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Breeding efforts to develop high-yielding, multiple pest-resistant sweetpotato germplasm in Uganda

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Abstract. Uganda is among the largest producer of sweetpotato worldwide. However, major constraints to increased sweetpotato productivity in the country and in East Africa in general include, declining soil fertility, poor yielding varieties of low nutritive value (low dry matter and low or no β-carotene), shortage of high quality planting materials, marketing problems, and limited range of processing and utilization options, leading to high post harvest losses, estimated between 30-35%, sweetpotato weevils, and sweetpotato diseases, mainly sweetpotato virus disease (SPVD), and *Alternaria* blight. Resistances to the major diseases and pests must be combined in a common background to develop sweetpotato cultivars preferred by consumers and farmers. Uganda's sweetpotato research program has released twelve cultivars that include five land race varieties and seven improved varieties. The released cultivars have high field resistance to SPVD and Alternaria blight in a high dry matter (about 30%) and good taste background, and one of the cultivars has orange-fleshed (high β-carotene) storage roots. Modified recurrent mass selection coupled with sequential selection schemes, and intense selection rates of 0.2-11% to handle large numbers of generated populations from polycross nurseries has been successful in developing sweetpotato germplasm with resistance to SPVD and Alternaria blight but not weevil resistance. In a high SPVD pressure location, progeny generated from families with parents of white-fleshed roots, and families with parents that have white- and orange-fleshed storage roots, the ratio of progeny with orange-fleshed roots to the total number of progeny ranged between 0.0 and 1.0. The segregation ratio is a rough indication that progress can be rapid in breeding cultivars with high β-carotene (orange flesh colour) that must be crossed to parents with high dry matter and resistance to SPVD and Alternaria blight to incorporate the latter traits.

Introduction

Sweetpotato, (*Ipomoea batatas* (L. Lam.), annual production from 414,000 – 572,000 ha in Uganda ranges between 1.7 – 2.5 million tons. This production ranks Uganda Africa's largest producer of the crop and second after China in the world (FAO, 2003). In Uganda, sweetpotato plays an important role in the diet and food security of the population as indicated by the high per capita consumption, 85 kg/cap/year (International Potato Center, 1999). Sweetpotato is the most important food crop in the country after cooking bananas and cassava (Bashaasha *et al.*, 1995). It is increasingly playing a significant role as a ready source of cash income from sale of storage roots, vines and processed products

in rural and urban markets. However, sweetpotato yields in the country are very low (4.4 t/ha) compared to yields of over 20 t/ha (24t/ha, 32 t/ha for Japan, and Israel, respectively (FAO, 2003). Todate major constraints to increased sweetpotato productivity in Uganda and in East Africa in general include, declining soil fertility, low yielding varieties of low nutritive value (low dry mater and low β-carotene content), sweetpotato diseases [mainly sweetpotato virus disease (SPVD), and *Alternaria* blight], pests, (mainly, sweetpotato weevils), genetic erosion, shortage of high quality planting materials, marketing problems, and limited range of processing and utilization options, leading to high post harvest losses, estimated between 30-35% (Woolfe, 1992).

Resistances to the major diseases and pests must be combined in a common background to develop sweetpotato cultivars preferred by consumers and farmers. Uganda's sweetpotato research program has released twelve cultivars that include five local landraces and seven improved varieties. The released cultivars have high field resistance to SPVD and Alternaria blight in a high dry matter (about 30%) and good taste background, and one of the cultivars has orange-fleshed (high β-carotene) storage roots (Mwanga *et al.*, 2001a, 2003). The major sweetpotato breeding objectives at NAARI are: (1) develop germplasm with desirable traits (2) combine the desirable traits with multiple resistance, namely, resistance to SPVD, Alternaria stem blight and sweetpotato weevil. This paper highlights the procedures that have led to the release of the improved high yielding, multiple-resistant sweetpotato germplasm in Uganda. Modifications to improve selection rates, and results are presented and discussed.

Materials and Methods

The following approaches have been used to develop sweetpotato cultivars with multiple-pest resistance:

Germplasm evaluation and breeding. The initial step at NAARI in 1987 to 1989 was to screen a total of 380 out of 450 sweetpotato landrace accessions assembled in 1986 as previously described (Mwanga *et al.*, 1991; Mwanga and Otim-Nape, 1992). Superior landrace entries were subsequently evaluated with promising clones screened from base (source) populations generated at NAARI and tested in Uganda's major agroecologies as reported (Mwanga and Mateeka, 1994). A total of 259 introductions imported in different batches, mainly as pathogen tested in vitro plantlets from mainly the International Potato Center (CIP), Lima, Peru, and to a less extent the USA, and the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, were field-tested with emphasis on resistance to SPVD between 1989 and 2003.

Generation of breeding populations and screening. The base (source) populations were obtained from: 1) local and introduced germplasm and 2) improved populations and families generated from polycross nurseries. Most of the source populations were generated by polycrosses that were open-pollinated mainly by honeybees and hand crosses of specific male and female parents to combine virus resistance and other desirable traits as previously described (Mwanga and Mateeka, 1994). A total of 18-24 promising local landraces and improved clones selected from source populations were used as parents in the polycrosses. A new combination of parents formed a new polycross nursery each year between 1989 and 2003.

Selection scheme. The recurrent selection used for population improvement was half-sib family testing and selection between and within families. Mass selection was used for screening for virus resistance. Basically, the selection system is a modification of recurrent mass selection coupled with sequential selection schemes developed by Jones et al. (1986) and Hahn (1980). The source

populations were screened and advanced through seedling nursery (around 100,000 seedlings at the start), clonal evaluation, preliminary, intermediate, advanced, and on-farm yield trials before release, lasting 7-8 years (two seasons per year) to 14-16 years (one season per year). Rigorous screening for SPVD resistance, 0.2-11% selection rate was used in the early cycles of selection, seedling nursery, clonal evaluation, and preliminary yield trials (Mwanga *et al.*, 2000, 2001).

Generation of breeding populations and selection for increased β-carotene. To obtain a rough idea of prediction based on choice of sweetpotato parents to increase β-carotene in storage roots, segregation of orange flesh colour in the roots was recorded in progeny of parents with white flesh, orange flesh roots or both. Flesh colour of storage roots was recorded in the following seedling families at 5 months after planting in November 2002:

1) families generated from specific crosses of parents previously selected for white flesh and high dry matter
2) families raised from open pollinated seed of parents with white flesh storage roots previously selected for white flesh
3) families raised from open pollinated seed of parents with orange flesh and white flesh roots
4) families raised from specific crosses of parents with orange, yellow, cream or white flesh.

The segregation ratio of number of seedlings with orange flesh colour (OFC) to the total was computed for the four types of seedling families.

SPVD resistance evaluation. SPVD was screened in the field and confirmed in the screenhouse. SPVD is due to dual infection by *sweetpotato feathery mottle potyvirus* (SPFMV) transmitted non-persistently by aphids and *sweetpotato chlorotic stunt crinivirus* (SPCSV) transmitted semi-persistently by the whitefly (*Bemesia tabaci*). Field resistance to SPVD was confirmed by graft-inoculation using SPVD-infected scion and the test genotype as stock. Double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) and triple antibody sandwich antibody sandwich immunosorbent assay (TAS-ELISA) were used to detect SPFMV and SPCSV, respectively, as previously reported (Mwanga et al. 2002a). Test plants giving negative results in serological tests were grafted on the indicator plant, *Ipomoea setosa* to confirm freedom from viruses as previously described (Mwanga *et al.*, 2002b).

Selection under high and low SPVD pressure. Breeding efforts to date in the country to produce orange-fleshed sweetpotato [OFSP (high in beta carotene/ Vitamin A)] cultivars have focused on generation of improved clones for release. Based on one of the most severe constraints to sweetpotato production, sweetpotato virus disease (SPVD), large numbers of the base (source) populations (50,000-100,000 genotypes) are required to start a screening cycle in high virus pressure areas. The number of genotypes selected in the early cycles of selection is always between 1-15%. To establish whether efficiency of selection for SPVD resistance in different agroecologies would be improved by using an extra site with low virus pressure, a set of trials (seedling, observational, clonal and diallel) were planted at NAARI in 2002. The selection rates in the different trials based on SPVD were recorded. In the first season of 2003, seeds of 40 families (807 genotypes) were planted at Serere Agricultural and Animal Production Research Institute (SAARI), a low SPVD pressure environment. In the same season at NAARI, a high SPVD environment, 93 families (3,620 genotypes), including the 40 families planted at SAARI, were planted at NAARI, and selection rates at the two sites (NAARI and SAARI) were established.

Genetics of SPVD resistance and DNA markers. The genetics of SPVD resistance and markers was investigated using full-sib

families generated from 10 parents crossed in half diallel as previously described (Mwanga *et al.* 2002b). Control of resistance to SPCSV and SPFMV being mediated by genes was investigated using randomly amplified polymorphic DNA (RAPD) and amplified fragment length polymorphisms (AFLP) as previously described (Mwanga *et al.,* 2002a).

Alternaria blight resistance evaluation. Sweetpotato germplasm and breeding populations were screened for resistance to Alternaria blight as previously described (Mwanga *et al.* 2001a, b).

Field and laboratory rating tests for sweetpotato weevil resistance. Resistance of germplasm and breeding populations was rated routinely in breeding trials on a subjective scale of 1-5, where 1 = no damage, and 5 = total damage. This screening was not efficient when weevil populations were high. The resistance of recently introduced sweetpotato clones to sweetpotato weevils, *Cylas puncticollis* and *C. brunneus,* the most damaging pests of the crop, was not known in Uganda. Therefore, field studies were carried out at Serere Agricultural and Animal Production Research Institute (SAARI), to establish the extent to which the introduced sweetpotato clones differed in susceptibility to field infestation by *Cylas* spp. Two field trials were conducted between September 2000 and May 2001, in which 27 sweetpotato clones from USA and CIP, Lima, were screened in a randomized complete block design (RCBD) with four replications. Two laboratory tests with three replications each were conducted at NAARI in June - September and December 2001 – March 2002, to relate infestation and damage levels obtained from field trials to laboratory results. Data were collected on time (days) of F_1 generation emergence, and total number of weevils emerged.

Results and Discussion

Germplasm screening and breeding. Five sweetpoato cultivars (New Kawogo, Tanzania, Tororo 3, Wagabolige, and Bwanjule) screened from the 380 local landrace cultivars and one breeding line (Sowola) were released in 1995 (Mwanga et al. 2001). Approximately 300,000 seedlings were screened between 1989-1995 of which Sowola was the only cultivar released. Six more cultivars (NASPOT 1 to NASPOT 6), including an orange-fleshed one (NASPOT 5) were released in 1999 (Mwanga et al. 2003). The combination of the released cultivars has good storage shapes, high dry matter content (>30%), high consumer acceptance, moderate to high levels of field resistance to SPVD and Alternaria blight, and high root yields compared to the average national root yield average of 4 t/ha (CIP, 1999). Of interest to multiple resistance, Cervantes-Flores *et al.* (2002) at North Carolina State University, Raleigh, USA, found two of the released cultivars, Wagabolige and Tanzania resistant to all three nematode species tested. The nematode species evaluated were *Meloidogyne arenaria* (Neal) Chitwood (two races), *M. incognita* (Kofoid and White) (four races), and *M. javanica* (Treub) Chitwood.

A total of 220 improved sweetpotato cultivars and breeding lines from CIP, USA, and IITA (Table 1 and 2) were field tested as received in different batches between 1989 and 2003 at NAARI in Uganda. Except for Naveto and Huarmeyano (CIP 420020) that exhibited moderate field resistance to SPVD, all the introduced accessions degenerated under natural SPVD pressure within one to three seasons of testing. The implication is that for any of the introduced genotypes to be grown in the farming system in the high SPVD agroecology, there is need to supply virus-free material every season or every time the cultivars degenerate.

Selection of promising clones resistant to SPVD. The number selected of sweetpotato clones resistant to SPVD and Alternaria blight was small in all breeding trials, especially in the early cycles of selection throughout the years of evaluation. The selection rate, for example in the different trials in 2002 varied

Table 1: Sweetpotato germplasm introductions (*in-vitro* material) from CIP evaluated at NAARI, Uganda 1989-1999.

Code	CIP No.	Code	CIP No.	Code	CIP No.	Code	CIP No.	Code	CIP No.
1	187001.1	36	420064	71	440049	107	440107	142	440222
2	187001.21	37	420065	72	440055	108	440111	143	440223
3	1870004.1	38	420066	73	440056	109	440122	144	440226
4	187004.2	39	420068	74	440057	110	440113	145	440237
5	187012.12	40	420091	75	440058	111	440120	146	440239
6	187016.2	41	420093	76	440059	112	440121	147	440240
7	187018.1	42	440001	77	440060	113	440122	148	440242
8	1880021.1	43	440002	78	440062	114	440123	149	440243
9	188004.2	44	440004	78	440063	115	440127	150	440244
10	400001	45	440005	80	440066	116	440129	151	440248
11	400004	46	440006	81	440067	117	440130	152	440252
12	400005	47	440007	82	440070	118	440137	153	440254
13	400009	48	440009	83	440071	119	440138	154	440255
14	400010	49	440014	84	440072	120	440143	155	440258
15	400016	50	440020	85	440073	121	440144	156	440263
16	400018	51	440021	86	440074	122	440149	157	440281
17	400020	52	440022	87	440075	123	440150	158	440283
18	400025	53	440023	88	440077	124	440151	159	440287
19	420004	54	440024	89	440078	125	440154	160	440288
20	420008	55	440025	90	440080	126	440158	161	440293
21	420017	56	440027	91	440082	127	440159	162	440303
22	420018	57	440029	92	440084	128	440160	163	440313
23	420020	58	440030	93	440085	129	440164	164	440333
24	420021	59	440031	94	440086	130	440176	165	440337
25	420023	60	440034	95	440087	131	440189	166	440374
26	420024	61	440036	96	440088	132	440194	167	440376
27	420025	62	440037	97	440089	133	440197	168	440377
28	420026	63	440038	99	440090	134	440199	169	440380
29	420028	64	440040	100	440092	135	440200	170	440384
30	420030	65	440041	101	440093	136	440201	171	440386
31	420031	69	440043	102	440096	137	440205	172	440388
32	420033	67	440044	103	440101	138	440206	173	440391
33	420038	68	440045	104	440102	139	440208	174	440342
34	420048	69	440046	105	440105	140	440215		
35	420053	70	440047	106	440106	141	440216		

from approximately 1% to 12% (Table 1), which was typical of selection rates of previous years (Mwanga and Mateeka, 1994). Natural field infection under high SPVD pressure and graft inoculation of promising families with SPVD consistently resulted in severe SPVD in all the families. The distribution of SPVD scores was skewed toward highly susceptible categories (SPVD scores 4 and 5), eliminating almost all the resistant categories (scores 1 and 2). The response of diallel progeny of 15 promising families to SPVD in 1998-2000 is presented as an example of distribution expected of populations screened for SPVD resistance (Fig. 1). Sometimes all the evaluated populations fell in the susceptible category (score 4 and 5), resulting in discarding those populations due to high susceptibility.

Selection for increased β-carotene. The segregation of progeny for root flesh colour in 98 families (36,616) is shown in Table 3. Of the 24 families (1,198 seedlings), raised from specific crosses of parents previously

Table 2: Sweetpotato germplasm introductions (*in-vitro* material) from CIP and IITA evaluated at NAARI, Uganda 1989/90 (TIB and TIS names only) and 1999-2003.

Code	CIP No.	Name clone	Code	CIP No.	Name of clone
175	199004	CC89.147. 4 x OP	198	440076	TIS 9291
176	199004	CC89.147. 4 x OP	199	440131	Naveto
177	199005	CHGU 1.002 x OP	200	440136	Caromex
178	199015	LM92.032 x OP	201	440140	Kandee
179	199015	LM92.032 x OP	202	440141	Julian
180	199024	SR91.109 x OP	203	440157	Ningshu 2
181	199024	SR91.109 x OP	204	440170	Kemb 37
182	199025	SR92.095. 3 x OP	205	440188	Kyukei 63
183	199026	SR92.095. 8 x OP	206	440203	Unknown
184	199027	SR92.095. 10 x OP	207	440218	101274
185	199034	SR95.628 x OP	208	440228	CARI 9
186	199035	SR95.636 x OP	209	440229	CARI 426
187	199036	SR95.636 x OP	210	440236	CN1831-14
188	199036	SR95.636 x OP	211	440264	WON 1
189	199036	SR95.636 x OP	212	440443	Nashu 88 (81-88)
190	199057	LM94.422 x OP	213	556638	Jewel
191	199062	SPV 78.001. 3 x OP	214	-	Blesbok
192	420005	Nemanete	215	-	Mafutha
193	420009	Japon Tresmesino	216	-	TIB10(3)
194	440010	W-215	217	-	TIS5125
195	440016	Excel	218	-	TIS5801
196	440018	W-223	219	-	TIS82/0395
197	440069	TIS 5125	220	-	TIS83/170

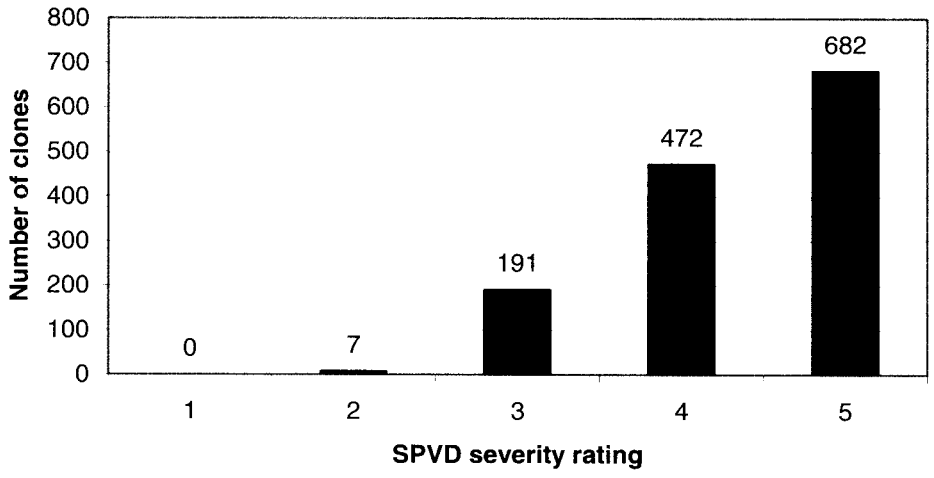

Figure 1: Frequency distribution of sweetpotato virus disease (SPVD) severity scores among 15 promising diallel families (1352 genotypes) at Namulonge Uganda, 1999-2000. SPVD severity rating, 1 = no symptoms, 5 = very severe symptoms.

Table 3: Number of entries and selection rate in some selected sweetpotato breeding trials, 2002.

Trial	Trait screened for	Number of genotypes grown	Selection	
			Number of clones	%
Seedling (pre-selection)	SPVD[1] resistance, Alternaria resistance, high dry matter content (DMC)	70,279[2]	68,874	98
Observational	SPVD resistance, Alternaria resistance, DMC	1,270	74	5.2
OFSP[3] Clonal	SPVD resistance, Alternaria resistance, DMC, Orange flesh (high β-carotene)	137	12	8.8
Diallel cross progeny	SPVD resistance, Alternaria resistance, DMC	694	85	12.2

[1] SPVD = sweetpotato virus disease
[2]Number planted = 140,520 seeds were planted
[3]OFSP = Orange-fleshed sweetpotato.

selected for white flesh and high dry matter, none had orange flesh colour (OFC). A very small fraction, 0.009 (97 seedlings) of the 33 families (6,994 seedlings) raised in category two (open-pollinated, white-fleshed parents) had OFC. In category three (open-pollinated, OFC parents) of 15 families (17,775 seedlings), the ratio of seedlings (3,730) with OFC to the total number increased to 0.22. The ratio (0.39) of OFC to total number of seedlings was highest in the 26 families (649 seedlings) raised from specific crosses, including parents previously selected for OFC (Table 4). The segregation ratio of progeny with OFC roots to the total number of progeny ranged between 0.0 and 1.0. This segregation ratio is a rough indication that with the right choice of parents, progress can be rapid in breeding cultivars with high β-carotene (orange flesh colour). However, the improved clone must be crossed to parents with high dry matter, and resistance to SPVD and Alternaria blight to incorporate the latter traits. In all screenhouse and field evaluations none of the genotypes screened through the years exhibited immunity to SPVD.

The proportion of genotypes selected compared to NAARI under natural high SPVD pressure was significantly increased from about 1-12% to about 95% under low SPVD pressure at SAARI (Table 5). SAARI will therefore be a second site to NAARI for seedling screening for resistance to SPVD in subsequent field evaluations to increase the proportion of selected genotypes under low SPVD environments.

Genetics of SPVD resistance and DNA markers. Graft inoculation with SPVD (SPCSV and SPCSV) of two promising families (Tanzania x Bikilamaliya and Tanzania x Wagabolige) produced severe SPVD in all progenies (294 genotypes). Inoculation of the two promising families with SPCSV and SPFMV, and Mendelian segregation analysis for resistant vs susceptible categories for the two viruses based on ELISA results suggest that resistance to SPCSV and SPFMV is conditioned by two, separate major recessive genes. In the proposed model for inheritance, the two genes are inherited in a hexasomic or tetradisomic manner (Mwanga *et al.*, 2002). Subsequent molecular marker studies yielded two DNA markers associated with resistance to SPCSV and SPFMV. The AFLP and RAPD markers linked to SPCSV and SPFMV resistance explained 70% and 72% of the variation in resistance, respectively (Mwanga *et al.*, 2002b). These AFLP, RAPD and QTL analyses suggest that, in the presence of both SPFMV and SPCSV, additional genes mediate oligogenic or multigenic horizontal

Table 4: Segregation of orange flesh colour (OFC) in storage roots of sweetpotato seedlings.

No. of families	Parental type	Number of seedlings		Ratio	Range of ratio
		(a) with OFC	(b) Total	a:b	
24	Crosses (white-fleshed) parents	0	11,198	0	0
33	Open pollinated (white-fleshed parents)	97	6,994	0.01	0.01-0.07
15	Open pollinated (OFC parents)	3,730	17,775	0.21	0.04-0.67
26	Crosses + OFC parents	237	649	0.37	0.00-1.00

Table 5: Selection rates in orange-fleshed families at Namulonge Agricultural Research Institute (NAARI) and Serere Agricultural and Animal Production Research Institute (SAARI), Uganda in 2003.

Location	Number of families	Number of seedlings	Selection	
			No. of seedlings	%
NAARI (high virus pressure)	93	3,620	325	9.4
SAARI (low virus pressure)	40	807	770	95.4

eggs laid in storage roots developed into adults. From previous studies, for *Cylas brunneus*, this period covered 32-41 days. The antibiosis study (no-choice experiment) revealed that clones such such as Ivoire, TIS 8266, Kemb37, Zapallo and NC196-20 with delayed and low emergence of weevils could be good clones in the national breeding program as sources of weevil resistance (Fig. 4). However, the same clones with delayed and low weevil emergence, exhibited greening and sprouting storage roots. The physiological processes of greening and sprouting could have affected weevil emergence, since phytoalexins produced during greening are toxic to weevils.

These results are similar to results reported in literature, where despite years of extensive screening, no highly resistant germplasm is currently available for weevil control (Mullen *et al.*, 1985; Thompson *et al.*, 1999). Production losses due to weevil feeding may often reach 60% to 100% (Stathers *et al.*, 2003). The search for host resistance to SPW in the sweetpotato germplasm has yielded no reliable result worldwide. The use of biotechnological approaches to introduce 'resistance genes', therefore, holds the greatest promise to protect sweetpotato against weevils. According to Matin Qaim (2001), weevil resistance technology would create welfare gains of 9.9 million US $ and estimated internal rate of return on biotechnology research investment of between 33 to 77%. Therefore, the most practical way to rapidly incorporate resistances into sweetpotato is by plant transformation (Prakash and Varadarajan, 1992).

Scientists conversant with the SPW problem believe that the use of Bt genes, *Bacillus thuringiensis,* currently represents the most feasible means of achieving sustainable control under African farming systems. The identification and transfer of genes that produce a protein that is toxic to weevils represents such an approach. Crops containing Bt genes are the second most widely grown transgenic plants. To date, a body of experience has been achieved that confirms the safety of Bt to human health, its

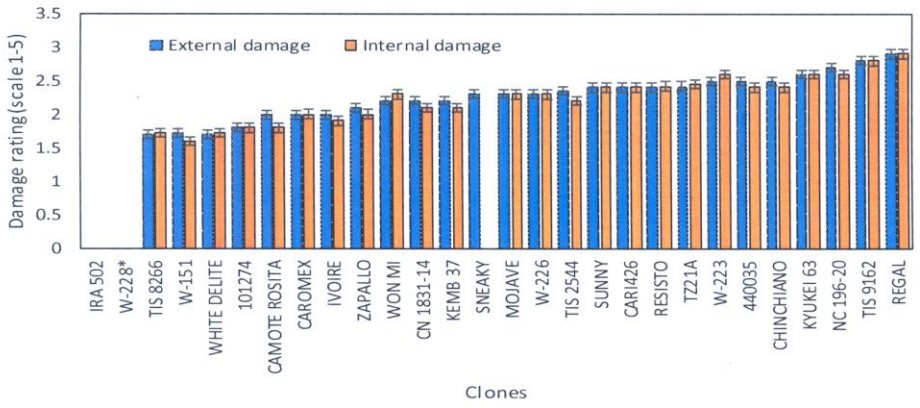

Figure 2: External and internal damage of vines of sweetpotato clones at SAARI, 2000 season. *No data available due to destruction of clones by sweetpotato virus disease.

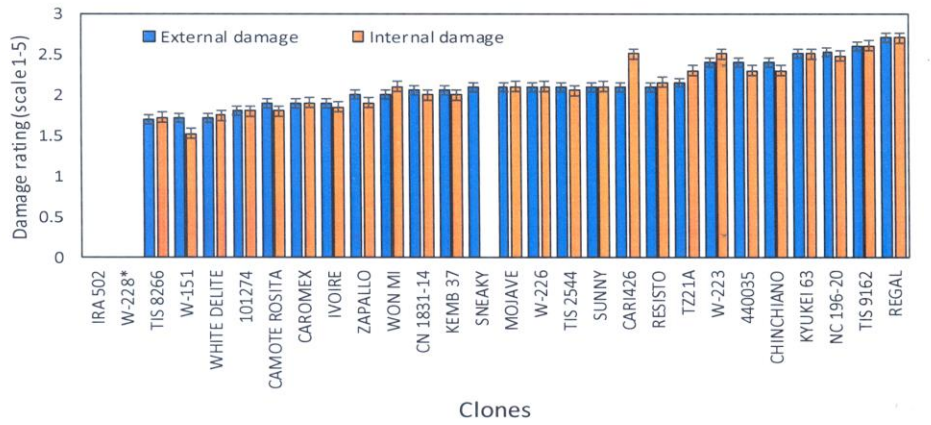

Figure 3: External and internal damage of vines of sweetpotato clones at SAARI, 2001 season. *No data available due to destruction of clones by sweetpotato virus disease.

(Quantitative) effects in the progenies studied for resistance to SPVD.

Resistance to Alternaria blight resistance. Efficiency of screening sweetpotato germplasm and breeding populations for resistance to Altemaria blight depended on prevalence of the disease under field conditions. Ideal conditions for screening were during wet and humid seasons in the different agroecologies and more ideally at high altitude. Released cultivars Bwanjule, Sowola, NASPOT 3, NASPOT 5 and NASPOT 6 exhibited moderate to high field resistance to Altemaria blight. The other cultivars were susceptible to the disease and were therefore adapted to warm agrocoecologies where the disease was not severe.

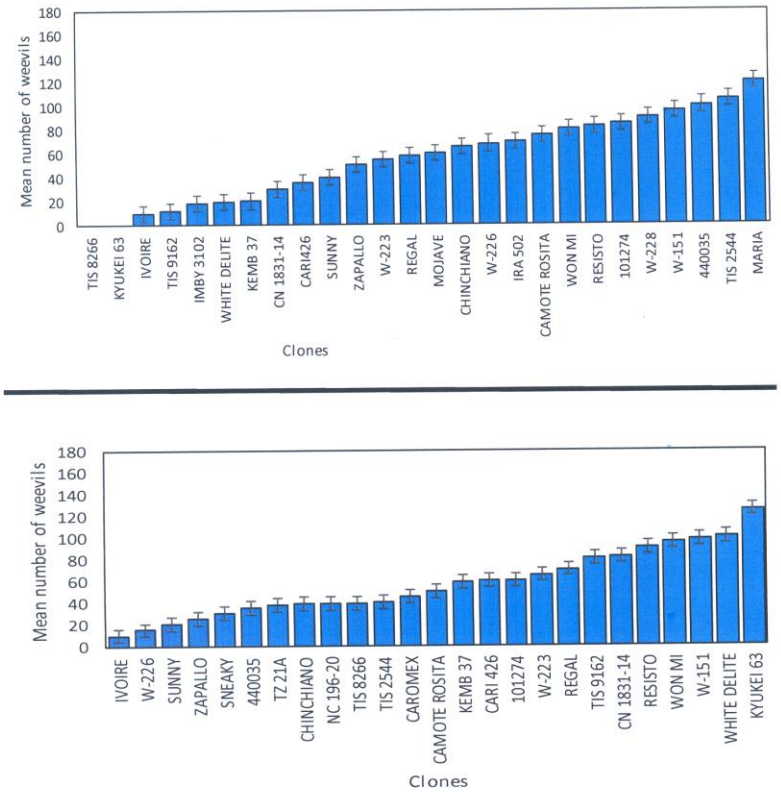

Figure 4: Mean number of adults of *Cylas brunneus* adults emerging from single roots of sweetpotato clones during 11-week emergence period in 2001 (upper graph) and 2002 (lower graph).

Field and laboratory rating tests for sweetpotato weevil (SPW) resistance. In all breeding trials there were differences in susceptibility to SPWs in the field under low weevil populations. However, under high weevil pressure all clones were equally infested. Introduced clones were observed for their reaction to SPWs. Clone Ivoire exhibited some evidence of shoot resistance in field and root resistance in laboratory tests as compared to Tanzania (local check), due to possibly antibiosis mechanism of resistance. None of the clones, including Ivoire showed consistent high resistance ratings in field and laboratory experiments in the two tested seasons (Figs. 2-4). High number of soil cracks on mounds significantly ($P<0.05$) increased the numbers and weights of infested storage roots per plant due to increased access to the storage roots by the weevils. There was also a positive association between the number of storage roots and the number of soil cracks on mounds attributed to the increased pressure within the mound from the bulking of storage roots (data not shown).

Weevil emergence peaked during the seventh week. The experiments for both seasons were conducted up to 18 weeks but data is presented for only the first 1 1 weeks to exclude second-generation adult weevil counts. There was no weevil emergence from week one to four. This was the period when

positive impact on the environment, and its effectiveness in controlling highly targeted pests (Betz *et al.*, 2000; Shelton *et al.*, 2002).

Conclusions

Good progress has been made in Uganda in breeding sweetpotato with multiple resistance, particularly resistance to sweetpotato viruses and Alternaria stem blight. These resistances can be incorporated in genotypes with desirable traits but are susceptible to any of the diseases using conventional breeding. To date, however, despite intense global search for resistance, no highly resistant germplasm is currently available for sweetpotato weevil control. Therefore, the most practical way to rapidly incorporate resistances into sweetpotato is by plant transformation using Bt genes.

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