1. Activities related to research on frog skin disease (FSD)

1.1 Characterizing cassava genotypes for their reaction to Frogsking disease (FSD) under field conditions

1.1.1 Rationale

Frogskin is currently considered as the disease that most limits cassava cultivation, causing losses of more than 90%. It affects not only farmers but also researchers—breeders, entomologists, physiologists, and others—whose research focuses on improving varietal yields and ensuring production stability[1]. Evaluations under controlled conditions to readily select undesirable materials are impossible. Without these methodologies, conducting yield trials and regional evaluations that are free of susceptible materials becomes increasingly difficult. Nor can susceptible materials be identified to monitor them and thus prevent the continual presence of disease-bearing inocula.

Compounding these problems is the factor of continuity in cassava-breeding programs. Continuity is particularly important because of the length of each selection cycle, which may be as long as 5 years. Hence, a constant risk exists of losing materials with significant traits such as yield, resistance to pests, carotenes, dry matter, and starch to severe attacks from the disease, cutting the cycle and putting back the experiments. Quarantines and closed seasons must be established, and materials cleaned through tissue culture. These processes are costly and time-consuming.

Pathologists are seeking the most efficient and lasting tools and methodologies that would speed up and improve the management of this disease. Increasingly, they focus more on using genetic resistance as a major component of the integrated management of frogskin disease. To do so, they work with classical and molecular breeders.

The objective of this work was to evaluate the resistance of elite clones and commercial varieties of cassava to frogsking disease (FSD).

1.1.2 Methodology

We selected 3 commercial varieties and 5 elite genotypes of cassava for their agronomic characteristics and evaluated their resistance under natural FSD pressure, on the farm at Santander de Quilichao (Cauca), where the disease is endemic.

For the evaluation the cassava plants were arranged in a randomized complete block experimental design involving treatments (varieties) with four replications. Evaluations took place on 6 months and 10 months after planting according to

1. Production stability is important for food security and is achieved when the material developed has genetic tolerance or resistance to the principal biotic and abiotic factors that limit production (CIAT 2002).

a scale of severity of 1 to 5, where 1 corresponded to root with no symptoms and 5 to fibrous root killed by the disease.

1.1.3 Results

Clone CM 4574-7, elite for agroecological zone 2, was the most resistant to the pathogen (Table 1). Other clones with resistance were Roja and Verde. The commercial variety CM 523-7 (ICA Catumare), showed field resistance in different regions of the Eastern Plains.

Table 1. Resistance of cassava genotypes to frogsking disease, at Santander de Quilichao (Cauca), Colombia.

Genotypes	Total roots weight (kg)	Commercial roots weight (Kg)	Dry matter (Kg)	Number of commercial roots	Severity %	Disease severity
CM4574-7	29.6a*	20.8a	31.7a	38a	0.1d	1c
MPER183	21.9ab	18.9a	46.5a	26ab	0.1d	1c
Roja	16.1abc	12.5ab	33.4a	18abc	4.2cd	1.1c
Mcol1505	17.2abc	11.4ab	38.8a	25abc	31.5b	2.2ab
Negra	16.9abc	11.8ab	35.9a	22abc	35.7ab	2.2ab
CM523-7	16.2abc	9.7ab	56.8a	20abc	23.7bc	1.8bc
Verde	6.7bc	2.3b	29.4a	4c	3.3cd	1.1c
NIG11	5.7c	2.0b	34.0a	5bc	53.5a	2.8a

* Values followed by the same letter are not significantly different according to the R-E-G-W ($P<0.05$).

In Table 1 the genotypes CM 4574-7, MPER183, and Roja were the most resistant genotypes, which had shown resistance in research carried out in previous years.

1.2 Severity of FSD in family GM 306 under natural inoculum pressure

1.2.1 Rationale

A new, enhanced scale of symptoms to assess severity for cassava frogskin disease has been developed but needed validation under natural disease pressure in the target environment. The present work was conducted to validate and if possible improve the current scale for measuring disease severity using the full sib cassava family GM 306.

1.2.2 Materials and methods

We evaluated 65 individuals of the cassava family GM 306 (M Ecu 72 [maternal, highly susceptible] × M Per 183 [paternal, tolerant]), encompassing genotypes GM 306-88 to GM 306-153.

Evaluating the current scale. For each genotype, we evaluated a plot of 7 plants (10 months old, harvestable) for their reaction to frogskin disease under natural inoculum pressure, using the scale described in Table 2.

Table 2. Scale currently used to evaluate the severity of infection of cassava frogskin disease.

Score	Category	Observed symptoms
0	Healthy plant	Roots have filled, no symptoms; peel is thin and flexible
1	Very light	Roots have filled; few fissures or lip-like splits
2	Light	Roots have filled; lip-like splits
3	Moderate	Fissures or lip-like splits; some reduction in root filling
4	Severe	Presence of reticulation or honeycomb in some or many roots
5	Very severe	Presence of reticulation or honeycomb in some or many roots; roots appear woody or fibrous

Evaluating descriptors for the scale. In addition to this evaluation, we considered each of three individual descriptors: A = brilliance of peel; B = number of lip-like splits or lips; and C = root thickness. Each descriptor was also evaluated according to a quantitative scale of 0 to 5 (i.e., 0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0), where:

- For descriptor A, 0 = normal peel brilliance and flexibility, and 5 = peel is very opaque and thick, with a cork-like texture;
- For descriptor B, 0 = no presence of lips, and 5 = lips are pronounced throughout the lengths of most of the plant's roots; and
- For descriptor C, 0 = normal root thickness, and 5 = thin roots with pronounced lips and presence of rootlets (Figures 1 and 2).

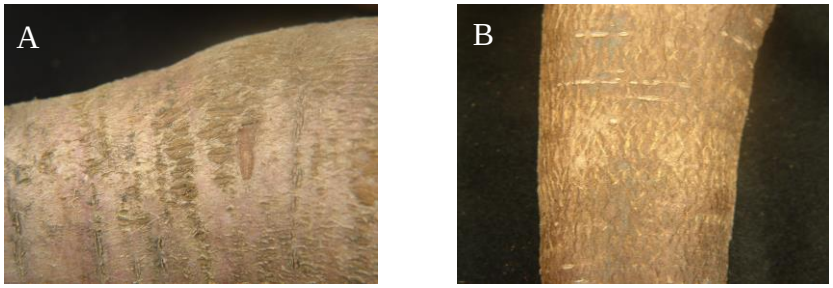

Figure 1. Number and intensity of lip-like splits in cassava roots, where, for example, grade 2.5 = lips are pronounced, but few in number and distributed irregularly (A); and grade 4 = lips are pronounced and regularly distributed throughout the root (B).

Figure 2. The extremes of the evaluation range for peel brilliance, where grade 1.0 = normal peel brilliance and flexibility (A), and grade 5.0 = peel is very opaque and thick, with a cork-like texture (B).

Evaluating the GM 306 cassava family with the 'Secundina' test to confirm the presence of the pathogen in the plant. In the greenhouse at CIAT, we planted 65 progeny genotypes, derived from sexual seed evaluated in the field. We use genotypes of the GM 306 Family as stock to graft on the indicator variety Secundina. The grafts were inoculated, and the reaction of each genotype evaluated. So far, symptoms have been expressed in the characteristic leaves of the indicator variety for only some genotypes. After completing three periods of evaluation, we hope to correlate the greenhouse observations with symptoms expressed in roots of genotypes established in the field.

1.2.3 Results and conclusions

We evaluated 368 plants and 2831 roots of 65 cassava genotypes from Colombia, finding high correlations (0.9) between fissures or lips on the roots with the current evaluation scale, and low correlations of root filling with peel flexibility and brilliance (0.3 and 0.4, respectively), indicating that the current scale takes into account mainly the most visible symptoms of the disease (i.e., fissures or lips) and these perhaps in very advanced stages. We observed a low correlation of the current scale with the disease's characteristic symptoms.

Based on these results, we propose a new scale for evaluating the severity of CFSD infection that would include not only the lip-like lesions observed on roots, but also root filling and the flexibility and brilliance of the outermost peel of the root (Table 3).

Table 3. Modifications to the scale of symptom severity currently used to Evaluate cassava frogskin disease.

Grade	Category of infection	Observed symptoms
0	**Healthy plant**	Roots have filled, no symptoms; peel is thin and flexible

1	**Very light**	Roots have filled; **few fissures** or lip-like splits **in some roots**; **peel slightly opaque and not very flexible**
2	**Light**	Roots have filled, with few fissures or lip-like splits **in many roots; peel opaque and brittle**
3	**Moderate**	**Greater number** of fissures or lip-like splits **in any part of the root** (basal, intermediate, and distal zones); some reduction of root filling; **peel opaque and brittle**
4	**Severe**	Presence of reticulation or honeycomb in some or many roots; **moderate reduction** of root filling; **peel is thick, cork-like, and brittle**
5	**Very severe**	Presence of reticulation or honeycomb in many roots; **severe reduction** of root filling; roots appear woody or fibrous; **peel is thick, cork-like, and brittle**

A scale of severity that clearly defines the initial, intermediate, and advanced symptoms of the disease may help prevent the dissemination of the pathogen and better characterize genotypes.

1.3 Field trials in the Department of Sucre, Colombia: results and analyses

1.3.1 Rationale

Field studies were conducted in the Department of Sucre on improved elite varieties of cassava with potential for human consumption and the starch and bioethanol agroindustries. The studies demonstrated the existence of different levels of tolerance of frogskin disease (FSD) among the varieties.

We evaluated 28 cassava varieties for resistance to FSD in the Department of Sucre, Atlantic Coastal Region, Colombia.

Evaluating resistance to frogskin disease

On the basis of CIAT's evaluation scale (2007), the clones used in the field trials fell into categories of "resistant", "tolerant", or "susceptible" to FSD, with none being "highly susceptible" (i.e., scoring 9.1 or more). The scores were as follows:

Highly resistant varieties, with scores ranging from 0 to 1.5:

SM 3106-5	SM 1565-17	CM 9912-126	SM 3190-34
GM 976-13	SM 1411-5		SM 3109-19
GM 437-26	SM 9955-12		

Susceptible varieties, with scores ranging from 3.1 to 6.8:

SM 3154-33	SM 3191-9	GM 259-167	CM 9955-14
CM 9912-173	SM 3128-14	SM 3061-31	SM 3191-9

Significant statistical differences ($P \leq 0.05$) were found between the most susceptible clones (SM 3154-33, with the highest average of 6.8, and SM 3191-9 with 3.2) and the most resistant clones (SM 3106-5 and SM 1565-17, both with 0.7; CM 9912-126 with 0.8; and SM 1411-5 with 0.9, which had the lowest values for severity) (Table 4).

Table 4. Scores for resistance to frogskin disease (FSD) in 26 improved cassava varieties, evaluated in the Municipality of Sampués, Department of Sucre, Colombia, trials.

Clone	Resistance to FSD[a]	Clone	Resistance to FSD[a]
SM 3154-33	6.8 a	SGB 765-2	1.9 defghi
GM 259-167	4.3 abc	SM 9946-108	1.7 efghi
CM 9955-14	4.1 abc	SM 9955-12	1.4 fghi
CM 9912-173	4.1 abcd	GM 437-26	1.4 ghi
SM 3128-14	3.9 abcde	SM 3109-19	1.4 ghi
SM 3061-31	3.7 abcdef	SM 9962-51	1.1 ghi
SM 3191-9	3.2 bcdefg	GM 976-13	1.0 hi
SM 2623-6	3.0 bcdefgh	SM 3190-34	1.0 hi
M Tai 8	2.8 bcdefgh	SM 1411-5	0.9 hi
CM 9962-31	2.3 cdefghi	CM 9912-126	0.8 i
CM 9958-106	2.3 cdefghi	SM 3106-5	0.7 i
Ginés	2.2 cdefghi	SM 1565-17	0.7 i

a. On a scale where 0 = resistant and 9 = highly susceptible. Values with the same letters in the column do not differ significantly, according to Duncan's test at 5%.

A third group of seven clones, scoring between 3.1 and 6.0 for tolerance of FSD, included those that were left to pollinate naturally (free pollination)—SM 3061-31, SM 3128-14, and SM 3191-9—and those with controlled (manual) pollination: GM 259-167, CM 9955-14, and CM 9912-173. The type of pollination, however, did not correlate significantly with resistance to FSD.

Of the resistant clones, some showed tolerance that is, scoring between 1.5 and 3.0. These clones were SM 2623-6, M Tai 8, CM 9962-31, CM 9958-106, Ginés, SGB 765-2, and SM 9946-108 (Table 4).

The clusters obtained from the "comparison of means" test showed clones SM 3191-9, GM 259-167, and CM 9955-14 as being the most susceptible, with scores ranging from 4.1 to 6.8. However, the clusters obtained through the scale test presented only one clone (i.e., 4%)—SM 3154-33—as being susceptible. Another 18 clones (65%) presented strong to adequate resistance to the disease (scoring 3 or less), while 8 (31%) clones were tolerant, scoring between 3.1 and 6.0. These results show that, overall, the clones performed well.

The commercial genotypes Ginés and M Tai 8 showed an intermediate resistance, scoring 2.2 and 2.8, respectively. Several clones, however, showed higher levels of performance than the two commercial ones. That is, 13 clones were more resistant to the disease than was clone Ginés (Table 4).

Nevertheless, clone Ginés was more tolerant than clone M Tai 8, which had 16 clones showing higher tolerance. Differences were as much as 75% when compared with the two most resistant clones (SM 3106-5 and SM 1565-17). Clones SM 1411-5 and CM 3106-5, were more resistant than M Tai 8. The finding of genotypes that performed better for the variable "resistance to FSD" than the commercial clones currently in use is significant. It should be

taken into account if commercial genotypes should develop increased susceptibility to the disease or if the disease becomes more aggressive in the zone.

Vegetative seed production

No statistical differences appeared for the quantity of seed produced per variety. On average, the varieties produced nine stakes per plant. That is, all the materials had normal seed production for the zone, as according to a CIAT study conducted in the Atlantic Coastal Region in 2003, when the Center obtained seven to eight stakes per plant.

Fresh-root yield

Significant differences appeared between treatments ($P \leq 0.05$) (Table 2). The clone that obtained the highest yield was SM 3106-5, with an average of 24.3 t/ha. These values contrasted with those for clones SM 3193-33, SM 3190-34, SM 3128-14, CM 9958-106, SM 3061-31, SM 3191-9, SM 3154-33, and SM 9955-12, which had yields ranging from 7 to 16 t/ha. Clone SM 3106-5 therefore has a good profile for industrial use in Sampués.

Table 5. Fresh-root yields (tons per hectare) of 26 cassava varieties evaluated in the Municipality of Sampués, Department of Sucre, Colombia.

Clone	Fresh-root yield[a]	Clone	Fresh-root yield[a]
SM 3106-5	24.3 a	GM 259-167	17.9 abc
CM 9962-51	23.0 ab	CM 9912-126	17.3 abc
M Tai 8	22.4 ab	SM 2623-6	16.9 abcd
SM 9946-108	20.9 abc	CM 9912-173	16.5 abcd
SM 1411-5	20.6 abc	Ginés	16.2 abcd
SM 3109-19	20.6 abc		
GM 976-13	20.5 abc	SM 3190-34	15.3 bcd
SM 3191-9	20.4 abc	SM 3128-14	14.0 cde
CM 9962-31	19.5 abc	CM 9958-106	13.4 cde
SM 1565-17	18.5 abc	SM 3061-31	12.8 cde
SGB 765-2	18.4 abc	SM 3191-9	9.3 de
GM 437-26	18.1 abc	SM 3154-33	7.7 e
CM 9955-14	18.1 abc	SM 9955-12	7.0 e

a. Values with the same letters in the column do not differ significantly, according to Duncan's test at 5%.

Clone CM 9962-51 (under manual pollination) and the commercial clone M Tai 8 respectively occupied second and third place for production. Clones SM 9946-108, SM 1411-5, and SM 3109-19 (all under free pollination) respectively ranked fourth, fifth, and sixth for fresh-root yield at 20.9, 20.6, and 20.58 t/ha, again respectively (Table 5). These clones look promising for use in industry as they show similar or superior yields and increased resistance to FSD as the commercial clone M Tai 8, currently the most heavily used variety in the zone.

Commercial clone Ginés produced only 16.2 t/ha, performing as one of the worst of the genotypes. This finding demonstrates the need to study new clones that have higher fresh-root yields. Clone M Tai 8 continues to perform as one of the best materials in the zone. However, it has tolerance to FSD (Table 4).

Table 5 shows that, overall, 15 of the 26 clones evaluated performed above average (i.e., >17 t/ha), with eight presenting yields of more than 20 t/ha.

Dry matter (DM) content

The percentage mean for dry matter for the clones evaluated was 27%. The clone with the highest average percentage of DM was SM 2623-6, with 28.8% (DM yield of 4.9 t/ha.). This was followed by clones CM 9962-51, with 28.1% (DM yield of 5.4 t/ha.) and SM 9955-12, also with 28.1% (DM yield of 2.0 t/ha). Significant differences found among treatments for DM content as tons per hectare are shown in Table 6).

Table 6. Evaluation of 26 improved cassava varieties in terms of selection indexes, showing data for fresh-root yield, percentage dry matter, harvest index, and resistance to frogskin disease (FSD), Municipality of Sampués, Department of Sucre, Colombia, trials.

Clone	Fresh-root yield (t/ha)	Dry matter (%)	Harvest index	Resistance to FSD[a]	Selection index
SM 3154-33	7.7	23.8	0.59	6.8	-51.3
SM 3191-9	9.3	23.3	0.56	5.2	-48.1
CM 9912-173	16.5	25.2	0.53	4.0	-19.4
SM 9955-12	7.0	28.1	0.53	1.4	-14.3
SM 3061-31	12.8	26.7	0.59	3.7	-11.2
CM 9955-14	18.1	24.7	0.61	4.1	-10.9
Ginés	16.2	26.1	0.52	2.2	-10.2
CM 9962-31	19.5	23.8	0.61	2.3	-7.2
SM 3128-14	14.0	25.8	0.66	3.9	-6.4
CM 9958-106	13.4	26.5	0.58	1.8	-6.3
SGB 765-2	18.4	25.8	0.54	1.9	-3.9
SM 1565-17	18.5	25.3	0.58	0.7	1.5
SM 9946-108	20.9	24.4	0.63	1.7	3.7
GM 259-167	17.9	26.8	0.65	4.3	5.7
SM 3193-33	16.0	26.3	0.65	1.7	6.9
SM 3190-34	15.3	26.6	0.63	1.0	7.2
SM 2623-6	16.9	28.8		3.0	10.7
CM 9962-51	23.0	28.1		1.1	10.6
GM 976-13	20.5	26.5	0.56	1.0	10.6
CM 9912-126	17.3	26.3	0.64	0.8	11.9
SM 3197-9	20.4	27.0	0.62	3.2	12.3
M Tai 8	22.4	26.2	0.61	2.8	12.6
GM 437-26	18.1	26.0	0.67	1.4	12.9
SM 3109-19	20.6	26.7	0.59	1.4	13.3
SM 1411-5	20.6	26.2		0.9	20.1
SM 3106-5	24.3	27.1		0.7	20.5
Average	17.1	27.4 for 25 var's			

a. On a scale where 0 = resistant and 9 = highly susceptible.

Table 7. Yield of 26 cassava clones in terms of tons of dry matter (DM) per hectare, Municipality of Sampués, trials.

Clone	DM (t/ha)[a]	Clone	DM (t/ha)[a]
SM 3106-5	6.6 a	CM 9962-31	4.6 abc

M Tai 8	5.9 ab	CM 9912-126	4.5 abcd
SM 3197-9	5.5 abc	CM 9955-14	4.5 abcd
SM 1411-5	5.4 abc	SM 3193-33	4.3 bcd
GM 976-13	5.4 abc	Ginés	4.2 bcd
CM 9962-51	5.4 abc	CM 9912-173	4.1 bcd
SM 3109-19	5.2 abc	SM 3190-34	4.1 bcd
SM 9946-108	5.1 abc	CM 9958-106	3.6 cde
SM 2623-6	4.9 abc	SM 3128-14	3.5 cde
GM 259-167	4.8 abc	SM 3061-31	3.4 cde
SGB 765-2	4.7 abc	SM 3191-9	2.5 de
GM 437-26	4.7 abc	SM 9955-12	2.0 e
SM 1565-17	4.6 abc	SM 3154-33	1.9 e

a. Values with the same letters in the column do not differ significantly, according to Duncan's test at 5%.

Although clone SM 2623-6 had the highest percentage of DM, clone SM 3106-5 had the highest DM yield at 6.6 t/ha (Table 7), with a percentage DM at 27.1%. For "weight of DM as fresh-root yield", this clone therefore performed as the best of the clones evaluated because of its high fresh-root yield.

The clones' overall percentage mean for DM content was low, compared with that obtained in other trials where averages were more than 30%. None of the clones evaluated surpassed this value. This finding may be attributed to a delayed harvest as a consequence of early rains in the area. The plants were therefore stimulated to produce new growth, thus expending energy and absorbing reserves. According to CIAT (2002), DM content diminishes considerably when a prolonged period of dryness is followed by a growth rebound.

Another situation to consider is the role that FSD plays in reducing the clones' DM content. Severe symptoms of FSD include the appearance of lip-like fissures covering the roots in a network or honeycomb pattern, tissues becoming cork-like (suberization), and reduced thickness in the roots. These symptoms may influence the accumulation of DM within the cassava plant, for example, clone SM 3154-33, which was the most susceptible of all the materials evaluated (Table 4), also presented the second-lowest percentage value for DM content (23.8%; Table 6).

On average, the clones yielded 4.4 tons of DM per hectare, with the best performers being SM 3106-5, M Tai 8, and CM 9962-51, which, respectively, produced 6.6, 5.9, and 5.4 tons of DM per hectare (Table 7). They were also among the best performers for fresh-root production (Table 5).

Harvest index (HI)

The ratio between roots and the rest of the plant (stems and leaves) in all clones was more than 50%, ranging from 52% to 67%, with no significant differences (Table 3). This indicates that all the materials evaluated had good harvest indexes. The best performer of the 26 clones was SM 1411-5, which also performed well for fresh-root production (at 20.6 t/ha; Table 5) and DM content (at 5.4 t/ha; Table 7). This genotype had also stood out for its high yields in regional trials conducted by CIAT in previous year.

Other clones with high harvest indexes were GM 437-26 (0.67) and SM 3128-14 (0.66) (Table 3). However, their performance was intermediate for fresh-root weight and DM accumulation. The commercial clones Ginés and M Tai 8 presented low and intermediate values for harvest index, with 0.52 for Ginés and 0.61 for M Tai 8 (Table 6).

In the case of Ginés, the roots produced only half of the plant's entire biomass, explaining the clone's low yield for fresh-root weight. Likewise, it explained the low DM content, which was one of the lowest of the 26 varieties evaluated. In contrast, M Tai 8 showed a better distribution of biomass towards the roots; its harvest index was 0.61 (Table 6).

Selection index

Clone SM 3106-5 had the highest value for fresh-root yield (Table 5). It was also one of the best clones for percentage of accumulated dry matter (27.1%; Table 3), the best for DM weight (6.6 t/ha; Table 7), and was the most resistant to FSD, scoring 0.7 (Table 6). Its selection index was therefore 20.5.

The clone with the second-best selection index was SM 1411-5, with 20.1 (Table 3). This material had also been evaluated by CIAT (2002) in different areas of the Atlantic Coastal Region and in evaluations carried out in the Department of Antioquia, with good results for production. However, it had not been evaluated for its acceptability in terms of resistance to FSD until the trials.

The third and fourth ranking clones for the selection index were SM 3109-19 and GM 437-26, respectively (Table 6).

Clone SM 3106-5, which had the best selection index (20.5), also had a fresh-root yield of 24.3 t/ha (Table 5), and a good percentage for DM (27.1%). It was also the most resistant clone to FSD, scoring 0.7 (Tables 1 and 3). Overall, it is a highly promising material for use in improving resistance to FSD in agronomically interesting varieties.

The use of a selection index enables us to more easily identify or select the best clones because it integrates, into one value, information on several traits. Thus, it facilitates the selection of clones with good yields and acceptable resistance to FSD.

CIAT (2002) considers clone SM 1411-5, which has the second-best selection index (20.1), as a representative of the new cassava generations for the subhumid areas of the Atlantic Coastal Region. Its high production potential can be regarded as a factor to take into account when replacing older, lower-yielding varieties. It also had the highest harvest index of the clones evaluated.

Clone M Tai 8 continues to consolidate itself as one of the best materials for the zone. We point out that only four clones (SM 3106-5, SM 1411-5, SM 3109-19, and GM 437-26) have higher selection indexes, and only two (SM 3106-5 and CM 9962-51) are higher yielding (Table 6). However, with a score of 2.8, clone M Tai 8 is less resistant to FSD than 16 clones, that is, 60% of all clones (Table 4).

The mean fresh-root yield for the 26 clones was 17.1 t/ha, and the average percentage of DM was more than 27% (Table 3). This is low, compared with CIAT's 2001, 2002, and 2003 trials in the region, when the percentages of DM exceeded 30%. These low values can be confidently attributed to a wet harvesting season (April) in which early rains caused new shoots to sprout and thus absorbing the plants' reserves of accumulated energy. However, we point out that clones SM 2623-6, SM 9955-12, CM 9962-51, SM 3197-9, and SM 3106-5 were the materials with the best percentages of DM, being 27% or more (Table 6). They can therefore be considered as having potential for conserving DM.

The selection indexes obtained for clones SM 3106-5 and SM 1411-5 (Table 6) corroborate the good traits that these materials had presented in the Atlantic Coastal Region where they had ranked among the best clones over several trials (Ceballos et al. 2002). Clone CM 9962-51 also stood out for yield, DM content (t/ha), harvest index, and resistance to FSD.

1.4 The field trials: Methodology

A varietal trial, located in Sampués, was harvested in August. The 38 varieties were:

CM 9912-12	GM 248-71	GM 273-82	GM 271-59
GM 924-3	GM 273-60	SM 3154-31	SM 3060-59
SM 3060-34	SM 3159-25	GM 291-90	SM 3106-14
GM 671-5	SM 3193-15	GM 976-9	CM 9954-74
SM 3158-26	CM 9912-16	SM 3150-17	GM 273-85
SM 3128-3	CM 9962-27	SM 3112-70	SM 3196-1
GM 290-78	CM 9910-46	CM 9912-1	GM 848-13
GM 279-64	GM 924-2	CM 9924-19	CM 2736-1

And the following commercial varieties:

Caiseli	Ginés	M Tai 8	Veronica
M Ven 25	M Ven		

Harvesting and data collection were conducted in September. The experiment was distributed according to a randomized complete block design, with 38 treatments (varieties) and three replications.

Crop management followed the farmers' traditional management in which two fertilizer applications and three manual weeding sessions were carried out throughout the year. Overall, insect pests and foliar diseases did not present problems for the trial.

1.4.3 The field trials: Results and analyses

For the parameter "fresh-root yield (t/ha)", the varieties with the highest yields were CM 9912-12, with a yield of 20.7 t/ha; followed by GM 273-60, with 19.1 t/ha; and GM 924-2, with 16.4 t/ha (Table 5). Of the commercial varieties, Ginés and M Tai 8, had the highest yields at 15.7 and 12.5 t/ha, respectively. The other four commercial clones had yields ranging from 8.9 to 2.7 t/ha (Table

5). These results demonstrate that several of the new genotypes evaluated were promising because of their high yields.

Table 8. Evaluation of 33 improved cassava varieties in terms of fresh-root yield, harvest index (HI), and resistance to frogskin disease (FSD), field trials.

Variety	Yield (t/ha)	HI	Resistance to FSD[a]
CM 9912-12	20.7	0.79	5.2
GM 273-60	19.1	0.88	4.4
GM 924-2	16.4	0.96	4.7
GM 271-59	16.3	0.87	3.3
GM 924-3	15.9	0.68	4.2
Ginés	15.7	0.68	6.7
SM 3060-34	13.7	0.51	6.1
SM 3159-25	13.6	0.77	3.5
SM 3154-31	12.7	0.82	4.7
SM 3106-14	12.6	0.74	4.3
GM 671-5	12.6	0.94	4.0
M Tai 8	12.5	0.75	3.9
GM 291-90	11.6	0.57	3.5
CM 9954-74	11.5	1.14	1.3
SM 3158-26	11.1	0.88	4.0
GM 976-9	10.4	1.04	2.9
GM 273-85	10.3	0.94	4.1
SM 3128-3	9.9	1.42	3.4
Veronica	8.9	0.72	5.9
SM 3150-17	8.9	1.27	4.3
SM 3196-1	8.6	0.79	4.5
Caiseli	8.5	1.29	6.5
CM 9912-16	8.1	0.76	5.2
SM 3112-70	8.1	0.99	5.0
GM 848-13	8.1	0.82	5.5
CM 9962-27	7.5	1.15	4.8
CM 9912-1	7.3	0.79	8.0
GM 279-64	6.7	0.85	2.7
CM 9910-46	6.5	0.95	1.0
CM 9924-19	6.4	0.49	3.0
M Ven 25	5.2	1.62	6.0
GM 248-71	5.0	2.05	2.2
M Ven	2.7	0.89	7.2

a. On a scale where 0 = resistant and 9 = is highly susceptible.

For the harvest index, genotypes with low ratios of foliage weight to total root weight were those of agronomic interest while those with high ratios were not so desirable in that they produced a lot of foliage and few roots. Harvest indexes for the high-yielding varieties CM 9912-12, GM 273-60, and GM 924-2 were high, ranging from 0.79 to 0.96 (Table 7). Commercial varieties M Tai 8, M Ven, and Ginés also had high, although lower, harvest indexes, ranging from 0.68 to 0.89 (Table 8). However, a low harvest index does not necessarily imply a high

fresh-root yield; for example, clone CM 9924-19 has the lowest HI at 0.49 but a low yield of 6.4 t/ha.

The evaluations of resistance to FSD in Sampués enabled us to discover that the 33 cassava genotypes were either resistant (18%), tolerant (67%), or susceptible (15%), with none being highly susceptible. Varieties with yields exceeding 15 t/ha were tolerant of FSD, with scores ranging from 3.3 to 5.2 (Table 8). These varieties were CM 9912-12, GM 273-60, GM 924-2, GM 273-59, and GM 924-3. The commercial clone Ginés was an exception in having an acceptable yield at 15.7 t/ha but a susceptible reaction to FSD, scoring 6.7 (Table 8).

Clones showing resistance (CM 9924-19, GM 976-9, GM 279-64, GM 248-71, CM 9954-74, and CM 9910-46) tended to have lower yields, ranging from 5.0 to 11.5 t/ha and variable harvest indexes that ranged from the lowest at 0.49 to the highest at 2.05 (Table 8).

The remaining 21 materials were either tolerant or susceptible, with low yields ranging from 2.7 to 13.7 t/ha (Table 8).

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1.5 Induction of flowering in cassava through grafting, photoperiod manipulation and exogenous application of plant growth regulators.

5.1 Rationale

Commercial multiplication of cassava is achieved through stem cuttings. Sexual reproduction, a key requirement for cassava breeding, is common and relatively easy to achieve. Inflorescences always develop at the apex of the stem. Sprouting of the buds below the inflorescence allows further growth of the plant. Therefore, every flowering event results in branching. Some genotypes flower frequently (3-5 times during a growth cycle) and others flower little or late. Erect, non-branching types, however, are often preferred by farmers because they facilitate cultural practices, enhance the production of stems (the vegetative planting material), and transport and storage of non-branched stems is easier. The long stems of non-branching types tend to retain their sprouting capacity for longer storage periods, thus it has become an important adaptive trait (Ceballos et al., 2011).

Synchronization of flowering for planned crosses can be a challenge because some clones flower relatively early at 4 or 5 months after planting (MAP) whereas others flower only after 10 MAP. The scarcity of flowers in erect, non-branching types only complicates matters further. Accelerating flowering in cassava would facilitate the routine operations in crossing nurseries, reducing the costs of operation and speeding up the production of segregating progenies. Moreover, the need for a protocol to accelerate flowering in cassava has become more urgent in recent years. The advantages to introduce inbreeding in cassava genetic enhancement have been demonstrated (Ceballos et al., 2015; 2016). Accelerated flowering would facilitate the development of inbred progenitors through successive self-pollinations. Induction of flowering in cassava would also allow taking full advantage of the benefits that genomic selection could offer to the crop.

5.2 Materials and methods

Three different approaches have been used to induce flowering in cassava: i) Grafting branches from non-flowering genotypes on an early, profuse flowering understock; ii) Extending the photoperiod with red light; iii) Exogenous application of plant growth regulators.

5.3 Results

The work is still ongoing but already positive results have been obtained. The research through grafting is more advanced.

5.3.1 Induction of flowering through grafting

Six non- or late-flowering genotypes were selected for grafting on a profuse, early flowering understock. Grafted stems did not branch and flower while attached to the understock. Four cuttings from each grafted stem were taken and planted the following season. Paired-row cuttings from non-grafted stems of the same genotypes were planted as checks. Three phenotypic responses to grafting were found. One genotype failed to branch and flower, independently of the origin of the cuttings. Four genotypes branched but did not produce flowers. However, plants from grafted cuttings tended to branch earlier, particularly after the second branching event. Finally, in one genotype (SM3348-29), grafting induced not only earlier branching but also earlier and

more abundant production of flowers, fruits and seeds than their counterparts of plants from non-grafted stems. This is the first report of grafting effects on the induction of earlier flowering in cassava. Results indicated a delayed effect of grafting which was genotype-dependent based on materials used in this study. The contrasting responses to grafting may be useful for understanding the effect of plant growth regulators and photoperiod manipulations of ongoing research. A manuscript describing this research has been accepted for publication in the *Journal of Plant Breeding and Crop Science.*

The pioneering grafting work revealed that responses are genotype dependent: not all genotypes responded similarly. Further work used three genotypes representing the three phenotypic responses observed in this study: *i)* grafting did not induce branching, nor flowering (NB/NF); *ii)* grafting induced earlier branching but not flowering (EB/NF); *iii)* grafting induced earlier branching and profuse flowering (EB/PF).

By mid-2016 a follow up experiment was planted to determine if the induction of earlier flowering in one of the six genotypes initially used, would remain active during a second season after grafting.

5.3.2 Induction of flowering through extension of photoperiod
This work is done in collaboration with Cornell University. The hypothesis is that providing additional red light after sunset would trigger earlier flowering in cassava, based on the assumption that cassava is a long-day species. The influence of photoperiod on flowering has been known for many years (Tornois 1914) and successfully used in different crops (Searle and Coupland, 2004).

Figure 4 illustrates how the plots looked in the evening hours. Six different genotypes were used to assess the impact of photoperiod in timing and abundance of flowering. The research took advantage of the more advanced work based on grafting, which had demonstrated that genotypes responded differentially to grafting. Three genotypes representing the three differential reaction to grafting (NB/NF; EB/NF and EB/PF) were included in the photoperiod study. The fourth genotype was an “asparagus” cassava plant type that is very reluctant to flower (Figure 2). The remaining two genotypes were chosen because they typically flower at about 5-6 (GM971-2) and 7/8 months (CM4919-1) after planting, respectively. Four different red light intensity levels were used based on 5 or 10 individual LED lamps (maximum wave length at 634 nm) and one or two 20-cm LED tapes (maximum wave length at 649 nm) per plant. LED lights were on at sunset, throughout the night, until sunrise.

Results of this ongoing research are already positive. The two genotypes of intermediate and late flowering (GM971-2 and CM4919-1) responded uniformly across the four LED intensity treatments by a considerably earlier flowering compared with the checks that were not illuminated. In addition, the genotype that responded favorably to grafting (SM3348-29) branched considerably earlier than in the non-illuminated check, but failed to flower. Finally, a similar response (branching without flowering) was observed in the “asparagus” cassava.

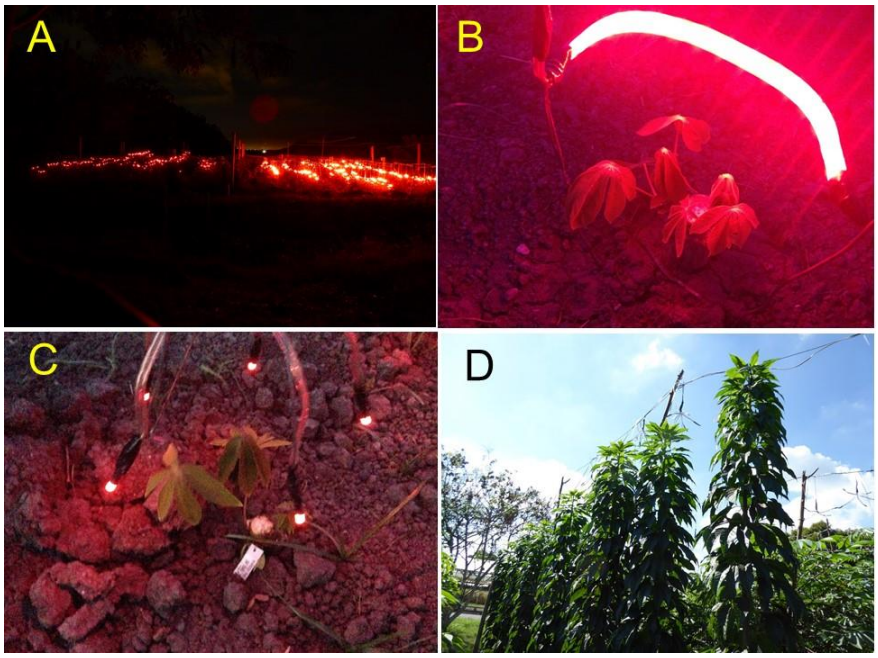

Figure 4. Illustration of the experiment to induce flowering through an extension of the photoperiod. **A.** A photograph showing two of the four levels of light intensity; **B.** A plant illuminated with the third most intense light intensity (a LED tape 20 cm long); **C.** A small plant illuminated with the lowest light intensity (5 LED lights per plant); **D.** Photograph of the "asparagus" cassava plant type which is very reluctant to flower. Note how the LED lights had to be moved to adjust their position to the growth of the plants below.

5.3.3 Induction of flowering through the application of plant growth regulators (PGR)

This work is also done in collaboration with Cornell University. Flowering in plants is under genetic control and eventually involves some type of plant growth regulator (PGR) as reported in other crops. The exogenous application of PGR induce flowering not only in angiosperm species (Aliyu et al., 2011; Henny and Chen, 2011; Liverman and Lang, 1956) but also in gymnosperms (Luukkanen and Johansson, 1980). The same six genotypes described above for the photoperiod experiment were used in this experiment. Four treatments were used: *i)* Silver thiosulfate (STS); *ii)* Benzyladenine (BA); *iii)* BA + STS; and *iv)* water control. Figure 5 illustrates key results of this experiment.

The results of PGR were similar to those of extended photoperiod. Genotypes GM971-2 and CM4919-1 flowered considerably earlier and more abundantly than the respective non-treated checks (Figure 4). More importantly, all treated "asparagus" plants branched and flowered whereas the untreated check did not branch, nor flowered. "Asparagus" plants under extended photoperiod branched but did not flower. The application of PGR also resulted in some toxicity symptoms on the leaves and also induced sprouting of axillary buds (Figure 4).

Figure 5. Effect of the application of a combination of Silver thiosulfate and Benzyladenine. **A.** Inflorescence in the "asparagus" cassava; **B.** Comparison of treated (foreground) and untreated (background) "asparagus" cassava; **C.** Induced flowering in genotype GM971-2; **D.** Toxicity symptoms from the application of growth regulators; **E.** Another side effect of the application of growth regulator is the induction of sprouting of axillary buds.

5.4 Conclusions

Table 9 provides a summary of the differential response to grafting, photoperiod duration and the addition of plant growth regulators. The relevant conclusions are that different stimuli can elicit a differential reaction by different genotypes. Genotypic dependency is, therefore, obvious from this experiments. Also evident is that CIAT now has alternative approaches to induce early flowering in genotypes that have been difficult to cross. Particularly relevant is the fact that now crosses using the "asparagus" plant type are feasible and practical. It is possible, therefore, to start a breeding project to take advantage of this unique plant type. Finally, the differential response of different genotypes as described in Table 9, offers an ideal genetic material for further elucidating the genetic control of flowering in cassava.

Table 9. Summary of the different responses of contrasting cassava genotypes to strategies to induce earlier and more abundant flowering[a].

Genotype	Check		Grafting		Photoperiod		PGR	
	Branch	Flower	Branch	Flower	Branch	Flower	Branch	Flower
GM 3500-9	+	-	++	-	Not available			
SM 3402-42	+	-	++	-	Not available			
SM 3409-42	+	-	++	-	Not available			
SM 3409-43	-	-	-	-	+	-	-	-
GM 3500-2	+	-	++	-	+	-	+	+
SM 3348-29	+	±	++	++	+	-	-	-
GM 971-2	++	+	Not available		+++	++	++	++
CM 4919-1	+	±	Not available		+++	++	++	++
GM 3893-65 (Asparagus)	-	-	Not available		+	-	++	++

a Responses for branching or flowering. (-) Negative response; (+) Limited response, few flowers or late branching/flowering; (+) Positive response, intermediate number of flowers or time to flowering; (++) Positive response, considerable number of flowers or early flowering; (+++) Abundant number of flowers and very early flowering.

6. Evaluation of a new plant type for cassava that may lead to a "Green Revolution" for this crop.

6.1 Rationale

Genetic gains for root productivity in cassava have reached a plateau in the last two decades. Ceballos et al. (2015) suggested some alternatives to change this situation and emphasized that molecular approaches such as marker-assisted selection (MAS) or even genomic selection would **not** be among the viable alternatives. Before these technologies can provide the benefits that they have provided for other crops basic technological needs are required in cassava. Among these needs are the possibility of using inbred progenitors and the induction of flowering. The progress report provided above illustrates the coherence and holistic approach followed by CIAT researchers working in the genetic improvement of this crop.

One alternative to restart genetic progress relies on exploiting a new plant type developed at CIAT. This plant type is characterized basically by two features: the absence of petiole and branching/flowering. It is what was nicknamed "*asparagus cassava*" because of the narrow cylindrical plant shape and was already mentioned in the previous section. Genetic gains in maize over the last century can be summarized by a single strategy: increasing plant densities (Duvick, 2005). Changes in plant architecture were essential for the Green Revolution in wheat and rice as well. As soon as the "asparagus cassava" was identified scientists at CIAT realized its potential as a new plant type for the crop, and its potential for implementing a Green Revolution for cassava. However, before doing anything else two requirements needed to be fulfilled: *i)* A way to facilitate crosses among this "shy" flowering plant type (and the previous section has provided evidence that this problem has been successfully overcome); and *ii)* Demonstrate that cassava (as modern maize) responds positively to high planting densities.

6.2 Materials and methods

Three "normal" cassava plant types (HMC-1, CM 523-7 and CM 4574-7) and three "asparagus" cassava genotypes (GM3893-65, GM3920-19 and GM3923-2) were evaluated in replicated trials for two consecutive years. The "normal" types are in fact commercial varieties releases by their high productivity. They were chosen because of their outstanding productivity and because they offered interesting variation regarding plant architecture (from early to late branching).

In addition to the six genotypes and the two seasons these trials were grown, each genotype was planted at four different plant densities, starting at 10,000 plant/ha (which is the standard for cassava. In addition the trials included the following plant densities: 21,000; 37,000 and 42,000 plants/ha. The main interest was to assess if the asparagus cassava responded differentially better to high densities than the commercial "normal" plant types.

6.3 Results

The analysis of variance combined across the two years of evaluation is presented in Table 10. Two key parameters were analyzed (fresh root yield and dry matter content). For fresh root yield most sources of variation were statistically significant. For dry matter content only years and genotype resulted in significant differences. Figure 5 summarizes the averages if the three asparagus and three normal plant types across the four planting densities. On average the asparagus plant type responded slightly better than normal plant types to higher plant densities.

As expected the asparagus clones yielded considerably less than the commercial varieties. The latter had been selected because of their high productivity and their outstanding performance had been confirmed over the years. The asparagus cassava, on the other hand was only selected because of their particular plant architecture, but its root productivity had never been analyzed, nor selected for. These results, therefore, are not surprising.

Table 10. Analysis of variance for the agronomic performance of three "normal" and three "asparagus" cassava plant types evaluated in four different plant densities during two consecutive years.

Source of variation	df	Mean squares	
		Fresh root yield (FRY)	Dry matter content (DMC)
Year (Y)	1	4420.62**	189.01**
Rep(Y)	4	203.91**	2.06
Genotype (G)	5	1366.80**	70.35**
Density (D)	3	346.49**	6.80
G*D	15	19.88	1.70
G*D*Y	23	118.84**	2.18

** Significant at the 0.01 probability level

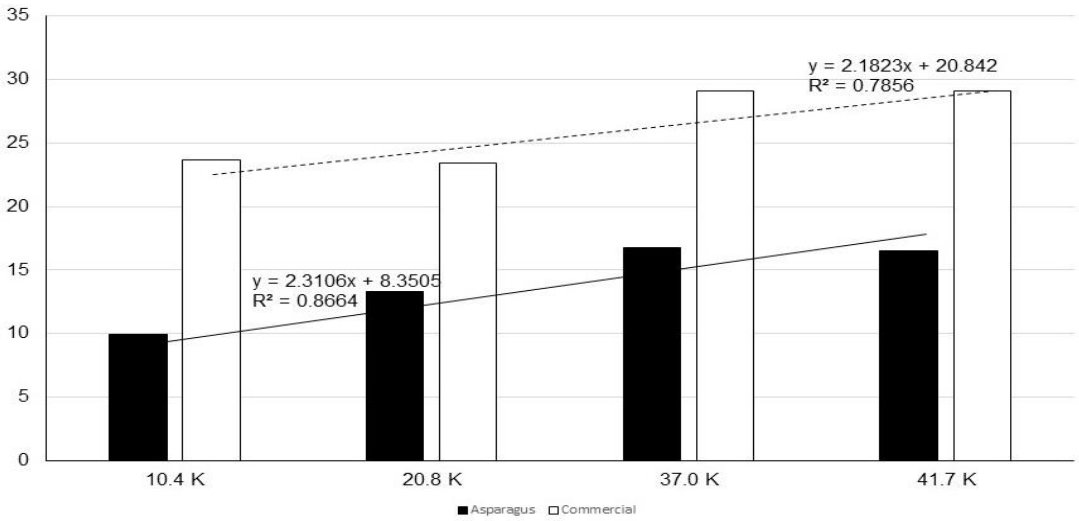

Figure 6. Response of three asparagus (black boxes) and normal plant type cassava clones (white boxes) to four different plant densities (ranging from 10,400 through 41,777 plants/hectare). Response measured in ton/ha of fresh root yield.

6.4 Conclusions

The availability of a method to make crosses among "shy" flowering cassava genotypes opens up the possibility of initiating a breeding program to take advantage of the special plant architecture offered by the asparagus plant type. Hopefully, in this selection process materials that are particularly productive at high planting densities will be identified.

7. Evaluation of new alternatives for controlled pollinations in cassava.

7.1 Rationale

For four decades cassava breeding has been done following basically the same scheme. The incorporation of molecular markers technology has not change the process. In fact, there is no reported application of marker-assisted selection (MAS) in spite of large financial investments in the technology and the two decades since the publication of the first molecular map in the crop (Fregene et al., 1997). As stated in the section related to the induction of flowering, one of the bottlenecks that need to be solved relates to the efficiency in the production of segregating botanical seeds (Ceballos et al. 2016). The protocol for controlled pollinations in cassava was published almost four decades ago (Kawano, 1980) (Figure 5). At that time, however, the limits for outcrosses were relatively relaxed as the main objective was to create genetic variability and certainty of the actual progenitors was not as critical as it is today. With the advent of molecular markers technology certainty of the origin of pollen is fundamental. Even for basic research for development of protocols for the production of doubled haploids through gynogenesis, androgenesis or wide crosses certainty of events related to fertilization are important. The cassava community, however, finds itself with a huge vacuum of knowledge in this regard. The objectives of this work were *i)* to clearly define the time the stigma in the female flower remains receptive; *ii)* test alternative methods for more efficient and reliable controlled pollinations.

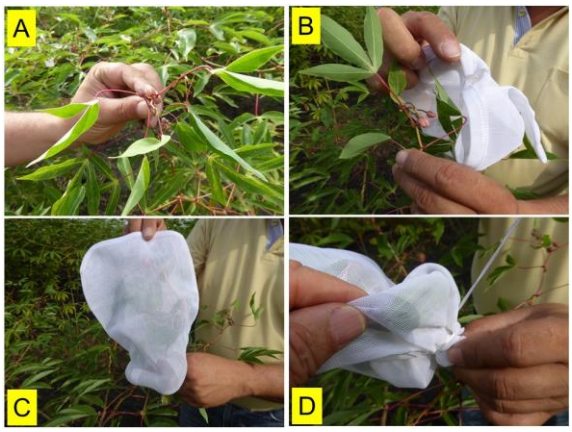

Figure 7. Illustration of the conventional method for controlled pollinations in cassava. **A.** Identification of female flowers before anthesis; **B and C.** Covering of the inflorescence with a mesh bag; **D.** Closing of the bag to prevent bees accessing to flowers inside.

7.2 Materials and methods

The duration of stigma receptivity, hundreds of female flowers from different genotypes were covered at anthesis with bags for one, two, three and four days and then uncovered. Flowers were clearly identified and monitored through time. As expected many of these flowers that could not be pollinated (and fertilized) because of the bags covering them, would abort within one or two weeks after anthesis. But the key response was to monitor number of flowers that eventually produced fruits and seed.

Several alternative approaches for controlled pollinations were also evaluated: **a)** The use of glue and a cotton tuft after pollinations have been made (Figure 8); **b)** The use of a plastic straw, with or without the removal of bracts (Figure 9); and **c)** The use of a new plastic bag (Figure 10).

Figure 8. The day after pollination (when pollen tube is expected to have reached the embryo sac in the ovule), the stigma is covered with glue (**A**) and a piece of cotton is added (**B**) to prevent bees pollinating the stigma. The stigma remained protected even after a severe rainfall (**C**).

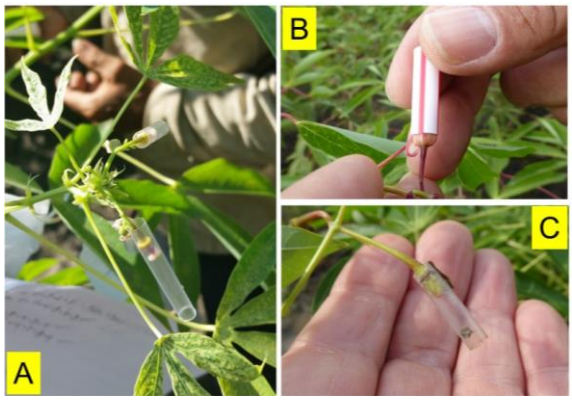

Figure 9. Flowers were pollinated and immediately after covered with plastic straws of different diameter. (**A**) Bracts were removed in some cases. (**B**) Wider plastic straws could be used without the need of bract removal. (**C**) If the straw is transparent, it was easy to observe when stigma dropped from the developing fruit.

Figure 10. Illustration of the new plastic bags that have small pores that allow air flow and prevent condensation of moisture.

7.3 Results and conclusions

This study is still going on as results need to include different genotypes and environmental conditions. However few conclusions can be drawn with the results already obtained.

Receptivity of stigma

Covering the flowers for one or two days after anthesis is not enough as an unacceptable proportion of flowers develop into seed-bearing fruits. This is an important and relevant conclusion as the standard procedure used in breeding projects usually removed the bags two days after anthesis. Covering the flowers for three days resulted in an unacceptable number of flowers developing into fruits. Upon analysis of the fruits many of them were seedless, but some of them still had one or two loci carrying seeds that may or may not have been viable. Covering the flowers for four days did not result in fruit formation. It is therefore recommended that for special studies when undesirable pollen needs to be prevented, flowers need to be covered for at least three days.

Alternative methods for controlled pollinations

Controlled pollinations have two basic requirements. They must prevent the occurrence of undesirable pollinations (e.g. presence of unwanted pollen) but must also promote maximum seed production of the desired cross. New methods should additionally be less expensive and faster the current system. The use of plastic straws was not satisfactory because often they fell and therefore the stigmas were exposed to undesirable pollinations. The use of glue and cotton was time consuming. The use of the new plastic bags, on the other hand, offered excellent results with minimum degree of contamination (e.g. formation of fruits in unpollinated flowers) and excellent seed set.

8. Selection for high dry matter content in roots from genotypes adapted to the acid soil savannas

8.1 Rationale

The eastern savannas of Colombia offer an ideal environment to select cassava clones adapted to acid soils and two important diseases (cassava bacterial blight or CBB and super-elongation disease or SED), which are prevalent and severe there. CBB is induced by *Xanthomonas axonopodis* pv. *Manihotis* also known as *X. campestris* pv. *Manihotis*. SED is induced by the fungus *Sphaceloma manihoticola* (Teleomorph: *Elsinoe brasiliensis*). As already stated above, improving fresh root yields in cassava has proven to be very difficult after the first couple of generations releasing improved varieties. Improving dry matter content (DMC), on the other hand, is easier and still offers potential for improvement (Ceballos et al., 2015; Kawano, 2003; Kawano and Cock, 2005).

The main objective is to identify cassava clones that have competitive levels of fresh root productivity and outstanding DMC in the roots. Harvests took place at the typical age (10-12 months after planting – MAP) when DMC reaches a maximum. But a distinctive feature is planting was done so that harvest could also take place at two additional ages from 16 through 20 MAP. The aim of this

"extended" harvest was to identify clones whose roots show a good stability of DMC. Farmers harvest cassava at the end of the dry season for two reasons: DMC is at a maximum and stems would have to be stored for a short period until the rains resume (Ceballos et al., 2011). Stems and roots are harvested at the same time and this offers a win-win alternative because root quality is excellent and the stems would be stored for few weeks until needed for planting a new season. A major impact of climate change, however, is the uncertainties regarding the beginning and end of the rainy season. If rains arrive before farmers can harvest their plots, cassava will reinitiate its growth which results in a drastic reduction of DMC (e.g. from 35 to 28%) which sharply reduces income. The roots of some clones have the capacity to quickly recover the commercial levels of DMC, whereas those of other genotypes never go back to acceptable levels of DMC. In other words, the stability of DMC is under genetic control and thus amenable for improvement.

8.2 Materials and methods

The cassava breeding program at CIAT is conducting this research in two stages. First a large population of segregating genotypes combining resistance to CBB and SED and high and stable DMC was developed and selection is going on to identify a relatively small number of genotypes that show excellent agronomic performance (resistance to CBB and SED, and competitive productivity at harvests done at the standard age of 10-12 MAP). Then, once the number of genotypes has been reduced and the availability of planting material increased, the genotypes will be planted in trials that allow harvests at about 11, 16 and 20 MAP in order to identify genotypes which also have stable DMC.

Evaluations were conducted in the eastern savannas of Colombia in the Meta Department. More than 650 genotypes were grown in a clonal evaluation trial (CET) which is the first stage of selection in the breeding scheme used at CIAT (Ceballos et al., 2016). This trial was harvested in April 2016 and a preliminary yield with the selected materials planted immediately.

8.3 Results

As expected there was a lot of segregation for the reaction to CBB and SED. Table 11 summarizes the results obtained from the CET harvested in April 14, 2016. The first variable described in the plant type score. This score is a visual assessment integrating plant architecture and vigor, as well as reaction to CBB and SED. A score of 1 means an excellent plant type. A score of 5 is a very poor plant architecture with early branching, tendency to lodge, poor vigor and/or unacceptable levels of CBB or SED. The second variable described in Table 11 is root score which also ranges from 1 (good) to 5 (bad). The following three variables are dry matter content, fresh root yield and a combination of these two (dry matter yield).

Table 11. Main results of the clonal evaluation trial (CET) planted in the acid soils environment of Colombia. A total of 656 experimental clones and 12 checks were evaluated.

Parameter	Plant type	Root	Dry matter content (%)	Fresh root yield (t/ha)	Dry matter yield (t/ha)
	Score (1 to 5)				
Minimum	1	1	17.37	1.22	0.34
Maximum	4	5	40.03	33.19	11.59
Average	2.94	2.73	35.02	16.24	6.50

St. Dev.	0.89	0.82	2.72	5.66	1.80

In this particular environment a dry matter yield above 6 t/ha is considered very competitive. As shown in Table 11, the average DMY was 6.5 t/ha. However, this figure may be misleading because almost half of the genotypes did not have available data for this variable because of unavailable data on FRY, DMC or both variables. Data for this variables would be missing as a result of susceptibility to diseases, deficient vigor or just lack of translocation of energy into the roots. What is important, however, is that as many as 234 genotypes showed DMY above 6 t/ha.

Based on the results of the CET described in Table 11, a group of 208 clones were selected and are currently growing in a replicated preliminary yield trial. These materials will be harvested in April 2017. The goal is to reduce the number of genotypes down to 30-40 and start the second phase of this project which is select for stable DMC.

8.4 Conclusions

It was very encouraging to identify a large proportion of segregating progenies with excellent levels of resistance to CBB and SED. Breeding cassava should focus on combining few traits with high heritabilities. This guarantees success in deploying outstanding germplasm that can offer advantages over the materials currently grown by farmers. Certainly the variables used for selection must have a positive impact on the productivity. Also relevant is the idea that breeding should shift its attention to the effect of climate change. In the case of cassava climate change will most likely affect negatively farmers through unpredictable rainy and dry seasons. This research is a result of this vision and concern.

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