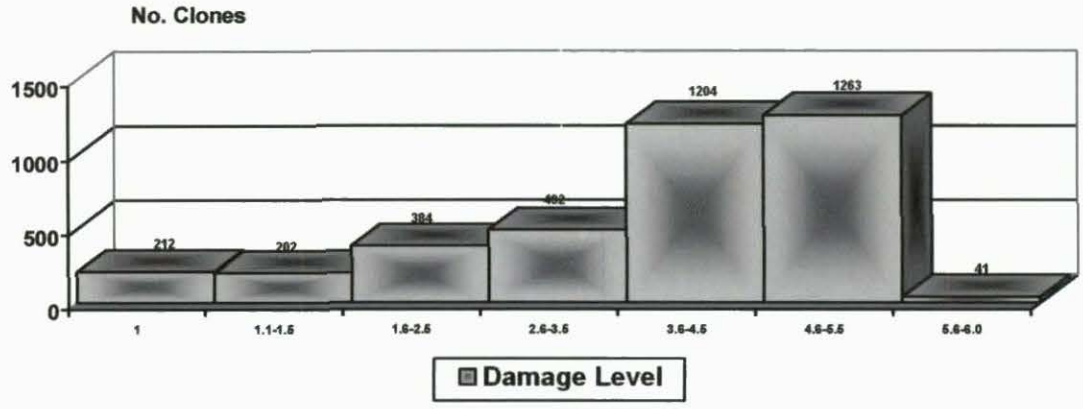

Figure 1. Scores for severity of damage caused by the whitefly on all cassava germplasm (3798 clones) evaluated at CEUNP, CIAT, 2001.

The first objective in a mass screening of germplasm for arthropod pest resistance is to identify susceptible germplasm and this can be achieved with the very first evaluation. There is no need to re-evaluate the susceptible genotypes as by definition, there are no "escapes." Based on this premise therefore, we were able to eliminate more than 2500 clones or 63% of those evaluated as being susceptible to *A. socialis* infestation.

The whitefly population scores were expectedly high, corresponding to the damage that had been scored. In all, 2640 clones (69.6%) had high whitefly populations, scores of 3.6 and above (on the 1 to 6 evaluation scale, Figure 2), indicating a good selection pressure. Only 25 clones, or 0.7%, were void of whiteflies. Again, these may be escapes and therefore deserving of further screening.

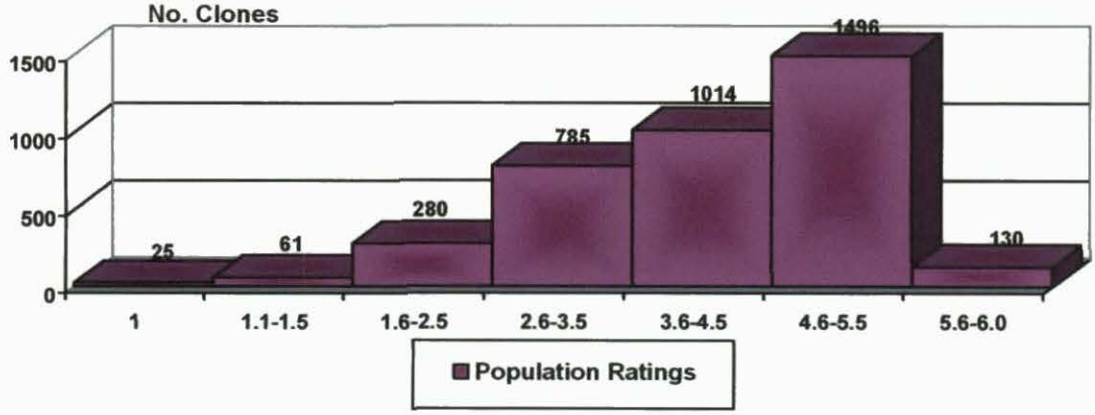

Figure 2. Whitefly population (nymphs and pupae) on 3791 clones making up the cassava germplasm evaluated at CEUNP, CIAT, 2001, for resistance to *Aleurotrachelus socialis*.

Of the 2117 genotypes from the germplasm bank evaluated a CEUNP, 1136 or 537% were highly susceptible (insect damage severity scores of 3.6 to 6, Figure 3), while 187 clones (8.8%) had a damage rating of 1, and 461 (21.8%) a rating of between 1.1 and 2.5. The corresponding scores for the populations of *A. socialis* were as shown Figure 4. In this case, it was observed that 1887 clones, or 89.2%, had the pest population scores of above 2.6. Nine clones (0.4%) were devoid of whiteflies and 228 clones (10.8%) had population scores of below 2.5. These results indicate an overall moderate to high populations of *A. socialis* on the cassava accessions. It is noteworthy that these were uniformly distributed throughout the entire field.

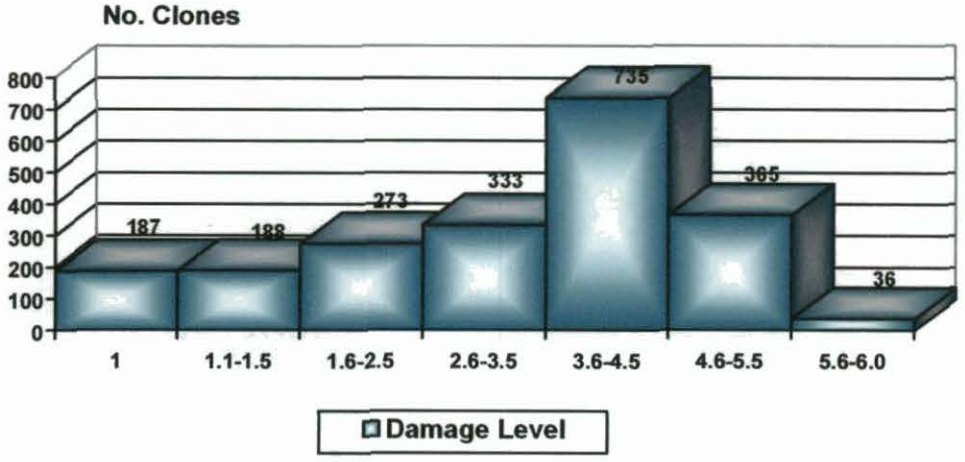

Figure 3. Scores for severity of damage caused by the whitefly (*Aleurotrachelus socialis*) on 2117 cassava clones at CEUNP/CIAT in the 2001 evaluations.

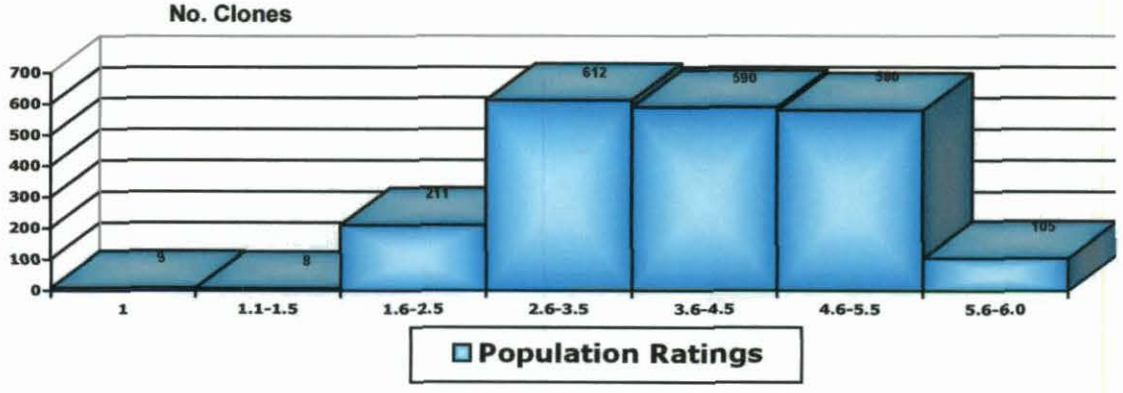

Figure 4. Whitefly, *Aleurotrachelus socialis*, populations (nymphs and adults) scores on the evaluated 2117 cassava clones at CEUNP/CIAT in 2001.

Figures 5, 6, 7 and 8 show the damage severity scores for the different groups of cassava genotypes. For those genotypes from the controlled crosses (CW), 72 clones, or 22.4% had damage scores below 2.5, and 224 (69.8%) above 2.6 (susceptible) as shown in Figure 5.

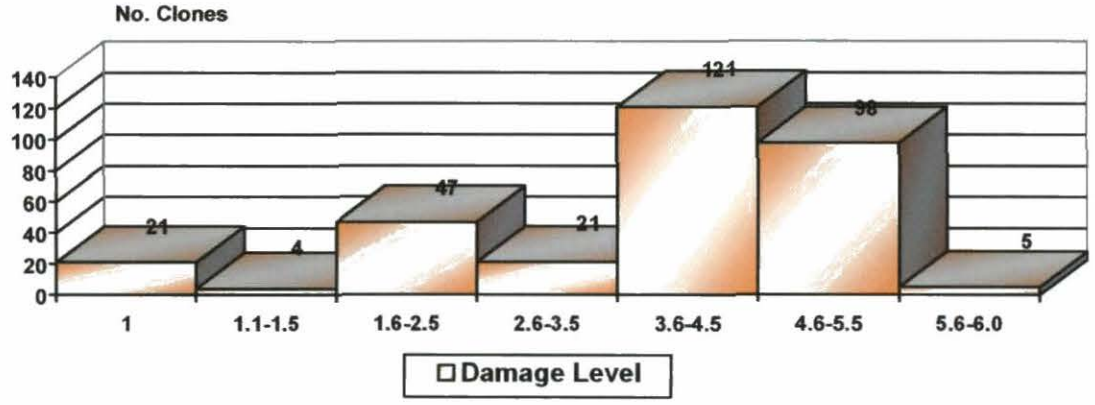

Figure 5. Scores for severity of damage caused by the whitefly, *Aleurotrachelus socialis*, on cassava accessions derived from controlled crosses (CW) at CEUNP/CIAT during 2001.

For those genotypes from the open crosses (OW), 79 clones, or 13.0% had damage ratings below 2.5, and 527 (87.0%) above 2.6 (Figure 6). For the progenies from the Family K (MNGA2 X CM2177-2), nearly all of them were highly susceptible to *A. socialis* (Figure 7). No cultivars received a damage severity score below 2.5; only 4 cultivars had a score below 3.5 and 99 or 96% had scores above 3.6 and therefore susceptible. Since neither of the parents had shown *A. socialis* resistance, it was not surprising that no resistance was observed in the progeny.

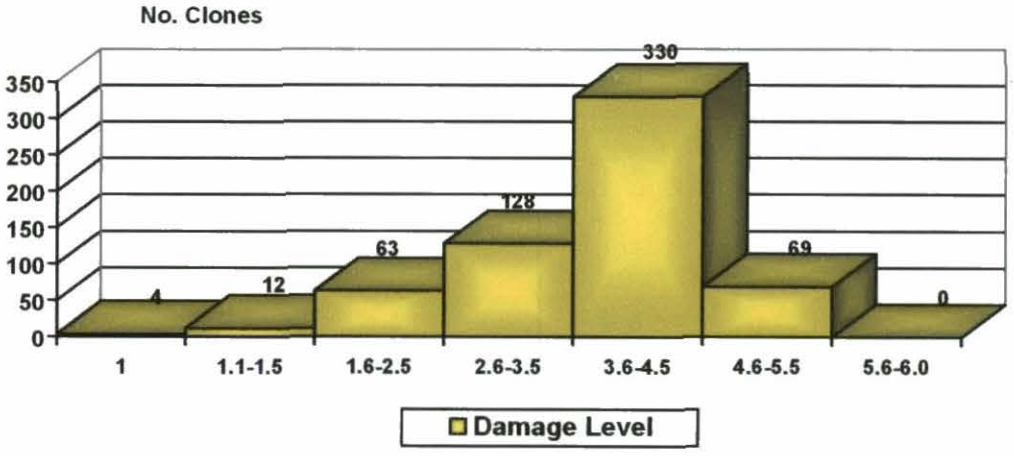

Figure 6. Scores for severity of damage caused by the whitefly, *Aleurotrachelus socialis*, on cassava accessions derived from open crosses (OW) at CEUNP/CIAT in 2001.

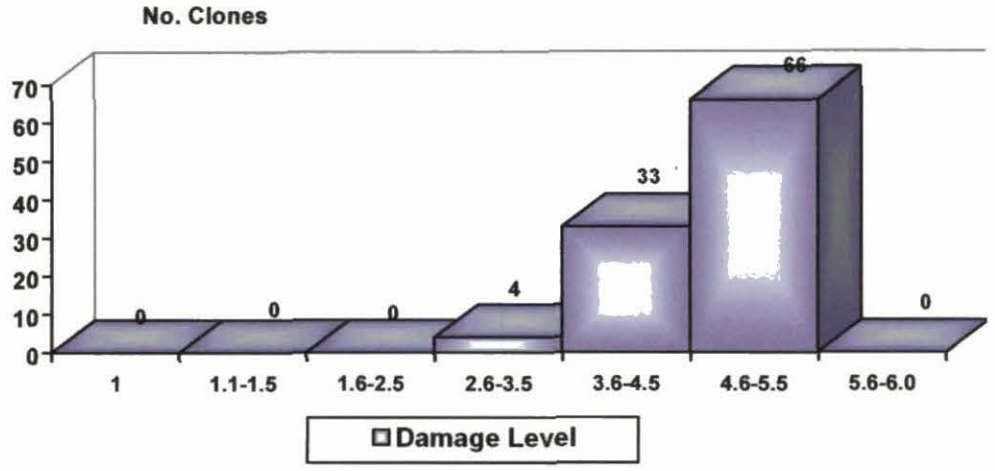

Figure 7. Scores for severity of damage caused by the whitefly, *Aleurotrachelus socialis*, on the Family K cassava accessions at CEUNP/CIAT in 2001.

Results from the observational field (CO) were similar; only 13 clones or 2%, scored below a 2.5 rating (Figure 8), while 88% (555 clones) had damage scores above 3.6. Sixty-four clones, about 10% had scores ranging between 2.6 and 3.5. This indicates that there may be some low to moderate levels of *A. socialis* resistance in this germplasm group.

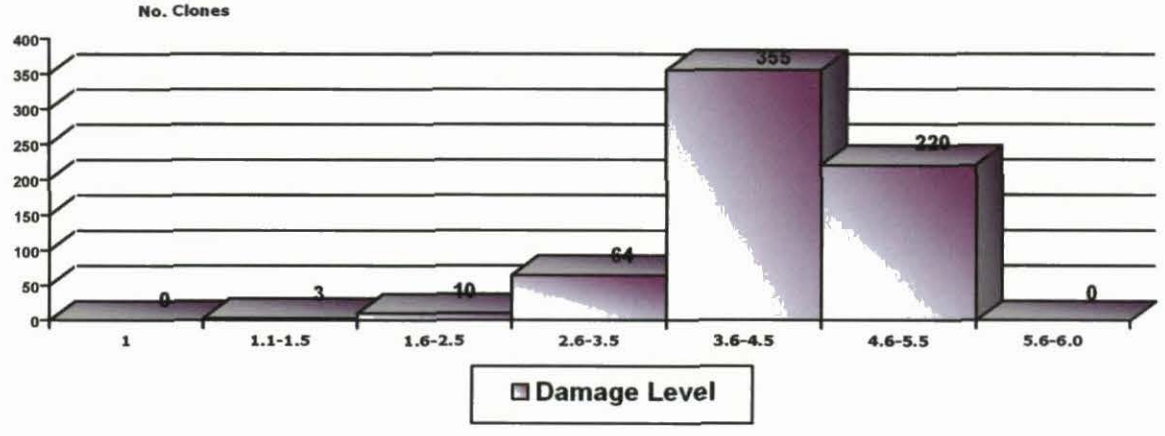

Figure 8. Scores for severity of damage caused by the whitefly, *Aleurotrachelus socialis*, on cassava accessions from the observation field (OC) at CEUNP/CIAT in 2001.

Table 2 summarizes the damage and population scores for all of the genotypes evaluated. It is shown that both host plant damage and population levels of the pest were consistently high indicating that this site (CEUNP) was suitable as a reliable test site for cassava germplasm resistance to for *A. socialis* infestation.

Table 2. Scores for the severity of damage caused by the whitefly (*Aleurotrachelus* socialis) and for the population of the pests by germplasm groups evaluated at CEUNP in 2001.

Group Germ.	No. of clones	% Clones by Damage Severity Scale				% Clones by Population of Pests Scale			
		1.0	1.5-2.5	2.6-3.5	4.0-6.0	1.0	1.5-2.5	2.6-3.5	4.0-6.0
E.G	2117	8.8	21.8	15.7	53.7	4.3	10.4	30.0	60.3
C.W	317	6.6	16.1	6.6	70.7	3.4	18.4	12.5	65.7
O.W	606	0.7	12.4	21.1	65.8	0.8	10.7	22.7	65.7
Fam K	103	0.0	0.0	3.9	87.4	0.0	0.0	4.9	95.1
O.C	652	0.0	2.0	9.8	88.2	0.0	1.7	8.9	89.4

E.G = Elite Germplasm O.C = Observation Field

Table 3 is a listing and summary of all of the genotypes evaluated, and represents the best materials selected in each of the groups of genotypes evaluated. In group 1 consisting of the elite accessions from the Cassava Germplasm Bank (CGB), 187 accessions had a damage severity score of 1.0. The 43 accessions listed in Table 3 also had pest population scores below 2.0, and for that reason are listed as the best materials.

Table 3. A list of the best cassava genotypes selected from germplasm evaluations for whitefly (*Aleurotrachelus socialis*) resistance at CEUNP, Valle del Cauca, in 2001.

Severity of Damage Ratings by Groups				
(1)	(2)	(3)	(4)	(5)
Elite (CGB) (1.0)	CW (< 2.0)	OW (< 2.0)	Family K (< 3.5)	CO (< 2.5)
PER 320	CW 14-8	OW 106-3	K-108	SM 2649-4
PER 594	CW 14-9	OW 229-5	K-41	SM 2653-5
CM 1288-17	CW 14-11	OW 105-6	K-58	SM 2588-5
CM 2298-3	CW 14-12	OW 238-1	K-73	SM 2649-5
BRA 759	CW 14-13	OW 153-2	K-6	SM 2652-9
BRA 785	CW 14-15	OW 189-1	K-15	SM 2589-28
COL 304	CW 14-16	OW 228-3	K-38	SM 2589-31
COL 1722	CW 20-1	OW 179-1	K-51	SM 2649-3
CM 4013-1	CW 21-3	OW 101-7		SM2652-10
COL 2260	CW 21-5	OW 105-7		SM 2652-12
CM 2146- 3	CW 14-7	OW 108-4		SM 2653-6
CM 2766- 4	CW 21-1	OW 228-4		SM 2663-5
BRA 860	CW 21-2	OW 240-2		SM 2575-7
ECU 108	CW 14-3	OW 252-3		
COL 2156	CW 14-6	OW 103-8		
PER 534	CW 20-2	OW 252-4		
COL 225	CW 14-2			
BRA 627	CW 14-4			
COL 561	CW 21-4			
SM 536- 8	CW 14-10			
COL 2653	CW 14-17			
COL 2656	CW 40-2			
PER 554	CW 39-7			
PER 602	CW 39-8			
SG 250-3	CW 14-1			
SG 638-6	CW 14-5			
COL 183	CW 40-13			
COL 2016	CW 40-3			
COL 2379	CW 57-1			
ECU 72	CW 58-1			
PER 380	CW 58-2			
BRA 859	CW 58-4			
COL 403	CW 58-5			
COL 774	CW 39-1			
BRA 1123	CW 39-3			
PER 421	CW 39-5			
SG 787- 10	CW 39-9			
COL 327	CW 39-11			
COL 875	CW 41-1			
COL 1467	CW 41-2			
COL 1503	CW 41-3			
COL 1509	CW 41-4			
COL 2032	CW 57-2			
	CW 28-38			
	CW 28-34			

(1)=Elite accessions from germplasm bank.
(2)=Genotypes corresponding to controlled crosses.
(3)=Open crosses
(4)=Family K, controlled cross between Mnig 2 x CM 2177-2
(5)= Observation field, plant breeding section.

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Activity 2. Identification of marker linked genes conferring resistance to whitefly in cassava

Introduction

Whiteflies, as direct feeding pests and virus vectors, are one of the most important agricultural pests in the world. They cause major damage in cassava-based agroecosystems in the Americas, Africa and to a lesser extent in Asia. In cassava (*Manihot esculenta* Crantz), in the Americas, the whitefly species, *Aleurotrachelus socialis*, has caused crop losses greater than 70%. Stable host plant resistance (HPR) offers a practical, low cost, long-term solution for maintaining reduced whitefly populations.

HPR studies initiated at CIAT over 15 years ago have identified several sources of resistance to *A. socialis* (CIAT, 1999). The clone MEcu 72 has consistently expressed the highest levels of resistance. *A. socialis* feeding on resistant clones had less oviposition, longer development periods, reduced size and higher mortality than those feeding on susceptible ones. Whitefly-resistant clones, in field trials, showed no significant differences in yield between insecticide-treated and non-treated plots (Bellotti *et. al.* 1999).

Whitefly resistance in agricultural crops is rare. Given the importance of these pests therefore, there is a need to understand the genomics of the resistance that we are observing in MEcu 72 and other resistant clones. It would be especially advantageous to map whitefly resistance genes and understand their segregation in F_1 progeny. Crosses were, therefore, made between MEcu 72 and a susceptible genotype to map resistance genes by using molecular markers. This will aid in a more rapid selection of resistant germplasm and also isolate those genes involved in resistance.

Materials and Methods

A cross was made between the resistant genotype, MEcu 72 and the susceptible genotype MCol 2246. The latter cultivar was selected because of its high level of susceptibility to *A. socialis*, but also having tolerance to mites and thrips, two additional important pests of cassava. In addition MCol 2246 has good floration, an advantage in obtaining the high numbers of progeny necessary for genetic studies. This cross produced 282 F1 individuals.

The sexual seeds produced in the cross were grown in sterile soil, in 67 plastic trays, and held in the screen house for 6 to 8 weeks (Temp. ± 30°C). Seedlings were subsequently planted in the field for multiplication.

Greenhouse evaluations were done by *in vitro* multiplication that involved the sequential steps of cutting plant apices and transferring them to the laboratory. Here they were disinfected by washing them in deionized sterile water followed by 70% alcohol, then 0.25% hypochlorite (mild bleach) and finally three additional washings in deionized sterile water (Escobar, 1991). The apices were planted in 4E media (Roca, 1984), in 16mm test tubes. The growth period was 60-80 days and a second propagation in 4E media resulted in 5 tubes per clone. Later, apices of

each clone were cut and planted in 17N media (Roca, 1984) to obtain root growth, a period of 30-40 days. The plants were then ready for transfer to the greenhouse for evaluation.

The afore-mentioned methodology permits maintaining plants in optimal sanitary conditions, in addition to having sufficient material available on need in a reduced area or space. Greenhouse evaluations were done with the parents MEcu 72 and MCol 2246, and the progenies from their cross using the leaf snap-cages and infected with *A. socialis* adults from the CIAT colony.

Field trials were carried out at two sties, CIAT, Palmira, and in Nataima, El Espinal, Tolima. The parents and progeny were planted 1 x 1 meter in the field and exposed to natural whitefly infestations.

A batch of 343 Cassava microsatellite (Simple Sequences Repeat, SSR) markers were used in this study. The oligonucleotide PCR primer pairs for these SSR markers were used to amplify the corresponding regions in the genome of both the parents and the progenie for the mapping population. The PCR amplified products visualized on silver stained polyacrylamide gels.

Results and Discussion

***In vitro* propagation**

Through *in vitro* propagation, 224 genotypes from the MEcu 72 x MCol 2246 cross, were obtained and grown in test tubes on a 4E media. From each of these genotypes, 5 clones were multiplied and propagated in a 17N media in the greenhouse. The 58 remaining genotypes are being collected for multiplication.

SSR screening of the parents of the F_1 mapping population

The resistant (MEcu 72) and susceptible (MCol 2246) cultivars were screened with 343 cassava microsatellites, including 116 new SSRs from a cassava root and leaf cDNA library (Mba *et. al.*, 2001; Mba *et al.*, pers. com.). Approximately 60% of the microsatellites had at least one unique allele in one parent. Quite a few had a unique allele in both of the parents. These SSRs with at least one unique segregating allele were considered polymorphic and therefore to be used in screening the F_1 mapping progeny. In all, 180 of such polymorphic SSRs have been identified from screening the 2 parents.

Scoring of the segregation data

The segregation data for these 180 SSR markers on the F1 mapping population is being collected in a format that fits the JoinMap requirements. These data would be used to construct the molecular genetic map. Figure 9 shows the segregating alleles for one such SSR marker for the 282 individuals.

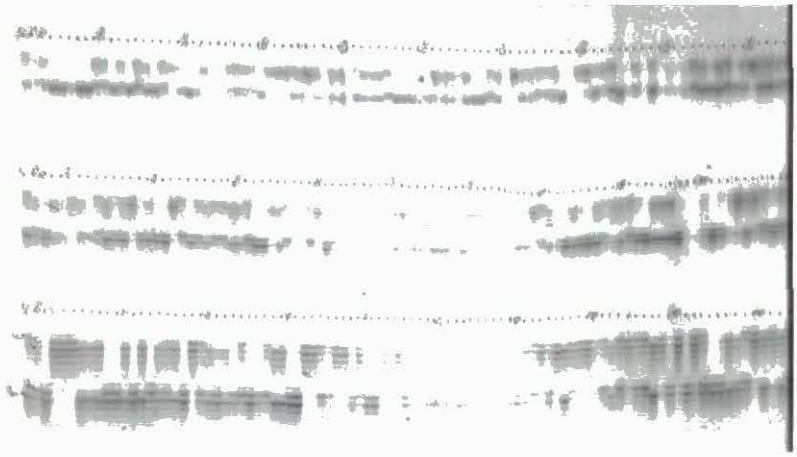

Figure 9. A silver stained polyacrylamide gel showing the segregation of the alleles of a SSR marker, 7 (F), for 282 F_1 individuals from the MEcu 72 x MCol 2246 cross.

Conclusions

The SSR markers displayed a high percentage of polymorphism, more than 60% or a total of 180 markers. This guarantees a high number of markers for the construction of a legitimate molecular genetic map. However still lacking is the *in vitro* propagation of a total of 58 F_1 progenies, and the field and greenhouse screening with *A. socialis*. Upon completing the collection of the segregation data for the polymorphic SSR markers on the 282 individual progenies, a comparison will be made between greenhouse and field data for resistance to *A. socialis*.

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Table 4. Cassava microsatellites for the parental cultivars MEcu 72 and MCol 2246.

SSR #	Size (bp)	T. Anneal °C	Polymorphic	SSR #	Size (bp)	T. Anneal °C	Polymorphic
SSRY1	197	45	X	SSRY51	298	50	X
SSRY2	225	55	X	SSRY52	266	55	X
SSRY3	247	45	X	SSRY53	138	55	Monomorphic
SSRY4	287	45	X	SSRY54	151	55	X
SSRY5	173	55	X	SSRY55	145	50	X
SSRY6	298	45	X	SSRY56	137	50	Monomorphic
SSRY7	250	45	X	SSRY57	293	55	X
SSRY8	288	45	X	SSRY58	217	55	X
SSRY9	278	55	Monomorphic	SSRY59	158	55	X
SSRY10	153	55	X	SSRY60	137	55	X
SSRY11	265	55	X	SSRY61	233	55	Monomorphic
SSRY12	266	55	Monomorphic	SSRY62	250	55	Monomorphic
SSRY13	234	50	X	SSRY63	290	55	Monomorphic
SSRY14	300	55	Monomorphic	SSRY64	194	55	X
SSRY15	215	50	Monomorphic	SSRY65	299	55	X
SSRY16	218	55	X	SSRY66	261	55	Monomorphic
SSRY17	277	50	X	SSRY67	278	55	Monomorphic
SSRY18	198	44	Monomorphic	SSRY68	287	55	X
SSRY19	214	50	X	SSRY69	239	55	X
SSRY20	143	55	X	SSRY70	249	55	X
SSRY21	192	55	X	SSRY71	217	55	X
SSRY22	299	43	Monomorphic	SSRY72	141	55	X
SSRY23	247	45	X	SSRY73	265	50	Monomorphic
SSRY24	100	45	Monomorphic	SSRY74	114	55	X
SSRY25	296	45	Monomorphic	SSRY75	284	55	X
SSRY26	121	55	X	SSRY76	273	55	X
SSRY27	277	50	X	SSRY77	275	55	X
SSRY28	180	55	Monomorphic	SSRY78	248	55	X
SSRY29	281	55	Monomorphic	SSRY79	210	55	X
SSRY30	220	50	X	SSRY80	299	55	X
SSRY31	188	50	X	SSRY81	204	55	Monomorphic
SSRY32	298	50	Monomorphic	SSRY82	211	55	X
SSRY33	273	50	Monomorphic	SSRY83	239	55	Monomorphic
SSRY34	279	55	X	SSRY84	203	55	X
SSRY35	282	55	Monomorphic	SSRY85	292	50	X
SSRY36	134	55	X	SSRY86	296	50	X
SSRY37	187	50	Monomorphic	SSRY87	102	55	X
SSRY38	122	55	X	SSRY88	243	55	X
SSRY39	293	50	X	SSRY89	120	55	X
SSRY40	231	50	X	SSRY90	193	55	Monomorphic
SSRY41	271		X	SSRY91	300	55	Monomorphic
SSRY42	221	50	X	SSRY92	171	55	Monomorphic
SSRY43	255	43	Monomorphic	SSRY93	289	55	X
SSRY44	194	50	Monomorphic	SSRY94	268	55	X
SSRY45	228	50	X	SSRY95	282	55	X
SSRY46	268	50	Monomorphic	SSRY96	149	55	X
SSRY47	244	55	X	SSRY97	194	55	X
SSRY48	178	50	Monomorphic	SSRY98	209	55	Monomorphic
SSRY49	300	50	Monomorphic	SSRY99	192	55	X

SSR #	Size (bp)	T. Anneal °C	Polymorphic	SSR #	Size (bp)	T. Anneal °C	Polymorphic
SSRY50	271	50	X	SSRY100	210	55	X
SSRY101	213	55	X	SSRY153	117	45	X
SSRY102	179	55	Monomorphic	SSRY154	318	55	X
SSRY103	272	55	X	SSRY155	158	55	X
SSRY104	258	52	Monomorphic	SSRY156	160	44	Monomorphic
SSRY105	225	55	Monomorphic	SSRY157	500	45	Monomorphic
SSRY106	270	55	X	SSRY158	224	45	Monomorphic
SSRY107	120	45	X	SSRY159	159	45	Monomorphic
SSRY108	203	55	X	SSRY160	151	50	X
SSRY109	125	55	X	SSRY161	220	55	X
SSRY110	247	55	Monomorphic	SSRY162	126	43	X
SSRY111	235	55	Monomorphic	SSRY163	231	44	Monomorphic
SSRY112	117	55	X	SSRY164	187	55	X
SSRY113	187	45	X	SSRY165	243	55	X
SSRY114	167	55	X	SSRY166	244	55	X
SSRY115	296	.	Non-amplified	SSRY167	183	45	X
SSRY116	167		Non-amplified	SSRY168	277	55	Monomorphic
SSRY117	142	55	X	SSRY169	100	55	X
SSRY118	169	55	Monomorphic	SSRY170	299	55	X
SSRY119	155	55	X	SSRY171	291	55	X
SSRY120	139	55	X	SSRY172	201	55	X
SSRY121	168	43	X	SSRY173	281		NO
SSRY122	273	45	X	SSRY174	136	43	X
SSRY123	136	55	X	SSRY175	136	55	X
SSRY124	146	55	Monomorphic	SSRY176	112	45	Monomorphic
SSRY125	247	55	Monomorphic	SSRY177	268	55	X
SSRY126	245	55	Monomorphic	SSRY178	104	55	Monomorphic
SSRY127	130	44	Monomorphic	SSRY179	226	55	X
SSRY128	243	45	X	SSRY180	163	55	X
SSRY129	205	55	Monomorphic	SSRY181	199	55	X
SSRY130	223	55	X	SSRY182	253	50	Monomorphic
SSRY131	111	45	Monomorphic	SSRY183	221	50	X
SSRY132	196	45	Monomorphic	SSRY184	163	50	X
SSRY133	295	55	Monomorphic	SSRY185	243	50	X
SSRY134	213	55	Monomorphic	SSRY186	297	55	
SSRY135	253	55	X	SSRY187	160	55	
SSRY136	296	55	Monomorphic	SSRY188	198	55	Monomorphic
SSRY137	157	55	Monomorphic	SSRY189	185	55	X
SSRY138	129	50	Monomorphic	SSRY190	164	55	
SSRY139	129	44	Monomorphic	SSRY191	186	55	Monomorphic
SSRY140	212	43	Monomorphic	SSRY192	183	55	X
SSRY141	262	55	X	SSRY193	218	55	X
SSRY142	206	55	X	SSRY194	196	55	
SSRY143	153	55	Monomorphic	SSRY195	186	55	X
SSRY144	117	55	X	SSRY196	188	55	
SSRY145	143	45	X	SSRY197	209	55	X
SSRY146	139	45	X	SSRY198	219	55	
SSRY147	113	45	Monomorphic	SSRY199	205	55	
SSRY148	114	55	Monomorphic	SSRY200	205	55	X
SSRY149	500	45	X	SSRY201	197	55	X
SSRY150	175	45	Monomorphic	SSRY202	191	55	

SSR #	Size (bp)	T. Anneal °C	Polymorphic	SSR #	Size (bp)	T. Anneal °C	Polymorphic
SSRY151	182	55	X	SSRY203	246	55	X
SSRY152	233	45	X	SSRY204	182	55	X
SSRY205	201	55	X	SSRY257	280	55	Monomorphic
SSRY206	219	55		SSRY258	400	55	Monomorphic
SSRY207	199	55		SSRY259	220	55	Monomorphic
SSRY208	198	55		SSRY260	100	55	
SSRY209	195	55		SSRY261	210	55	X
SSRY210	219	55	Monomorphic	SSRY262	140	55	Monomorphic
SSRY211	202	55	Monomorphic	SSRY263		n.a.	
SSRY212	238	55		SSRY264		n.a.	
SSRY213	199	55		SSRY265	230	55	X
SSRY214	234	55		SSRY266	220	55	Monomorphic
SSRY215	204	55	X	SSRY267	265	55	Monomorphic
SSRY216	210	55		SSRY268	215	55	solo SSR55
SSRY217	181	55	X	SSRY269	200	55	
SSRY218	203	55	X	SSRY270	220	55	
SSRY219	190	55	X	SSRY271	280	55	Monomorphic
SSRY220	190	55	X	SSRY272	220	55	
SSRY221		n.a.		SSRY273		n.a.	
SSRY222	150	n.a.		SSRY274	280	55	
SSRY223	170	55	X	SSRY275		50	X
SSRY224		n.a.		SSRY276	260	55	X
SSRY225		n.a.		SSRY277	210	50	Monomorphic
SSRY226		n.a.		SSRY278	210	55	Monomorphic
SSRY227	200	55	Monomorphic	SSRY279	170	55	Monomorphic
SSRY228	210	n.a.		SSRY280	180	55	Monomorphic
SSRY229	200	55	X	SSRY281	195	55	Monomorphic
SSRY230	185	55	X	SSRY282	200	55	X
SSRY231	260	55	Monomorphic	SSRY283	215	55	X
SSRY232		n.a.		SSRY284	210	55	Monomorphic
SSRY233	205	55	Monomorphic	SSRY285	290	55	X
SSRY234		n.a.		SSRY286	220	55	Monomorphic
SSRY235	250	55	X	SSRY287	220	55	Monomorphic
SSRY236	220	55	X	SSRY288	180	55	Monomorphic
SSRY237	200	55	X	SSRY289	195	55	Monomorphic
SSRY238	225	55	X	SSRY290	300	55	Monomorphic
SSRY239	220	55	X	SSRY291	210	55	X
SSRY240	200	55	X	SSRY292		n.a.	
SSRY241	220	55	X	SSRY293		50	Monomorphic
SSRY242	280	55	X	SSRY294	175	55	Monomorphic
SSRY243	400	n.a.		SSRY295	185	55	X
SSRY244	220	55	Monomorphic	SSRY296	175	55	X
SSRY245	300	55	Monomorphic	SSRY297	180	55	X
SSRY246	210	55	X	SSRY298	170	55	Monomorphic
SSRY247	300	55	Monomorphic	SSRY299	190	55	X
SSRY248	250	55	X	SSRY300	260	55	Monomorphic
SSRY249	400	55	Monomorphic	SSRY301	265	55	Monomorphic
SSRY250	200	55	X	SSRY302	200	55	X
SSRY251	220	55		SSRY303	190	55	Monomorphic
SSRY252	220	55	X	SSRY304	240	55	Monomorphic
SSRY253	190	55	X	SSRY305	300	55	X

SSR #	Size (bp)	T. Anneal °C	Polymorphic	SSR #	Size (bp)	T. Anneal °C	Polymorphic
SSRY254	220	55	Monomorphic	SSRY306	265	55	X
SSRY255	190	55	Monomorphic	SSRY307		n.a.	
SSRY256	210	55	Monomorphic	SSRY308	280	55	Monomorphic
SSRY309	220	55	Monomorphic	SSRY327		n.a.	
SSRY310		50	Monomorphic	SSRY328	240	55	X
SSRY311	200	50	Monomorphic	SSRY329	210	55	X
SSRY312	200	55	X	SSRY330		52	X
SSRY313	205	55	X	SSRY331		52	X
SSRY314	190	55	Monomorphic	SSRY332		52	X
SSRY315	230	50	X	SSRY333		52	Monomorphic
SSRY316		50	Monomorphic	SSRY334		52	Monomorphic
SSRY317		50	Monomorphic	SSRY335		52	Monomorphic
SSRY318		50	Monomorphic	SSRY336		52	Monomorphic
SSRY319		50	X	SSRY337		52	Monomorphic
SSRY320		50	Monomorphic	SSRY338		52	Monomorphic
SSRY321		50	Monomorphic	SSRY339	220	55	X
SSRY322		50	X	SSRY340		55	Monomorphic
SSRY323		50	Monomorphic	SSRY341	200	55	X
SSRY324	200	55	X	SSRY342	210	55	Monomorphic
SSRY325	240	55	Monomorphic	SSRY343	300	55	Monomorphic
SSRY326		n.a.					

Activity 3. The CORPOICA collaborative evaluations of cassava varieties and hybrids resistant to the whitefly, *Aleurotrachelus socialis,* in the Upper Magdalena Valley

Rationale

The whitefly, *Aleurotrachelus socialis* is the principal insect pest limiting cassava production in the Tolima Department, a sub-region of the Upper Magdalena Valley. Cassava yield losses in this region, due to whitefly attack have been reported as high as 68%. Farmers in the region often resort to the use of agrochemicals to combat whitefly attacks. However pesticide use is often ineffective, costly and also harmful to the natural enemies of this pest and also to the environment. In addition whiteflies easily acquire resistance to pesticides, if used continually or indiscriminately.

Host plant resistance (HPR) offers an effective, economically feasible and environmentally sound alternative for whitefly control. Over 15 years ago, CIAT and CORPOICA had initiated some HPR studies and from following from this, more than 5000 cassava clones from the CIAT cassava germplasm bank have been evaluated at either the CORPOICA (El Espinal, Tolima) or the CIAT (Palmira) sites. The consistently high *A. socialis* populations at the former site have made it an ideal location to accomplish HPR field evaluations over a prolonged period of time.

Earlier on in these evaluations, a source of *A. socialis* resistance was observed in the clone MEcu 72. This clone has consistently expressed high levels of resistance during numerous evaluations for several years and across several agroecosystems. MEcu 72 and MBra 12 (an agronomically desirable clone with some field tolerance to whiteflies) were used in a crossing program to provide high yielding whitefly resistant clones. A total of 127 progenies from this cross were evaluated at El Espinal over several growing cycles and four hybrids (progeny) were selected for their resistance to *A. socialis,* yield and consumer quality characteristics.

Complimentary investigations in greenhouse and field trials showed that *A. socialis* feeding on resistant clones had less oviposition, longer development periods, reduced size and higher mortality than those feeding on susceptible ones. In addition, whitefly resistant clones showed little or no significant differences in yield between insecticide-treated and non-treated plots. The progeny selected from the MEcu 72 X MBra 12 cross, CG 489-34, CG 489-4, CG 489-31, and CG 489-23, have consistently displayed moderate levels of resistance. (See photo on following page).

Collaborators at CORPOICA, Nataima, El Espinal, have been evaluating these materials, parents and hybrids for several years with high prospects for the release of these varieties as whitefly resistant.

Materials and Methods

Two "Evaluations of Agronomic Efficiency" were set up to evaluate whitefly resistant and susceptible germplasm by CORPOICA, one at the Nataima, El Espinal Station in Tolima, and the second at the Granja El Juncal at the South Colombian University in Neiva, Huila. Whiteflies are a problem at both sites.

Photo: **Whitefly resistant variety developed in a collaborative project between CIAT and CORPOICA, at Nataima, Colombia with MFAT support. This variety has now been approved for release by CIAT (Instituto Colombiano Agropecurario/MADR) and will be distributed to cassava producers during 2002.**

The experimental design used was the completely randomized blocks design with four replications and the treatments were 10 cassava genotypes (Table 5). Each experimental block was $36m^2$, six rows of six plants, leaving the 16 center plants for sampling. Cuttings of 20cm length, with at least four nodes were treated with a 5-minute insecticide/fungicide dip. Stake cuttings were planted vertically on ridges, and a herbicide (Diurón + Alaclor) was applied immediately after planting. Weeds were controlled manually during the growth cycle of the experiment. An application of *Bacillus thuringiensis* for cassava hornworm (*Erinnyis ello*) control was also made.

Table 5. Origin of cassava genotypes evaluated by CORPOICA, Nataima, El Espinal, Tolima.

Genotype	Origin or Source
MBra 12	Brazil
MEcu 72	Zamora, Chinchipe, Ecuador
CG 489-4	MEcu 72 x MBra 12 CIAT
CG 489-23	MEcu 72 x MBra 12 CIAT
CG 489-31	MEcu 72 x MBra 12 CIAT
CG 489-34	MEcu 72 x MBra 12 CIAT
CMC 40	Campinas, Brazil, Mantequierá, MCol 1468, Manihoica P-11
MCub 74	Señorita, Cuba
CM 4365-3	CM 976-15 x MCol 2207 CIAT
Aroma	El Guamo, Tolima, Colombia

Monthly evaluations of severity of whitefly damage and populations were carried out using standard damage and whitefly population scales (Tables 6 and 7). Prior to harvest, and during harvest, data were collected on morphological and agronomic characteristics of the varieties or genotypes involved in the evaluation. These data included, yield, harvest index, dry matter, and

culinary qualities, such as flavor, texture (root parenchyma), fiber, digestibility, HCN content and physiological deterioration.

Table 6. Scoring scales for the levels of adult and nymph whitefly populations

Population Scale (Nymphs and Pupae)
1 = no whitefly stages present
2 = 1-200 individuals per cassava leaf
3 = 201-500 individuals per leaf
4 = 501-2000 individuals per leaf
5 = 2001-4000 individuals per leaf
6 = > 4000 individuals per leaf

Table 7. Severity of whitefly damage to Cassava ratings.

Severity of Damage Scale
1 = no leaf damage
2 = young leaves still green but slightly flaccid
3 = some twisting of young leaves, slight leaf curling
4 = apical leaves curled and twisted; yellow-green mottled appearance
5 = same as 4, but with "sooty mold" and yellowing of leaves
6 = considerable leaf necrosis and defoliation, sooty mold on mid and lower leaves and young stems.

Results

3.1 Nataima A site

Figure 10 shows that significant differences (Tukey Test) in the severity of damage to cassava clones by whiteflies and the levels of infestations (pest population) were observed between the cassava genotypes evaluated at the Nataima site (Figure 10). The genotypes MEcu 72 and CG 489-31 had severity damage scores of 1 (no damage), while CMC-40, the susceptible control, and Aroma, the regional (farmers) variety recorded damage levels of 3.57 and 2.53, respectively. The levels of damage severity on CMC-40 and Aroma eventually reached 4.38 during the fourth month of growth (Figure 11). These data indicate that both varieties are susceptible to *A. socialis*. Other genotypes with low levels of damage severity were the hybrids (MEcu 72 x MBra 12), CG 489-34, CG 489-23 and CG 489-4 with severity scores of 1.08, 1.17 and 1.17, respectively, again indicating high levels of resistance (Table 8).

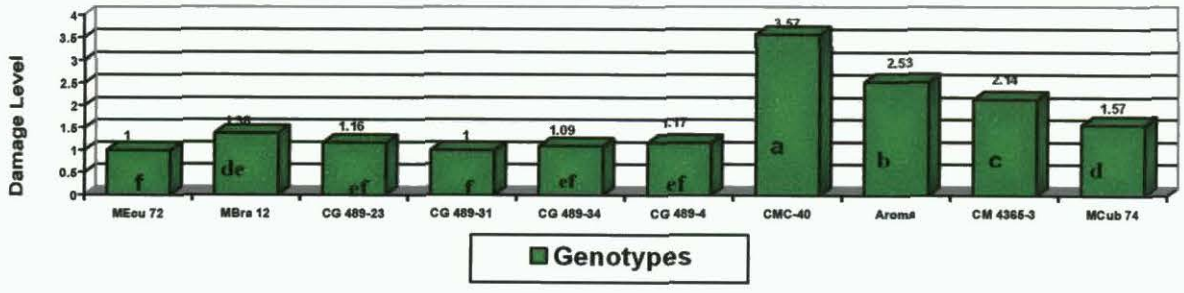

Figure 10. Average damage severity levels by whitefly (*Aleurotrachelus socialis*) for 10 cassava genotypes at CORPOICA, Nataima using a 1 (no damage) to 6 (severe damage) scale.

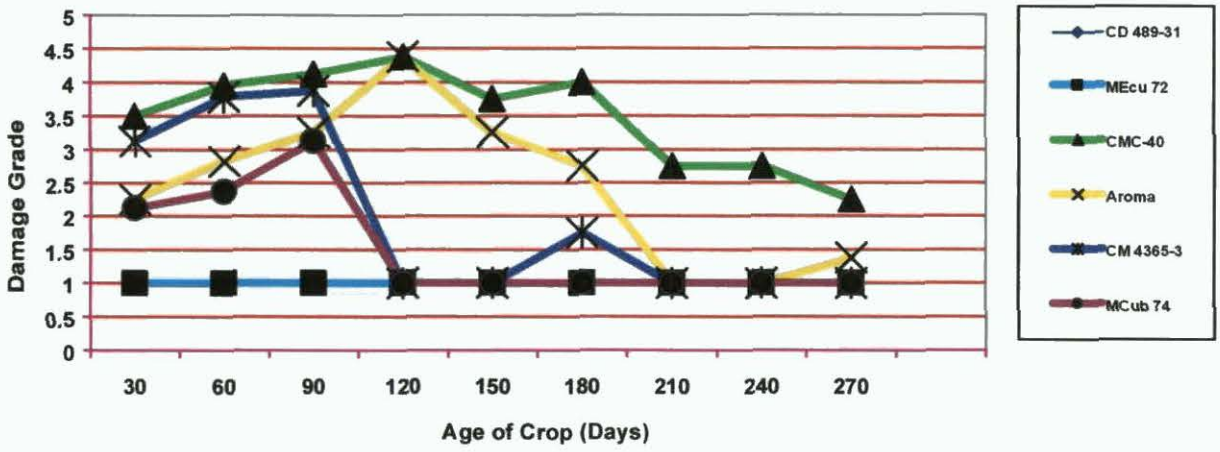

Figure 11. Monthly whitefly (*Aleurotrachelus socialis*) damage severity ratings for 6 cassava genotypes recorded at CORPOICA, Nataima.

Table 8. The whitefly (*Aleurotrachelus socialis*) damage severity ratings on 10 cassava genotypes during a 9-month growth cycle at Nataima, Tolima.

	Age of Crop (Months)/Damage Rating[1]									
Genotype	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Average**
CG 489-31	1	1	1	1	1	1	1	1	1	1
CG 489-34	1	1	1.75	1	1	1	1	1	1	1.08
CG 489-23	1.37	1.37	1.75	1	1	1	1	1	1	1.17
CG 489-4	1	1.5	1.87	1	1	1	1	1	1	1.17
MBra 12	1	2.62	2.25	1	1.02	1	1	1	1	1.38
MEcu 72	1	1	1	1	1	1	1	1	1	1
MCub 74	2.12	2.37	3.12	1	1	1	1	1	1	1.57
CMC-0	3.5	3.95	4.12	4.375	3.75	4	2.75	2.75	2.25	3.57
CM 4365-3	3.12	3.78	3.87	1	1	1.75	1	1	1	2.14
Aroma	2.25	2.82	3.25	4.375	3.25	2.75	1	1	1.38	2.53

[1] Damage rating: 1 = No plant damage.
2 = Severe damage, leaf necrosis, stems thin and weakened, considerable sooty mold.

The results as shown in Table 8 also demonstrate that on the whole, the severity of whitefly damage was highest during the first 5 months of the growth cycle and reduced during the remaining 4 months (months 6 through 9). For the accession CMC-40 however, the damage severity rating remained relatively high throughout the growth cycle and along with the regional variety Aroma, tapered off during the final three months (months 7 through 9). This clone, CMC-40 and Aroma were the only two cultivars that had damage ratings above four (4) during the growth cycle. Plant damage at this level is expressed by severe leaf distortion, and yellow to green speckling on apical and mid leaves with a presence of sooty mold. CMC-40 also showed some leaf necrosis during the third to 6th month of crop growth.

Expectedly, there is a correlation between the severity of plant damage and whitefly populations. The genotypes CG 489-31 and MEcu 72 had low average pupal populations, 28 and 46 pupae

per lower leaf, respectively (Figure 12). The pupal population is an indication of how many whitefly individuals are able to complete their life cycle on a given genotype. For this index there was a highly significant difference ($p<1\%$) between the genotypes evaluated. The genotypes CMC-40 and Aroma, the susceptible control and the farmers' regional variety, had 485 and 461 pupae per lower leaf, respectively (Figure 12). In addition, Table 9 also shows that pupal populations on the middle third of the leaves were highest on CMC-40 (419 per leaf) and Aroma (272) and lowest on MEcu 72 (2) and CG 489-31 (6). The pupal populations were also significantly lower on the three additional progeny CG 489-34, CD 489-23 and CG 489-4 (Table 9). Nymphal populations were lowest on CG 489-31 (8) and MEcu 72 (14), intermediate on the hybrids and highest on CMC-40 (192) and Aroma (158). MEcu 72 and CG 489-31 had about a 96% lower nymphal population than the two susceptible genotypes.

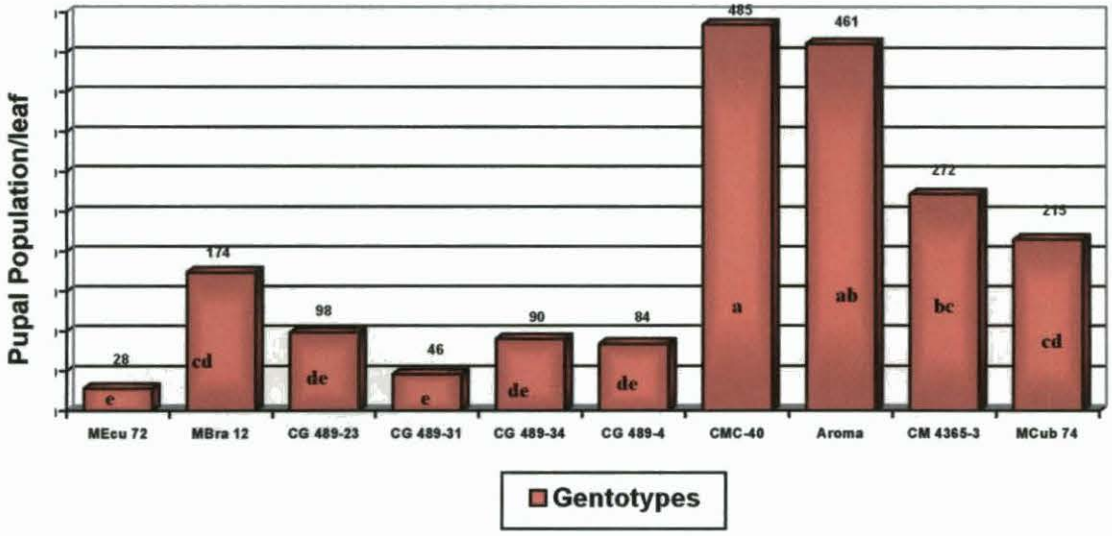

Figure 12. Whitefly (*Aleurotrachelus socialis*) pupal populations per lower (1/3) leaf recorded in the evaluations of 10 cassava genotypes at CORPOICA, Nataima, El Espinal, Tolima.

Table 9. Populations of different whitefly (*Aleurotrachelus socialis*) stages on 10 resistant and susceptible cassava genotypes at CORPOICA, Nataima, Tolima.

Genotype	Pupae/Leaf Lower Third	Nymphs/Leaf Middle Third	Pupae/Leaf Middle Third	Adults/Leaf Upper Third	Egg/Leaf Upper Third
CG 489-31	46 e	8 f	6 ef	3.6 e	7.2 e
CG 489-34	90 d	26 ef	20 ef	7.8 cde	15.8 d
CG 489-23	98 d	76 de	56 de	8.2 cde	14.8 d
CG 489-4	84 d	28 f	24 ef	11.0 bcd	18. d
MBra 12	174 c	90 cd	96 cd	15.0 b	153.2 c
MEcu 72	28 e	14 f	2 f	5.8 de	5.8 f
MCub 74	215 c	84 cd	76 cd	13.8 dc	95.6 c
CMC-40	485 a	192 a	419 a	79.4 a	485 a
CM 4365-3	272 b	134 bc	128 c	74.0 a	332 b
Aroma	461 a	158 ab	272 b	68.6 a	389 a
Signific.	**	**	**	**	**
CV (%)	13.96	8.01	9.56	7.62	7.91

** Significant differences, 1% level, Tukey.

Adult populations on the 10 genotypes gave similar results. The adult populations, observed mostly on the upper leaves of the plant, for MEcu 72 and CG 489-31 were 5.8 and 3.6 adults per leaf, respectively. In Figure 13, it is shown that they were intermediate on the progeny CG 489-34 (7.8), CG 489-23 (8.2) and CG 489-4 (11.0), and highest on CMC-40 (79.4), CM 4635-3 (74.0) and Aroma (68.6). Egg population (oviposition) was lowest on MEcu 72 (5.8) and CG 489-31 (7.2), intermediate in the hybrids, and highest in CMC-40 (485) and Aroma (389) (Table 9).

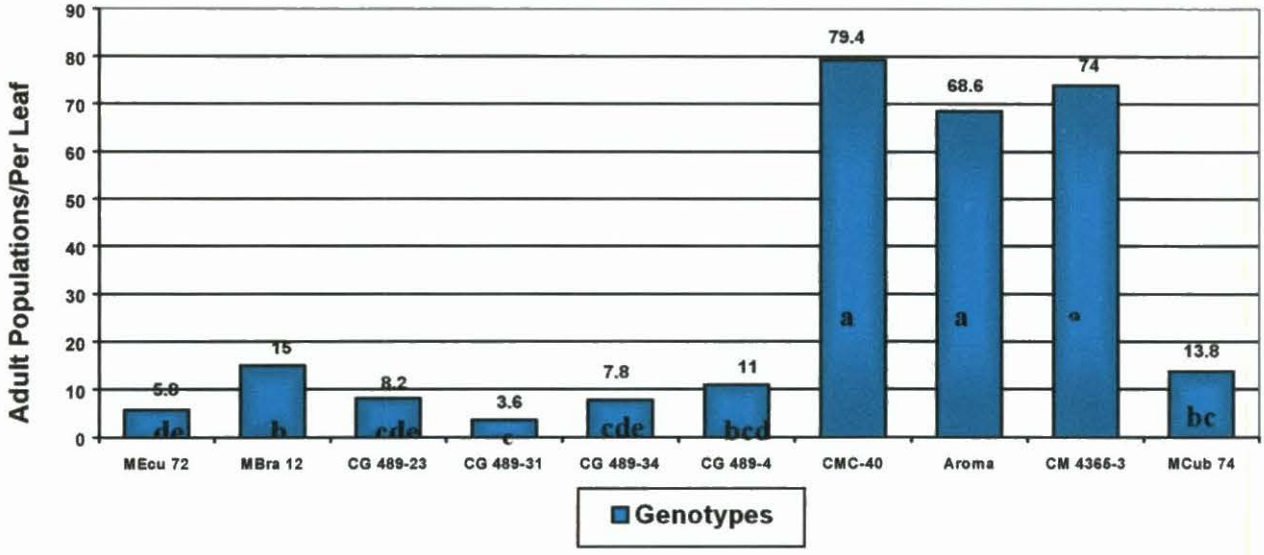

Figure 13. Population of adult whitefly (*Aleurotrachelus socialis*) per leaf on 10 cassava genotypes at CORPOICA, Nataima, El Espinal.

MBra 12, the male parent in the cross with MEcu 72, was usually intermediate in terms of whitefly populations and damage, but higher than any of the progeny. For example it had 174 adults, 90 nymphs, 15 adults, and 153 eggs, per leaf (Table 9), all higher than MEcu 72 and the four progeny, but not nearly as high as the susceptible clones CMC-40 and Aroma. These results indicate that the hybrid progeny have inherited considerable resistance from the female parent, MEcu 72. These results also reinforce the presence of an antibiosis mechanism involved in the resistance. The low numbers of adults and oviposition on the resistant genotypes may also signify an antixenosis mechanism for oviposition.

Yields were highest on the clones MCub 74, CM 4365-3, MBra 12 and CG 489-34 with 28.8, 26.8, 25.4 and 23.5 tons per hectare, respectively (Table 10). CM 4365-3, Aroma, CG 489-23 and CG 489-31 had the highest dry matter content with 40.49%, 38.1%, 36.0% and 39.94%, respectively. The lowest yields were recorded for Aroma (12.4 t/ha), CG 489-4 (3.3 t/ha) and MEcu 72 (17.1 t/ha). The low yield of CG 489-4 is mainly attributed to the high incidence of root rot, greater than 50% of the roots. Yield difference for all of the genotypes with the exception of CG 489-4, were not significant.

Whitefly populations, it should be noted, did not remain high on MCub 74 and CM 4365-3 (Figure 13) throughout the 9-month growth cycle. Whitefly populations were high only during

the first three months and therefore not during the root bulking stage of the plant. This may partially explain the higher yields with these two genotypes.

There was no significant difference in the number of stakes (cuttings) produced per plant (Table 10). The culinary quality evaluations show that all the genotypes were sweet, or low in HCN content, had good cooking qualities, were soft, had low fiber contents and were either cream or cream to white in color.

Table 10. Agronomic characteristics of 10 cassava genotypes evaluated under whitefly pressure at CORPOICA, Nataima, El Espinal.

Genotype	Total Root Yield (T/ha)	Harvest Index	Dry Matter %	Dry Matter Yield (Kg/ha.)	Cuttings/Plant
CG 489-31	18.2 AB	0.55 AB	35.94 C	6525 AB	12.6 A
CG 489-34	23.5 AB	0.69 A	32.99 EF	7685 AB	11.7 A
CG 489-23	18.5 AB	0.60 AB	36.00 C	6710 AB	12.0 A
CG 489-4	3.3 B	0.19 C	35.2 CD	1168 A	13.7 A
MBra 12	25.4 A	0.65 AB	35.37 CD	8952 A	15.2 A
MEcu 72	17.1 AB	0.57 AB	33.90 DE	5803 AB	112.9 A
MCub 74	28.8 A	0.64 AB	33.43 E	9666 A	17.0 A
CMC-40	19.5 AB	0.51 B	31.61 F	6108 AB	15.0 A
CM 4365-3	26.8 A	0.68 A	40.49 A	10862 A	13.2 A
Aroma	12.4 AB	0.48 B	38.10 B	4721 B	14.4 A
	**	**	**	**	N.S
Probab. %	0.97	0.01	0.01	0.66	44.5

** Significant differences at 5% level. Tukey Test.
NS = No significant differences.
Averages with the same letter are not significantly different.

3.2 El Juncal, Neiva (Huila) site

Whitefly populations at the El Juncal site were very low throughout the duration of the trials. The damage severity levels on all 10 genotypes remained at 1.0, and pupae populations ranged from 1.01 to 1.05 on the lower third of the leaves. There were no significant differences in pupal, nymphal and damage grades.

The lack of whitefly pressure was reflected in yield results, the highest yielding genotype was CMC-40, a vigorous, high yielding variety but very susceptible to pest damage, especially whiteflies. CMC-40 yielded 27.4 t/ha, MCub 74, 23.9 and CG 489-34, 23 t/ha Aroma the regional or farmers variety yielded only 14.7 t/ha (Table 11). There were however no significant differences between the yields of the 10 genotypes, with the exception of CMC-40 and MEcu 72, which yielded only 11.8 t/ha A significant aspect of this data, is that in the absence of whitefly pressure, high yielding but susceptible cultivars, such as CMC-40, can out-yield resistant cultivars. However under heavier whitefly pressure, CMC-40 is very susceptible to yield reduction, as was observed in the Nataima trial, where it was one of the lowest yielding varieties. It can also be noted from these data that MEcu 72, although highly resistant to whiteflies, is not a high yielding variety and therefore needs to be included in a breeding program where yields can be increased while its high resistance to whiteflies (as well as mites and thrips) can be retained.

Table 11. Agronomic characteristics, including yield and dry matter content, of 10 cassava genotypes evaluated under whitefly presence at El Juncal, Neiva, by CORPOICA.

Genotype	Total Root Yield (T/ha)	Harvest Index	Dry Matter %	Cuttings/Plant
CG 489-31	17,708 AB	0.43 CD	29.3ABC	15.1 A
CG 489-34	23,041 AB	0.55 AB	22.8 D	18.5 A
CG 489-23	20,227 AB	0.50 BC	27.3 BCD	13.3 A
CG 489-4	18,742 AB	0.49 BC	28.9 ABC	14.0 A
MBra 12	20,145 AB	0.52 BC	26.5 CD	11.8 A
MEcu 72	11,820 B	0.36 D	27.4 BCD	15.7 A
MCub 74	23,879 AB	0.59 AB	28.6 ABC	12.8 A
CMC-40	27,445 A	0.63 A	24.6 CD	11.7 A
CM 4365-3	22,227 AB	0.57 AB	33.2 A	11.7 A
Aroma	14,691 AB	0.41 CD	32.4 AB	12.2 A
Signific.	*	**	**	NS
CV %	26.7	8.8	7.9	29.9

* Significant differences at 5% level.
** Significant differences at 1% level.
NS = No significant differences.
Averages with the same level are not significantly different.

3.3 Nataima B

A second trial was planted at Nataima during the second semester of the year using the same genotypes and aforementioned methodologies (see Section 3.1).

Whitefly populations during this trial were higher than in the El Juncal, Neiva, but not as high as in the Nataima A experiment. However, populations were sufficiently high to result in significant differences in damage severity and yield. Whitefly damage severity scores were highest on CMC-40 (3.48), followed by Aroma (2.31) the regional variety, and CM 4365-3 (2.23). Damage was lowest on MEcu 72 (1.0 = no damage), CG 489-31 (1.0) CG 489-4 (1.01), CG 489-34 (1.02) and CG 489-23 (1.03) (Table 12). Damage was notably more severe on CMC-40 with severe leaf distortion, yellow mottling of upper leaves, sooty mold on the middle and lower leaves and some necrosis and defoliation of lower leaves. MEcu 72 and the four hybrid progeny were free of any of these damage symptoms, reinforcing the presence of considerable whitefly resistance in these genotypes. MBra 12 and MCub 74 showed some tolerance to whiteflies with low damage levels, 1.20 and 1.25, respectively.

As expected, whitefly populations followed a similar pattern to that of the damage scores (Table 12). The levels of pupae populations were lowest on MEcu 72 (1.06, see Table 6), CG 489-31 (1.05), CG 489-34 (1.19) and CG 489-4 (1.21) and highest on CMC 40 (3.10), Aroma (2.32) and CM 4365-3 (2.06). This ranking remained the same for pupal populations on the lower and middle third of the leaves although populations were higher on the lower leaves (Table 12). In actual numbers, CG 489-31 and MEcu 72 had 10 and 12 pupae per leaf respectively while CMC-40 and Aroma had 650 and 296 respectively, on lower leaves. These same differences proportionally occurred for pupal populations on middle leaves.

Nymphal populations followed a similar pattern to those of pupae. Lowest whitefly nymphal populations were on CG 489-31 (1.02 rating) and MEcu 72 (1.08) and highest on CMC-40

(2.63), Aroma (2.26) and CM 4365-3 (2.0). There was a significant difference in *A. socialis* nymphal rating between MEcu 72 and the four hybrid progeny, and CMC 40, Aroma and CM 4365-3 (Table 12). In actual numbers, CG 489-31 had only 4 nymphs per leaf, while CMC-40 had 389.

Adult *A. socialis* populations were highest on CMC-40 (2.04), CM 4365-3 (1.9) and Aroma (1.75) and significantly different from all the other genotypes (Table 12). Lowest adult populations were on the four hybrids and MEcu 72. In actual numbers, an average of only 1 whitefly per leaf was observed on CG 489-31, and only 3 per leaf on MEcu 72. Twenty-eight adults per leaf were collected, on average, from CMC-40. Oviposition was accordingly low on the hybrids and MEcu 72 (3.2 eggs per leaf) and highest on CMC- 40 (365 eggs per leaf) Aroma (260) and CM 4365-3 (212).

These results confirm the moderate to high levels of resistance to *A. socialis* that has been observed, and previously recorded, in the variety MEcu 72, and the four hybrid progeny.

Yields were highest on CM 4365-3 (35.0 t/ha), CG 489-31 (33.4 t/ha), MBra 12 (33.9 t/ha And CG 489-4 (33.0 t/ha) (Table 13). Yields were lowest for MEcu 72 (19.4 t/ha), CG 489-23 (20.5 t/ha), Aroma (21.7 t/ha) and CMC-40 (22.4 t/ha). The difference in yield between the susceptible control CMC-40 and the best hybrid, CG 489-31, was 33%. Compared to the regional farmers variety, Aroma, the difference was nearly 36%. In addition, CMC-40 had a very low dry matter, 26.7%, the lowest of any of the genotypes evaluated. Dry matter yield differences between CMC 40 and CG 489-31 was 41%.

The highest dry matter content were recorded for Aroma at 35.2%, CM 4365-3 (33.8%) and CG 489-23 (33.2%) while the lowest after CMC 40 were MEcu 72 (28.8%) and CG 489-34 (29.9%). Stake production was highest with MEcu 72 (23.7 per plant) and lowest with CG 489-23 (11.9), Aroma (12.5), and CMC-40 (12.8). Root rots incidence was lower in this trial than the Nataima A trial. For example CG 489-4 had only 4.9 % root rot while in the Nataima A trial it was 50.4%. However MEcu 72, CMC-40, and Aroma all suffered between 7 to 9% root rot. MEcu 72 had a low number of plants harvested slightly more than 50% over the maximum and this may account for its lower yield. Several other genotypes, especially CG 489-34 and CMC-40, also suffered plant losses. This may be due to poor germination, or pilfering, the Nataima site being historically been prone to this latter problem.

Table 12. Whitefly (*Aleurotrachelus socialis*) populations and damage severity ratings on 10 cassava genotypes during efficacy trials at CORPOICA, Nataima, El Espinal, Tolima.

		Lower Third		Mid Third				Upper Third			
Genotype	Damage Rating[1]	Pupae Rating	Pupae/ Leaf	Nymph Rating	Nymphs/ Leaf	Pupae Rating	Pupae/ Leaf	Adult Rating	Adults /Leaf	Oviposition Rating	Eggs /Leaf
CG 489-31	1.00 c	1.05 e	10	1.02 c	4	1.03 d	6	1.05 d	1	1.10 d	2
CG 489-34	1.02 c	1.19 de	32	1.27 c	54	1.19 cd	38	1.13 cd	2.6	1.32 cd	6.4
CG 489-23	1.03 c	1.42 cde	84	1.19 c	38	1.28 cd	56	1.21 cd	4.2	1.51 bcd	10.2
CG 489-4	1.01 c	1.21 de	42	1.17 c	34	1.21 cd	44	1.21 cd	4.2	1.42 bcd	8.4
MBra 12	1.20 c	1.82 bcd	164	1.63 bc	126	1.58 bcd	116	1.44 bc	8.8	2.18 b	3.6
MEcu 72	1.00 c	1.06 e	12	1.08 c	16	1.05 d	10	1.15 cd	3	1.16 d	3.2
MCub 74	1.25 c	1.96 bc	192	1.73 bc	146	1.58 cd	116	1.42 c	8.4	2.16 bc	52
CMC-40	3.48 c	3.10 a	650	2.63 a	389	2.86 a	458	2.04 a	28	3.55 a	365
CM 4365-3	2.23 c	2.06 bc	218	2.00 ab	200	1.91 bc	182	1.90 a	18	3.04 a	212
Aroma	2.31 c	2.32 b	296	2.26 ab	278	2.30 a	290	1.75 a	15	3.30 a	260
Signific.	**	**		**		**		**		**	
CV %	20.68	16.53		18.29		19.1		9.24		16.79	

* Significant different at 5% level, Tukey Test.
** Significantly different at 1% level, Tukey Test.
No significant difference.
Averages with the same letter are not significantly different.
[1] See Table 3.

Table 13. Agronomic characteristics, including yield, harvest index and dry matter content, of 10 cassava genotypes evaluated under whitefly (*Aleurotrachelus socialis*) pressure at CORPOICA, Nataima (B), El Espinal.

Genotype	Total Root Yield T/ha	Harvest Index	Dry Matter %	Cuttings/Plant
CG 489-31	33.4 a	0.56 ab	31.0 abcd	18.7 ab
CG 489-34	25.7 a	0.64 a	29.9 bcd	14.4 b
CG 489-23	20.4 a	0.53 ab	33.2 abc	11.9 b
CG 489-4	33.0 a	0.56 abc	32.7 abc	14.9 b
MBRA 12	33.9 a	0.63 a	31.0 abcd	13.9 b
MECU 72	19.3 a	0.43 c	28.8 cd	23.7 a
MCUB 74	25.8 a	0.49 bc	30.8 abcd	18.9 ab
CMC 40	22.4 a	0.57 ab	26.7 b	12.8 b
CM 4365-3	35.0 a	0.57 ab	33.8 ab	18.3 ab
AROMA	21.7 a	0.45 bc	35.2 a	12.5 b
Signific.	**	**	**	**
C.V. %	0.97	0.01	0.01	44.5

** Significantly difference at 5% level. Tukey Test.
Average with the same letter are not significantly different.

A combined analysis of the three trials (Table 14) showed that CM 4365-3 had the highest total yield at 28.0 t/ha, followed by MBra 12 (26.5 t/ha), MCub 74 (26.1 t/ha) and CG 489-34 (24.1 t/ha). In Figure 14, it is shown that the lowest combined yields were obtained for MEcu 72 (16.1 t/ha) and Aroma (16.2 t/ha). Significantly higher yields were obtained in the Nataima B trial when compared to the other two trials (Table 16) and the Nataima A trial had higher combined yields of the 10 genotypes than the Neiva trial in commercial root production.

Table 14. Total root yield of 10 cassava genotypes at three localities in the Upper Magdalena Valley, conducted by CORPOICA.

Genotypes	Total Root Yield T/ha	Total Root Yield T/ha	Total Root Yield T/ha	Total Root Yield	
	Nataima A	Nataima B	Neiva B	Average	Nataima A-B
CG 489-31	18.2	33.4	17.7	23.1 ab	25.8
CG 489-34	23.5	25.7	23.0	24.1 ab	24.6
CG 489-23	19.6	20.5	20.2	19.7 ab	19.5
CG 489-4	33.3	33.0	18.7	18.3 ab	18.1
MBra 12	25.4	33.9	20.1	26.5 a	29.7
MEcu 72	17.1	19.6	11.8	16.1 c	18.2
MCub 74	28.8	25.8	23.9	26.1 a	27.3
CMC-40	19.5	22.4	27.4	23.1 ab	21.0
CM 4365-3	26.8	35.0	22.2	28.0 a	30.9
Aroma	12.4	21.7	14.7	16.3 b	17.0
Average/Locality	19.4	27.1	20.04	22.1	23.2

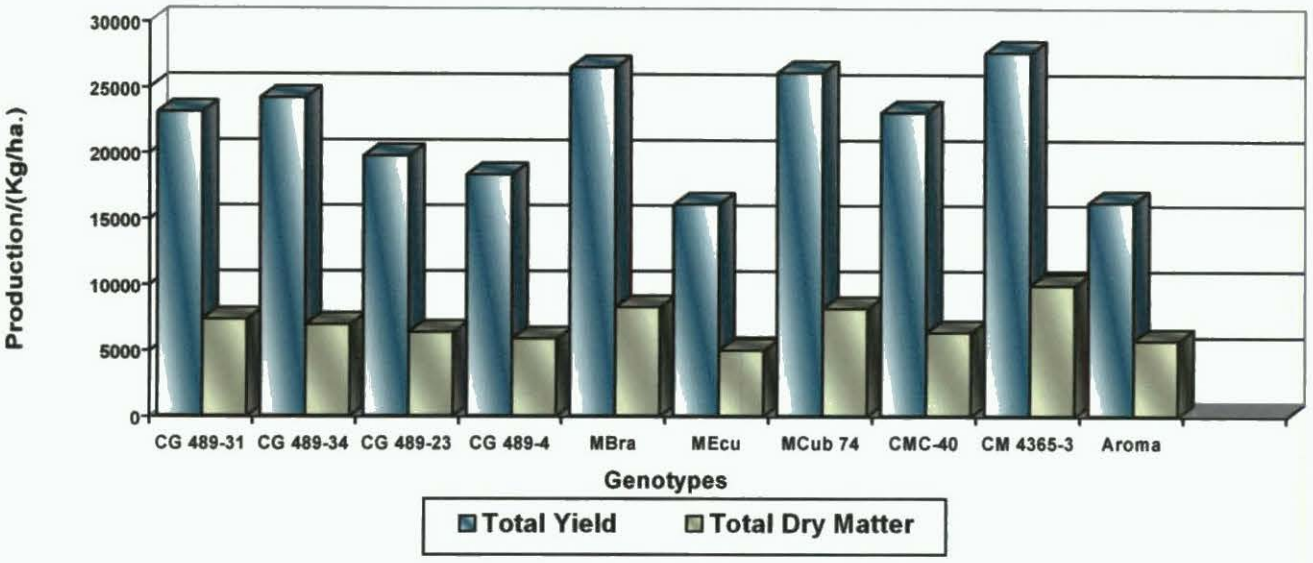

Figure 14. Average total yield and dry matter content combined over three whitefly resistance efficacy trials for 10 cassava genotypes in the Upper Magdalena Valley.

Table 15. Combined analyses for yield characteristics from efficacy trials of 10 cassava genotypes at three locations in the Upper Magdalena Valley.

Locality	Yield Commercial Root (kg/ha.)	Total Root Yield (kg/ha.)	Harvest Index	Dry Matter %	Total Dry Matter Production (kg/ha.)	Cuttings/ Plant	Leaf Weight
Neiva 99 A	10169 c	20011 b	0.50 b	28.10 c	5623 b	13.7 a	5715 a
Nataima 99 A	16553 b	19352 b	0.56 a	35.30 a	6831 b	13.8 a	1272 b
Nataima 99 b	19967 a	26968 a	0.54 a	31.30 b	8445 a	15.5 a	5518 a

Average with same letter are not significantly different. Tukey Test.

Considering the two Nataima trials, where whitefly populations were highest, CM 4365-3 (30.9 t/ha) and MBra 12 (29.7 t/ha) were the highest yielding clones while Aroma (17.0 t/ha) was the lowest. These results indicate that the farmers' regional variety has consistently yielded lower than all of the genotypes tested, although much of this data is not significantly different. In addition, it can also be noted that CMC-40 when grown where there is little or no whitefly pressure will yield as high or higher than the other whitefly resistant genotypes. However under high whitefly pressure, CMC-40 is quite susceptible and yields diminish, and are lower than the best resistant hybrids.

Although all of the hybrids yielded higher than Aroma, the regional variety, two hybrids CG 489-31 and CG 489-34 whose passport data are presented in Table 16 gave considerably higher yields. These two whitefly resistant genotypes would be recommendable under conditions of high whitefly pressure. CORPOICA, Nataima, the statutory agency responsible for crop varietal release has indicated that the hybrid CG 489-31 (Table 16) is the best candidate for release to farmers in the region. They cite the facts that CG 489-34 has high yield and dry matter in

addition to a high level of whitefly resistance, and its adaptations to the ecosystem as important characteristics for varietal release.

Table 16. Morphological characteristics of two cassava genotypes, CG 489-31 and CG 489-34.

Plant	CG 489-31	CG 489-34
Plant Height	250,4 (236,2 - 262,5) cm	231.4 (222 - 245) cm
Height, first branching	1400 (115,2 - 145,3) cm	112.8 (103 - 124) cm
Levels of branching	2	2.5 (2 - 3)
Branches at each level	3	02.8
Leaves		
Color: growing point	Light green	Light green
Pubescence: growing point	High	Intermediate
Shape: central leaf lobe	lanceolate	Elliptical elliptic
Leaf Color	Dark green	Dark green
Vein Color	Light green	Light green
Petiole Color	Dark red	Yellow-red
Leaf weight (kg/ha.)	4517	3236
Stem		
Epidermis (color)	Dark brown	Cream
Colenchyma (color)	Dark green	Light green
External color	Dark reddish brown	Yellowish-green-brown
Nodes	Prominent	Prominent
Cutting production/plant	15	14.8
Roots		
Form	Conical cylindrical	Conical cylindrical
Peduncle	Intermediate	Intermediate
External (outer) color	Dark brown	Cream (light brown)
Peel color	Rosy/pinkish	Rosy/pinkish
Pulp color	White	White to cream

101752

Activity 4. Evaluation of cassava genotypes for a resistance to the *B.* biotype of *Bemisia tabaci*

Rationale

Whiteflies are a major pest of many agricultural crops in many areas of the world, but especially in the tropics and subtropics. Yield losses are estimated in the hundreds of millions of dollars. Many whitefly species cause crop losses through direct foliar feeding, while others are very efficient vectors of numerous economically important plant viruses. There are approximately 1200 species with a wide host range, including legumes, fruits, root and tuber crops, vegetables, cotton and ornamentals.

Whiteflies cause considerable losses in cassava agroecosystems, both as direct feeding damage and as vectors of virus diseases. *Aleurochachelus socialis* and *Aleurothrixus aepim* reduce cassava yields considerably due to direct feeding damage in the neotropics. A single whitefly species, *Bemisia tabaci* (this is actually a complex of biotypes and may include the species *B. argentifolii*), is the vector of Africa Cassava Mosaic Disease (ACMD), Bean Golden Mosaic, Tomato Yellow Leaf Curl (TYLC) and at least 30 other geminiviruses of important food crops. This pantropical pest feed on cassava throughout Africa, several countries in Asia and more recently in the Neotropics.

Prior to 1990, the *B. tabaci* biotypes found in the Americas did not feed on cassava. It has been speculated that the absence of ACMD in the Americas was related to the inability of its vector, *B. tabaci*, to colonize cassava. Since the early 1990s a new biotype (B) of *B. tabaci*, considered by some a separate species (*B. argentifolii*), has been found feeding on cassava in the Neotropics. It is considered that ACMD now posses a more serious threat to cassava production given that most traditional cultivars in the Neotropics are highly susceptible to the disease. In addition the *B. tabaci* biotype complex is the vector of several viruses that infect other crop plants often grown in association with cassava or near it, especially in traditional cropping systems in the tropics. The possibility of virus diseases moving among these crops or the appearance of new viruses represents a potential threat.

Host plant resistance (HPR) studies initiated at CIAT over 15 years ago, are systematically evaluating the 6000 cultivars in the germplasm bank for whitefly resistance, especially to *A. socialis*. Several sources of resistance to *A. socialis* have now been identified (See Annual Report, CIAT, IP-2, 1998-2000). The clone MEcu 72 has consistently expressed the highest levels of resistance. Additional cultivars expressing high to moderate levels of resistance include MEcu 64, MPer 335, MPer 415, MPer 317, MPer 216, MPer 221, MPer 265, MPer 266 and MPer 365. MEcu 72 and MBra 12 (an agronomically desirable clone with field tolerance to whiteflies) were used in a crossing program to provide high-yielding, whitefly-resistant clones that showed no significant differences in yield between insecticide-treated and non-treated plots. The progeny CG 489-34 from this cross has demonstrated moderate to high levels of resistance in field and laboratory trials.

The purpose of the current research is to evaluate the resistance in cassava to the whitefly species, *A. socialis*, against the B biotype of *Bemisia tabaci*.

Materials and Methods

The establishment of *B. tabaci* colony on cassava

In 1997, the CIAT Bean Improvement Project (IP-1) established a colony of the 'B' biotype of *B. tabaci* on beans (*Phaseolus vulgaris*, var. ICA Pijao). This colony provided the stock for initiating a B biotype of *B. tabaci* colony on cassava. *B. tabaci* individuals (adults) were harvested from the bean colony and allowed to oviposit on poinsettia (*Euphorbia pulcherrima*), located in fine nylon meshed, wooden cages (1m height x 1m wide). The objective here was to first establish a colony of *B. tabaci*, biotype B, on a species related to *Manihot esculenta*, as *B. tabaci* did not transfer successfully from beans directly to cassava. *E. pulcherrima*, like cassava, is a Euphorbiaceae. Five potted plants were located in each cage.

The colony of *B. tabaci* (B) once established on poinsettia, after 5 generations, was transferred to Jatropha (*Jatropha gossypiifolia*), a closely related species to *M. esculenta*. After 5 generations on Jatropha, the colony was transferred to cassava (var. MCol 2063) (Figure 15). To initiate all colonies, plants with 4 to 6 leaves (about 30 to 50 cm in height) and insect free, were utilized. Infestations were done using the pupal stage, adults about to emerge.

To secure the identification of *B. tabaci,* B. biotype, the RAPD-PCR technique was used (Figure 16). In this study, the monitoring of the B biotype was done with H9 primer.

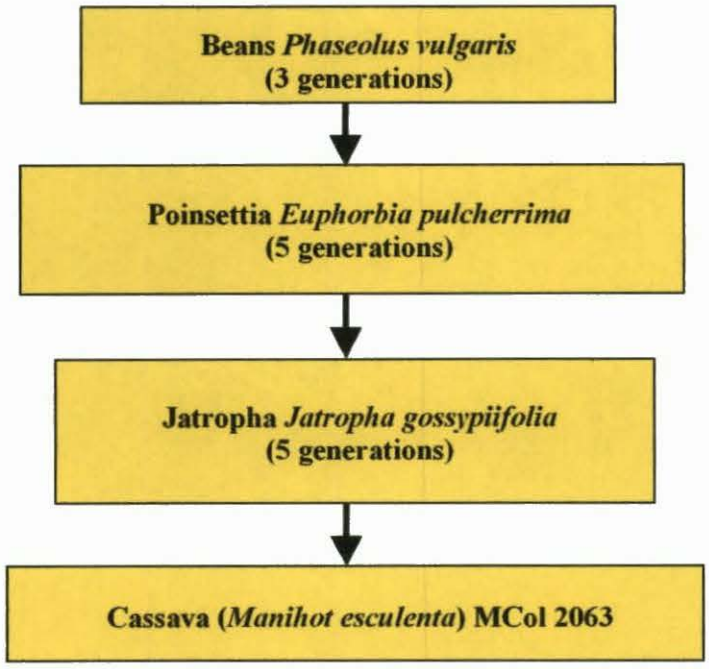

Figure 15. Plant species sequence for adapting the whitefly species, *Bemisia tabaci*, B. biotype from beans (*P. vulgaris*) to cassava.

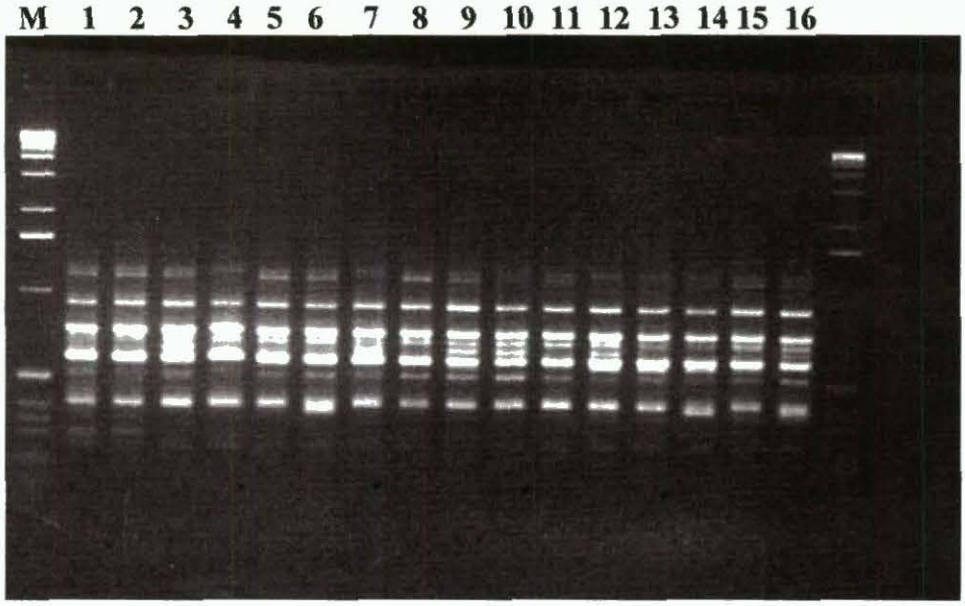

Figure 16. Amplification bands obtained using the H9 primer on *Bemisia tabaci*, B biotype individuals collected from different host plants; 1-4 biotype "B," 5-7 poinsettia, 8-10 bean, 11-13 Jatropha, and 14-16, cassava.

Results

Biotype B of *B. tabaci*, reared originally on beans, easily adapted, first to poinsettia and then on Jatropha. The colony remained stable on *J. gossypiifolia*, facilitating the establishment of the colony on cassava, variety MCol 2063. By first adapting to Jatropha, B. biotype of *B. tabaci* adults easily took to cassava, their populations multiplying rapidly (Figure 17).

The intrinsic rate of increase of B. biotype of *B. tabaci* populations on J. *gossypiifolia*

These studies were carried out in CIAT growth room (25±2°C, 70±5% RH, with 12 hrs. light). Adults utilized had been reared on *J. gossypiifolia* for 5 generations. Recently emerged *B. tabaci* adults were collected from the colony, sexed (1:1, M:F) and placed in small leaf snap cages (2.5cm diameter). At 24-hour intervals, adults were removed and transferred to another area of the leaf, until female death. Fecundity was estimated by the number of eggs oviposited in each 24 hour period.

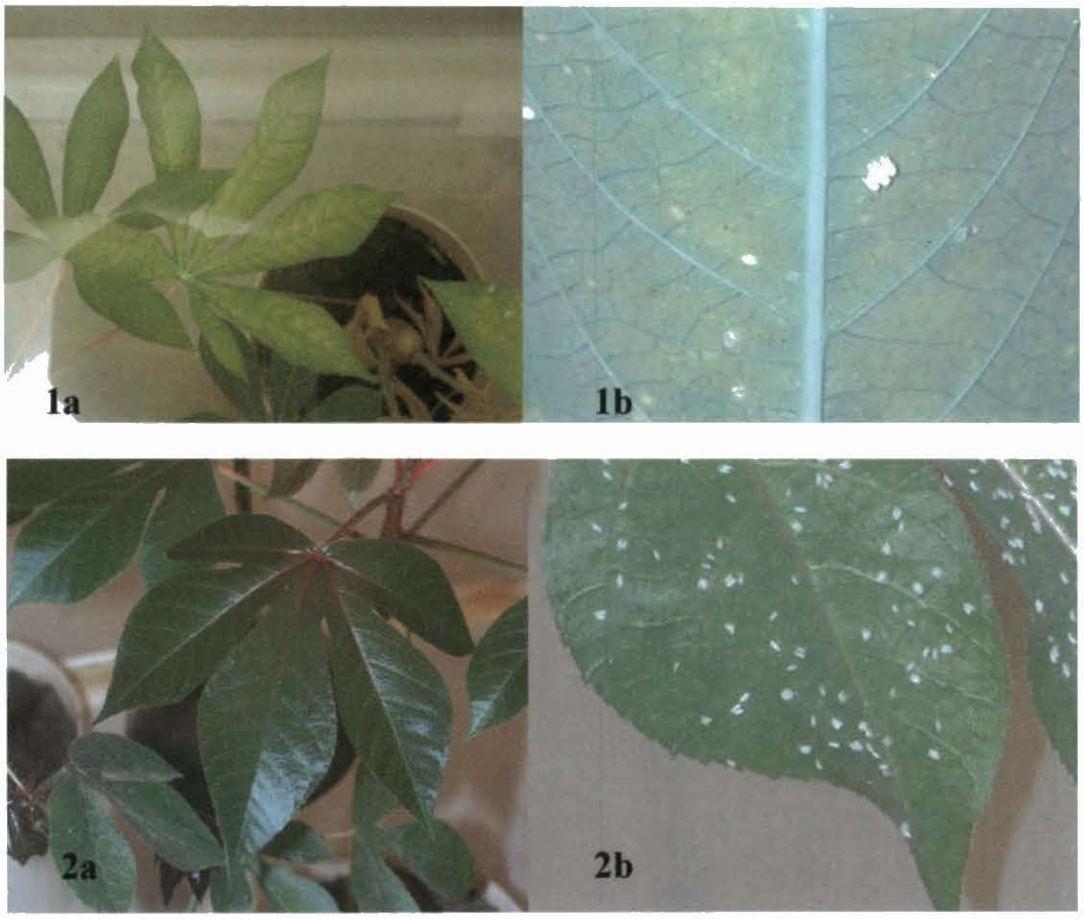

Figure 17. Adults and nymphs of "B" biotype of *B. tabaci* on cassava variety, MCol 2063 (1a and 1b), and Jatropha (2a and 2b).

Development time, survival rate, and female/male ratio were studied by placing 40 *B. tabaci* adults in leaf snap cages and allowing them to oviposit on the underside of Jatropha leaves. After 6 hours, adults were removed and 200 eggs of *B. tabaci,* B biotype were selected and allowed to develop. The development time and survival rate of immatures was recorded. By combining these data, the demographic parameters or life tables were developed. The net reproduction rate (Ro) represents the number of descendent females that females produce in each generation, and the generational time (T), is the period of time from parent birth to birth of the offspring. The intrinsic rate of increase of the population (IM) for the B biotype of *B. tabaci* was calculated using Carey's formula (1993).

$\sum \exp(-\square mx) lxmx=1$

Where: x = age

lx = age, specific survival
mx = proportion of female progeny of one female at age x

To calculate $\square m$ values, the age corrected as x + 0.5 was utilized.

Results and Discussion

Adult female longevity of *B. tabaci* on *J. gossypiifolia* was 30 days and fecundity was 23.8 eggs (Figures 18 and 19). The medium rate of oviposition (eggs/female/day) was 11.9.

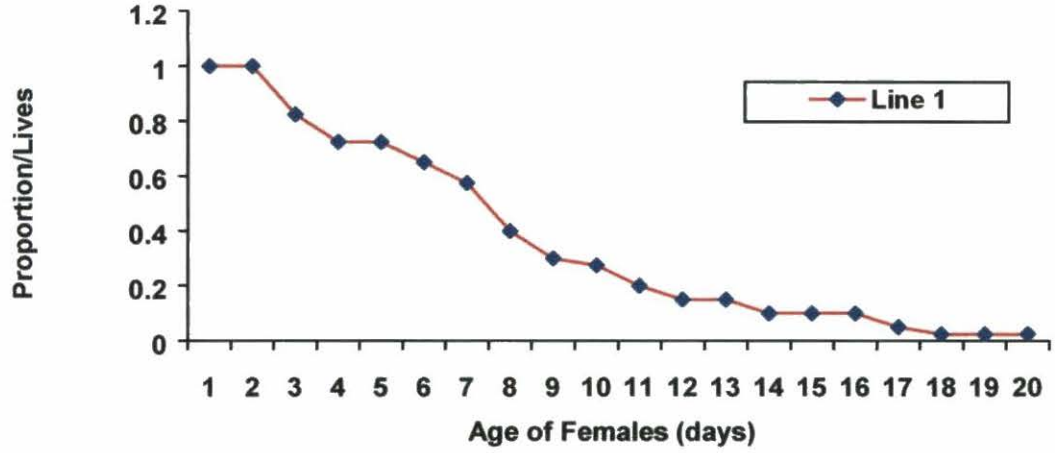

Figure 18. Survival curve of female whiteflies, biotype "B" of *Bemisia tabaci* on *Jatropha gossypiifolia.*

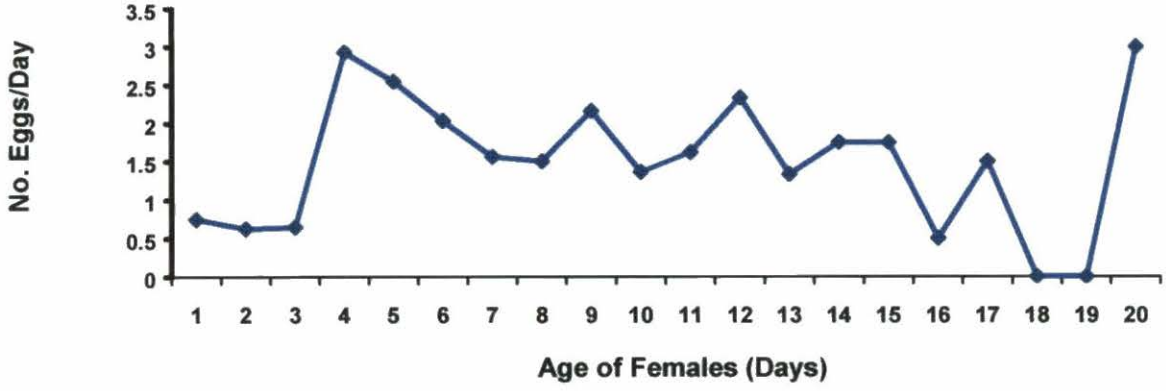

Figure 19. Reproduction curve of adult whitefly females of Biotype "B" of *Bemisia tabaci* feeding on *Jatropha gossypiifolia.*

Development time of B. biotype of *B. tabaci* on *J. gossypiifolia* was 32.5 days, and the survival rate of immatures was 46.5%. The female/male emergence was 49.46 and 50.54% respectively (Table 17).

Table 17. Demographic parameters (life table) of Biotype "B" of *Bemisia tabaci* whiteflies feeding on *Jatropha gossypiifolia*.

Parameters	J. gossypiifolia
	HR: 70±5% T: 25±2°C
Development time (Days)	32.5
Survival rate (%)	46.5
Proportion of females (%)	49.46
ſm, Intrinsic rate of increase of population (Days)	0.066
Ro, Net reproduction rate	66.298
∑lxmx	
T, generational time (Days)	37.474

Future Projection

The next stage of this research will be to determine the intrinsic rate of increase and demographic parameters (life stable) of B. biotype of *B. tabaci* on the cassava genotypes MEcu 72 (whitefly, *A. socialis*, resistant), CG 489-34 (moderately resistant) and CMC 40 (susceptible).

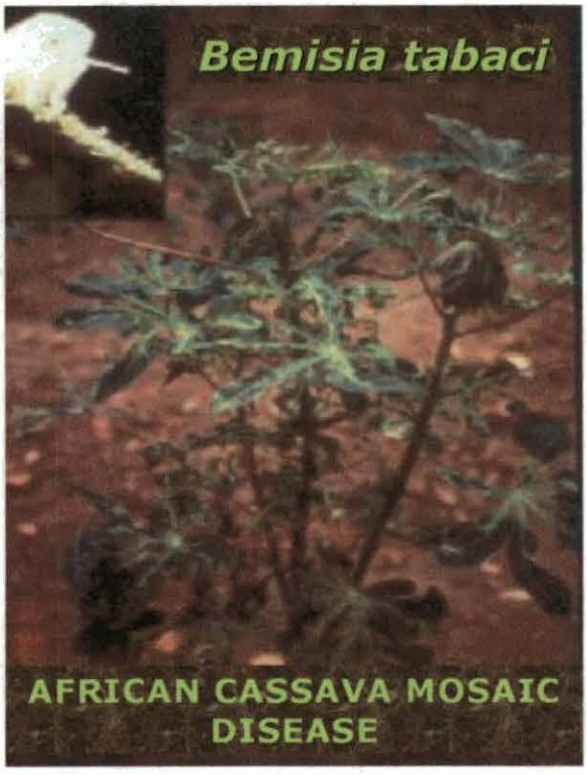

Photo: **The whitefly *Bemisia tabaci*, is the vector of African Cassava Mosaic Disease in Africa, where epidemics in recent years has caused considerable yield loss. A collaborative project with NRI in the UK is identifying resistance to *B. tabaci* in whitefly resistant CIAT genotypes.**

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Activity 5. Cassava genotype crossed to evaluate resistance inheritance

MEcu 72 has consistently shown high levels of whitefly resistance over more than 15 years of field evaluations. Field evaluations have been supported by laboratory studies. When feeding on MEcu 72, *A. socialis* had less oviposition, longer development periods, reduced size and high mortality than when feeding on susceptible genotypes (CMC-40). In addition crosses made between MEcu 72 and MBra 12, have produced hybrids with moderate to high levels of whitefly resistance, combined with good eating quality and high yields (see this report, Activity 3, page 24). These results support the observation that the whitefly resistance found in MEcu 72 is highly heritable.

During the 2000-2002 period MEcu 72 was crossed with MCol 2246; MCol 2246 is highly susceptible to whiteflies but is high yielding and an excellent plant type (upright growth, few primary stems and good stake production for planting material). Approximately 700 progeny were produced from this cross, planted during early 2001 and evaluated over the past 12 months for whitefly damage (resistance) as well as several agronomic and quality characteristics (Harvest index, root yield), dry matter, etc.). This trial was harvested in early April 2002 and the data provided will be analyzed in collaboration with "Crop and Food Research," Levin, New Zealand.

The trial was planted at the CORPOICA Field Experiment Station in Nataima, Tolima, Colombia. Whitefly populations were low during the initial months of the planting but increased to moderate to high levels as the trial progressed.

Only overall yield data will be presented at this time. Table 18 represents the 50 best or highest yielding progeny from this trial. A total of 50 progeny yielded 40 T/ha or higher. Although these results are based on only 3 plants of each line being harvested, these results are very encouraging. One line CM 8996-54 yielded over 80 T/ha; two lines CM8996-323 and CM 8996-48 yielded above 50 T/ha. All these progeny had low whitefly damage ratings (data not shown).

These primarily results are indicate that high yielding whitefly resistant hybrids can be produced and that the whitefly resistance is highly heritable. All 700 progeny have been replanted at two separate sites; the previously mentioned Nataima, Tolima site, and at Santander de Quilichao, in the Cauca Valley. The continued evaluation of these progeny over a period of several years will aid in identifying the genome inheritance of the whitefly resistance.

Table 18. Harvest data of selected progeny from a cross of the whitefly resistant cultivar MEcu 72 and the susceptible high yielding cultivar, MCol 2264, at CORPOICA, Nataima, Tolima, Colombia (condensed from a total of 701 progeny).

Clone	NPCS.	NRC	NRNC	PRC	PRNC	Weight Arial Plant	Total Weight/Plant	Harvest Index	Commercial Roots T/ha.	Air Weight	Water Weight	% Dry Matter
CM 8996-54	3	13	27	24.35	1.6	15.5	41.45	0.6260555	81.17	3400	257	29.24
CM 8996-323	3	19	3	21.65	0.9	12.1	34.65	0.6507937	72.17	2900	215	28.98
CM 8996-48	3	34	12	21.25	1.25	14.4	36.9	0.6097561	70.83	3200	230	28.56
CM 8996-216	3	22	12	20.85	1.6	19	41.45	0.5416164	69.50	2700	233	31.25
CM 8996-616	3	24	12	19.2	1.7	14.75	35.65	0.5862553	64.00	3000	284	32.85
CM 8996-706	3	20	17	18.7	3.35	11.2	33.25	0.6631579	62.33	2800	257	32.30
CM 8996-416	3	24	23	18.6	3.2	14.5	36.3	0.600551	62.00	3200	269	30.83
CM 8996-298	3	19	2	17.85	0.15	14.6	32.6	0.5521472	59.50	3200	287	31.90
CM 8996-506	3	21	10	17.8	1.55	16.1	35.45	0.5458392	59.33	3100	254	30.43
CM 8996-243	3	25	9	17.7	1.3	9.7	28.7	0.6620209	59.00	3200	345	35.43
CM 8996-449	3	26	14	17.7	2.25	14.15	34.1	0.585044	59.00	2800	229	30.40
CM 8996-608	2	16	6	16.6	1.15	8.6	26.35	0.6736243	55.33	3000	229	29.38
CM 8996-74	3	21	17	16.5	2.2	14.9	33.6	0.5565476	55.00	3000	221	28.89
CM 8996-643	3	26	19	16.2	2.3	11.7	30.2	0.6125828	54.00	3200	293	32.26
CM 8996-128	3	19	6	16	0.55	7.55	24.1	0.686722	53.33	3100	272	31.53
CM 8996-756	3	12	17	15.8	2.6	12.05	30.45	0.6042693	52.67	3400	313	32.35
CM 8996-353	3	27	10	15.6	1.85	13.85	31.3	0.557508	52.00	3000	318	35.07
CM 8996-592	2	25	27	15.5	4.5	11.65	31.65	0.6319115	51.67	3000	265	31.64
CM 8996-627	3	19	14	15.3	3	12.6	30.9	0.592233	51.00	3250	292	31.93
CM 8996-673	3	13	12	15.2	1.45	8.4	25.05	0.6646707	50.67	3300	270	30.41
CM 8996-206	3	22	8	15.1	1.3	12.1	28.5	0.5754386	50.33	2600	212	30.35

Clone	NPCS.	NRC	NRNC	PRC	PRNC	Weight Arial Plant	Total Weight/Plant	Harvest Index	Commercial Roots T/ha.	Air Weight	Water Weight	% Dry Matter
CM 8996-401	3	24	12	15	1.25	14.3	30.55	0.5319149	50.00	3200	281	31.54
CM 8996-487	3	16	10	14.85	1	8.2	24.05	0.6590437	49.50	3200	301	32.74
CM 8996-118	3	25	16	14.65	1.8	7.15	23.6	0.6970339	48.83	3500	303	31.30
CM 8996-217	3	28	11	14.3	1.25	10.65	26.2	0.5935115	47.67	3000	301	33.95
CM 8996-463	2	21	7	14.1	1.1	10.25	25.45	0.5972495	47.00	3400	286	30.84
CM 8996-259	3	21	12	14.05	2.1	8.35	24.5	0.6591837	46.83	3100	255	30.49
CM 8996-328	3	20	18	14	2.45	16.65	33.1	0.4969789	46.67	3000	262	31.45
CM 8996-42	3	22	22	13.9	3	14.4	31.3	0.5399361	46.33	3600	364	34.11
CM 8996-43	3	20	6	13.7	0.9	8.3	22.9	0.6375546	45.67	3300	282	31.09
CM 8996-638	2	19	5	13.65	0.9	5.75	20.3	0.7167488	45.50	3250	223	27.96
CM 8996-214	3	24	18	13.6	2.35	9.7	25.65	0.6218324	45.33	3000	296	33.63
CM 8996-467	3	20	8	13.6	0.9	9.45	23.95	0.605428	45.33	3200	313	33.46
CM 8996-712	3	16	16	13.4	2.7	8.7	24.8	0.6491935	44.67	3200	322	34.01
CM 8996-472	3	28	14	13.25	1.7	9.4	24.35	0.613963	44.17	2800	256	32.23
CM 8996-79	3	16	9	13.2	1.29	7.15	21.64	0.6695933	44.00	3000	271	32.02
CM 8996-508	3	19	14	13	1.9	14.1	29	0.5137931	43.33	3000	194	27.24
CM 8996-198	3	15	18	12.95	2.55	13.55	29.05	0.5335628	43.17	3000	291	33.30
CM 8996-63	3	22	16	12.9	1.9	10.5	25.3	0.5849802	43.00	3200	302	32.80
CM 8996-208	3	25	16	12.8	1.95	10	24.75	0.5959596	42.67	3000	335	36.20
CM 8996-426	3	19	6	12.8	0.9	6.65	20.35	0.6732187	42.67	3200	233	28.73
CM 8996-666	3	20	8	12.8	1.3	9	23.1	0.6103896	42.67	3400	304	31.84
CM 8996-714	3	14	10	12.6	1.7	5.55	19.85	0.720403	42.00	3300	318	33.18
CM 8996-30	3	21	10	12.4	1.35	9.7	23.45	0.5863539	41.33	3600	324	31.96

Clone	NPCS.	NRC	NRNC	PRC	PRNC	Weight Arial Plant	Total Weight/Plant	Harvest Index	Commercial Roots T/ha.	Air Weight	Water Weight	% Dry Matter
CM 8996-211	3	22	11	12.35	1.25	12.25	25.85	0.5261122	41.17	3000	247	30.50
CM 8996-155	3	18	19	12.25	2.7	7.65	22.6	0.6615044	40.83	3000	292	33.37
CM 8996-453	3	20	8	12.25	0.8	7.6	20.65	0.6319613	40.83	2500	241	33.19
CM 8996-443	3	20	6	12.2	0.9	6.9	20	0.655	40.67	3000	221	28.89
CM 8996-464	3	28	9	12.2	0.9	12.35	25.45	0.5147348	40.67	3000	275	32.28
CM 8996-398	3	22	18	12	2.55	14.1	28.65	0.5078534	40.00	3150	247	29.77

Photo 1: **Field evaluations of progeny from an MEcu 72 x MCol 2246 cross at Nataima, Tolima. Photo demonstrates high root yield and ideal plant type, producing abundant and high quality planting material.**

Photo 2: **Field evaluation at CORPOICA, Nataima, Tolima of cassava progeny from an MEcu 72 x MCol 2246 cross.**

Photo 3: **Field evaluations of cassava progeny from controlled crosses at CORPOICA, Nataima, Tolima for root yield, foliar production and other agronomic characteristics.**

Photo 4: **Cassava planting material prepared for shipment and replanting at CORPOICA, Nataima, Tolima. Differences in stake colour is an indication of genetic variability present in the MEcu 72 x MCol 2246 cross.**

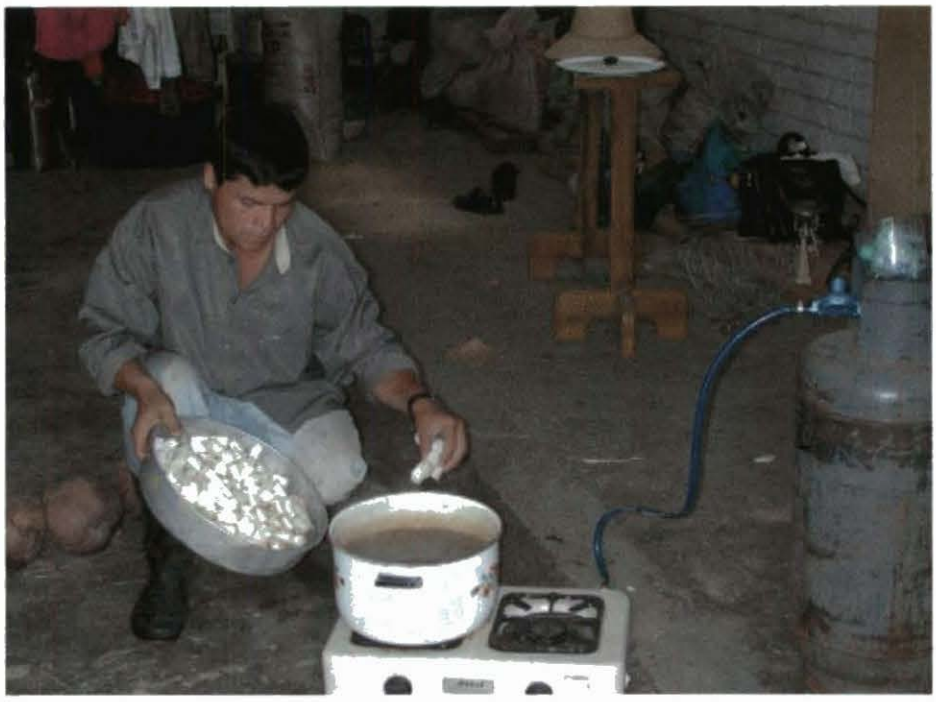

Photo 5: **Evaluation of cooking and eating quality of cassava roots of progeny from an MEcu 72 x MCol 2246 cross.**

Photo 6: **Field evaluations of cassava genotypes at CORPOICA, Nataima, Tolima; weighing and selection of cassava roots.**