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Genetic incompatibilities in sweetpotato and implications for breeding end-user preferred traits

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Abstract

Sweetpotatoes utilization is low in Ghana due to lack of farmer and consumer preferred cultivars. Poor flowering and incompatibilities among genotypes limit breeding progress in its improvement. The objective was to assess compatibilities among sweetpotato genotypes to select good parents for breeding end-user preferred varieties for increased utilization. Twenty-one genotypes selected from 115 accessions evaluated across three contrasting environments were crossed using full diallel mating scheme. In all, 6388 crosses were carried out and 3214 seeds produced. This study sought to understand the genetic incompatibilities based on the number of seeds set per capsule after self- or cross-fertilization. Lack of flowering or poor flowering, and self- and cross-incompatibilities were major constraints to sweetpotato improvement found. Four genotypes (Histarch, Apomuden, Beauregard, and Ogyefo) were the best parents based on cross compatibilities and they can be used to determine the genetic control of beta-carotene, dry matter and sugar content in sweetpotato. Histarch and Ogyefo are recommended as parents for the development of non-sweet, high dry matter sweetpotato varieties that are the preferred cultivars in Ghana because of their low sugar content. Use of many genotypes in hybridization and establishment of crossing blocks in the minor cropping season is highly recommended.

Keywords: Breeding; compatibility; end-user; sweetpotato; traits.
Abbreviations: AGRA_Alliance for a Green Revolution in Africa, ANOVA_Analysis of Variance, BC_beta-carotene; CIP_International Potato Centre, CRI_Crops Research Institute, CSIR_Council for Scientific and Industrial Research, DW_Dry weight, ID_Identity, MS_Microsoft, RCBD_Randomised complete block design, RE_Relative efficiency, RH_Relative humidity, S_ Sugar, WACCI_West Africa Centre for Crop Improvement.

Introduction

Sweetpotato *(Ipomoea batatas)* is in the botanical family *Convolvulaceae* (Thottappilly, 2009). It is a major staple crop, particularly in numerous tropical countries (Lebot, 2009). The crop is rich in dietary fibre, minerals, vitamins and antioxidants, such as phenolic acid, anthocyanins, tocophenols and beta-carotene (Ray and Tomlins, 2010). Sweetpotato preference varies with ethnic background as well as geographic location. Consumers in Ghana prefer non-sweet, high dry matter sweetpotato cultivars (Sam and Dapaah, 2009; Baafi, 2014; Baafi et al., 2015). However, locally available clones are very sweet, limiting their consumption as a staple food (Missah and Kissiedu, 1994; Baafi et al., 2015). Recently introduced orange-fleshed varieties, which possesses the vitamin A precursor to combat vitamin A deficiency at relatively lower cost, have low dry matter content (Baafi et al., 2015). High dry matter is one of the important consumer preferences in most of Sub-Saharan Africa (Tumwegamire et al., 2004). As a result, there is a very low utilization of sweetpotato in Ghana compared with the other root and tuber crops like cassava, yam and cocoyam. There is the need to develop farmer and consumer preferred sweetpotato varieties for increased utilization as a staple food crop in Ghana. Three ways of obtaining improved sweetpotato varieties and releasing them to farmers as cultivars are collection, evaluation, and selection from local germplasm, importing/introducing cultivars that have been bred elsewhere and evaluating them under local conditions, and developing cultivars through hybridization in local breeding programmes. Thirteen improved varieties of sweetpotato released in Ghana to date were obtained through the second option without adequate concern for farmer and consumer preferences and taste. Hence, their rate of adoption has been poor. It is important to adjust breeding and selection procedures of sweetpotato in Ghana to meet farmer and consumer preferences. Hybridization and subsequent selection of new varieties can accomplish this. Hybridization depends on sexual reproduction which breaks the asexual cycle of the crop. It permits breeding and selection of desirable end-user traits such as higher yield, resistance to biotic and abiotic stresses, and culinary and industrial qualities. One of the main problems in developing hybrid varieties is the selection of good parents (Dar et al., 2014). Choice of parents that have good combinability is important, but *per se* performance of parents is not a true indicator of combining ability in hybrid combination (Sharma and Mani, 2008). Evaluation of combining ability requires crossing different genotypes. The ability of genotypes to successfully cross pollinate in sweetpotato is a pre-requisite to assess

combining abilities and elucidate the nature and magnitude of genetic control of end-user preferred traits. Crossing incompatibilities hinder hybrid breeding because parents with desirable traits of interest cannot be crossed to combine desired traits into one genetic background. In addition, the use of a genotype for hybridization is impeded by lack of flowering or poor flowering. Poor flowering and incompatibility among genotypes limit breeding progress in sweetpotato. It is therefore, very critical to ascertain the compatibility status in sweetpotato breeding population to find good parents to obtain high breeding progress. This will facilitate and ensure efficient use and management of breeding resources. The objective of this study was to assess compatibilities among sweetpotato genotypes to select good parents for breeding end-user preferred sweetpotato varieties for increased utilization in Ghana and beyond.

Results

Number of crosses and seeds obtained to generate the F_1 population

The hybridization blocks established in the screen house failed. For those established in the field, a total of 6388 crosses were made to generate the F_1 seeds. There were 4575 crosses from the beta-carotene/dry matter study and 1813 crosses from the sugar content study. In all, 3214 seeds were produced which includes 2356 seeds from the beta-carotene/dry matter content study and 858 seeds from the sugar content study. For the beta-carotene/dry matter content study, the parents varied for number of flowers and crosses. CIP 442264 (BC 64) did not produced any flowers (Table 3). The highest number of flowers and crosses made were from Histarch (BC 87), Apomuden (BC 50), Faara (BC 27) and Beauregard (BC 82). CIP 442896 (BC 53) and Resisto (BC 21) produced the lowest number of flowers. Crosses between Faara (BC 27), Histarch (BC 87) and Apomuden (BC 50) were the most successful and also produced the highest number of seeds while crosses involving CIP 442896 (53), Resisto (21), and CIP 442850 (BC 109) were not very successful (Table 4). For the sugar content study, only Ouagadougou 02 (S74) did not produce flowers. The other genotypes produced variable number of flowers. More crosses were made between Histarch (S87) and Apomuden (S50), Histarch (S87) and Ogyefo (S61), Histarch (S87) and Paga 01 (S43), and Histarch (S87) and B/Faso 002 (S15) than the other parents (Table 5). These parents also produced the highest number of flowers. The least number of flowers (Table 5) and quantity of seeds (Table 6) were produced by Ehiamankyene 01 (S97).

Degree of success and seedling vigour of selected crosses

The number of crosses ranged from 1 for CIP 443035 × CIP 442850 (79 × 109) to 157 for Histarch × Apomuden (87 × 50) (Table 7). The number of capsules ranged from 1 to 79 for the same crosses. The mean for the number of crosses and the number of capsules were 45.41 and 22.70, respectively. The success rate of the crosses ranged from 50% to 100%, with a mean of 54.10%. Only 18% of the crosses had a success rate above the mean. The number of seeds produced varied from 1 for Beauregard × CIP 442850 (82 × 109) to 186 for Histarch × Apomuden (87 × 50) with a mean of 24.74. The mean number of seeds per capsule was 1.21 and it ranged from 0.14 for Beauregard × CIP 442850 (82 × 109) to 4 for CIP 443035 × Beauregard (79 × 82). The mean number of seeds sown was 14.74 and mean seeds geminated was 13.85. The range was 1 – 89 and 1 – 80, respectively. The germination rate ranged from 80% to 100% with a mean of 96.30%. The cross Apomuden × Resisto (50 × 21) gave the lowest germination rate whilst a number of crosses gave 100% germination rate.

Climatic data for the hybridization blocks environment

For the hybridization blocks established in the screen house, the minimum value for all the weather data were obtained in August 2012, except for relative humidity which was in April 2012 (Table 8). The maximum value for all the data were recorded in April 2012 except for total rainfall and average relative humidity which recorded peak values in June 2012. The total rainfall and the average relative humidity (RH) ranged from 4.60 mm to 204.00 mm and 83.24% to 89.52%, respectively. The range for the minimum and maximum temperatures were 21.28 – 22.47^{o}C and 28.42 – 32.63^{o}C, while that of the mean temperature was 24.93 - 27.51^{o}C.
For the hybridization blocks established in the field, the total rainfall and the average relative humidity (RH) during the hybridization period ranged from 0.00 mm (February 2013) to 215.20 mm (October, 2012), and 56.63% in January 2013 to 88.42% in October 2012 (Table 9). The range for the minimum and maximum temperatures were from 15.68^{o}C (January 2013) to 20.51^{o}C (November, 2012), and 33.65^{o}C (October 2012) to 37.34^{o}C (January 2013), respectively. The mean temperature ranged from 23.34^{0}C to 28.18^{0}C.

Discussion

The screen house study failed because of lack of flowering and poor flowering among the genotypes, and severe virus incidence on the grafted parents. Poor flowering of most genotypes and failure of capsules to produce seeds due to severe virus incidence when the parents were grafted onto *Ipomoea setosa* in the screen house for flower induction, necessitated the re-establishment of the crossing blocks in the field. Lack of flowering is a severe impediment to understand the genetics and also making gains through selection in sweetpotato. The use of a parent for hybridization may be impeded by poor flowering. This makes it prudent to verify flowering ability at the start of a hybridization programme. Improvement of sweetpotato through conventional breeding is hindered by poor flowering and incompatibility (Martin and Cabanillas, 1968). In this work, 70% of the sweetpotato parents did not flower when the hybridization blocks were first established in the screen house, and those that did (30%) produced only few flowers. For this reason, the sweetpotato parents were grafted onto a flower inducing rootstock *I. setosa,* and flowering was improved. However, this technique failed before capsule maturation due to wilting and dying of the root stock since the *I. setosa* could not tolerate virus particles in the apparent clean scion. The *I. setosa* is commonly used as an indicator plant for virus detection in sweetpotato since it is susceptible to most viruses infecting sweetpotato. This indicates that flower promotion using *I. setosa* in sweetpotato could be successful only if laboratory certified virus-free scions are used. Unavailability of laboratory certified virus-free planting materials necessitated the re-establishment of the crossing blocks in the field. The parents varied in flowering prolificacy in the field and the differences may be attributed to varietal differences. According to Fekadu et al. (2013), flowering prolificacy in sweetpotato is variety dependent. Some varieties do not

Table 1. List of sweetpotato parents used for establishing dry matter/beta-carotene crossing block.

Crossing block ID	Genotype	Dry matter content (%)	Beta-carotene content (mg/100g)DW
BC87	Histarch	45±2.00	9.85±1.01
BC64	CIP 442264	45±2.00	7.74±1.01
BC27	Faara	42±2.00	12.27±1.01
BC61	Ogyefo	42±2.00	6.83±1.01
BC115	Ouagadougou 03	41±2.00	9.74±1.01
BC53	CIP 442896	40±2.00	11.27±1.01
BC108	BOT 03-020	39±2.00	17.35±1.01
BC79	CIP 443035	36±2.00	19.75±1.01
BC109	CIP 442850	27±2.00	20.21±1.01
BC82	Beauregard	32±2.00	24.31±1.01
BC21	Resisto	38±2.00	27.53±1.01
BC50	Apomuden	27±2.00	33.67±1.01

Table 2. List of sweetpotato parents used for establishing the sugar content crossing block.

Crossing block ID	Genotype	Sugar content (%)
S109	CIP 442850	30.34±1.75
S50	Apomuden	28.97±1.75
S15	B/Faso 002	24.04±1.75
S82	Beauregard	22.90±1.75
S43	Paga 01	22.84±1.75
S75	B/Faso 001	22.69±1.75
S48	CIP 440071	21.84±1.75
S113	Ukerewe	21.10±1.75
S97	Ehiamankyene 01	12.54±1.75
S72	AAT 03-025	12.26±1.75
S31	CIP 440095	12.06±1.75
S61	Ogyefo	11.67±1.75
S64	CIP 442264	11.06±1.75
S87	Histarch	10.43±1.75
S74	Ouagadougou 02	9.83±1.75

Table 3. Number of crosses made in the field to generate the F_1 population for the beta-carotene/dry matter content study.

Parents	BC 27	BC 108	BC 115	BC 53	BC 61	BC 64	BC 87	BC 50#	BC 109#	BC 79#	BC 21#	BC 82#
BC27	*11	33	54		26		443	224	94	21	19	55
BC108	34	*			4			39	12	19		10
BC115	8	6	*					20	8	3	4	3
BC53	7			*			3	6				2
BC61	24				*		27	29	13			25
BC64						*						
BC87	443	50	34	84	137		*	157	37	67	74	145
BC50#	533	227	118	91	112		143	*	81	31	22	102
BC109#	1	1	23	4	6		22	20	*	1		6
BC79#	38	10	4	3	17		19	10	1	*	21	2
BC21#	35	1		13	6		8	12	4	5	*	3
BC82#	98	14	1	9	20		42	35	13	11	9	*

#High beta-carotene and low dry matter parents. BC27 (Faara), BC108 (BOT 03-020), BC115 (Ouagadougou 03), BC53 (CIP 442896), BC61 (Ogyefo), BC64 (CIP 442264), BC87 (Histarch), BC50, (Apomuden), BC109 (CIP 442850), BC79 (CIP 443035), BC21 (Resisto), BC82 (Beauregard)

flower at all and others produce very few flowers. In addition, many sweetpotato clones rarely flower under normal conditions as a result of differential response to seasonal variation. Furthermore, most sweetpotato genotypes are day length sensitive. Thus, while some genotypes flower readily in any season, flowering in others occur only during short day length (Martin, 1988). Seasonal observations in north-western Argentina showed that sweetpotatoes flower best at daily maximum temperature of 23 – 24^{0}C and minimum temperature of 13 – 19^{0}C (Folquer, 1974). Night temperature of 16 – 17^{0}C and day temperature of 24 – 30^{0}C appeared to be optimum (Edmond and Martin, 1946). The best season for pollination in Taiwan in the northern hemisphere is from the beginning of November to the middle of December, when the average daily temperature is between 20^{0}C and 25^{0}C with maximum seed set occurring at mean daily temperature of 23.9^{0}C (Wang, 1982). In this study, the daily minimum temperature for the hybridization blocks established in the field (15.68 – 20.51^{0}C) is in agreement with values reported to favour flowering but, that in the screen house (21.28 – 22.47^{0}C) was higher than reported values. The maximum daily temperature (28.42 – 32.63^{0}C) observed for the screen house study and that observed for the field study (33.65 – 37.34^{0}C) were higher than those reported elsewhere. Greenhouse crosses were best done in days of 12 hours and temperatures not excessively high (Jones, 1980), and 24^{0}C was the optimum temperature (Montelaro and Miller, 1951). Similar observation was made in Puerto Rico (Campbell et al., 1963), where flowering in the greenhouse did not occur above 27^{0}C. These suggest that day length may be important in promoting flowering in sweetpotato in addition to minimum temperature. In this study, the

Table 4. Seeds harvested in the field to generate the F_1 population for the beta-carotene/dry matter content study.

Parents	BC 27	BC 108	BC 115	BC 53	BC 61	BC 64	BC 87	BC 50#	BC 109#	BC 79#	BC 21#	BC 82#
BC27		34	21		14		45	404	78	10	3	12
BC108	11	*						36	7	5		1
BC115	2		*					1	1			
BC53				*								
BC61	17				*		26	53				14
BC64						*						
BC87	285	33	15	19	139		*	186	11	7	3	31
BC50#	384	76	45	9	63		18	*	16	4	4	13
BC109#	3	2	13		4		5	3	*			4
BC79#	12	17					3	15	3	*	2	4
BC21#	6	2		1	2			3	1		*	
BC82#	35	8			5		15	31	1			*

#High beta-carotene and low dry matter parents. BC27 (Faara), BC108 (BOT 03-020), BC115 (Ouagadougou 03), BC53 (CIP 442896), BC61 (Ogyefo), BC64 (CIP 442264), BC87 (Histarch), BC50 (Apomuden), BC109 (CIP 442850), BC79 (CIP 443035), BC21 (Resisto), BC82 (Beauregard).

hybridization blocks were established in the screen house when day lengths were generally longer and temperatures were generally higher than the optimum temperatures of about 20^0C for night and around 25^0C for day for flower promotion. The hybridization blocks in the screen house were established in the major cropping season when day lengths are longer while those established in the field were in the minor cropping season when day lengths are shorter. This may have resulted in the variable flowering prolificacy between the hybridization blocks established in the screen house and in the field. Establishing sweetpotato crossing blocks in the minor cropping season in the forest ecozone of Ghana where this work was done is better than the major cropping season. Furthermore, sweetpotato seeds mature in about a month, a little earlier under hot, summer temperatures and later in cool, fall temperature (Jones, 1980). This gives the minor cropping season crosses an advantage since capsules mature earlier saving money and time. Seed abortion would be higher due to dry spells, but this can be managed through supplementary irrigation as was done in this study.

Special efforts are necessary to promote flowering if sweetpotatoes are to be hybridized. While incompatibility is largely attributed to genetics, poor flowering can be overcome by applying various flower induction techniques which include physiological shocks such as grafting, girdling, and chemical treatment to induce flowering (Edmond and Martin, 1946). In this study, genotypes like CIP 442264 and Ouagadougou 02 which were difficult to use as parents for hybrid development because of their inability to produce flowers, should be subjected to such treatments in future to improve their chances of success. While the problem of poor flowering can be reduced by applying various flower induction techniques, incompatibility remains a global barrier for the genetic improvement and conservation of sweetpotato (Fekadu et al., 2013). Two methods have been suggested for determining incompatibilities in sweetpotato (Williams and Cope, 1967). These are the number of seeds set per capsule after self- or cross-fertilization, and *in vivo* tests of pollen germination on stigma and pollen tube penetration into the style at intervals ranging from 3 to 24 hours after pollination. This study sought to understand the genetic incompatibilities based on the number of seeds set per capsule after self- or cross-fertilization. Both self- and cross-incompatibilities were observed in this study. Among the selfings, only those of Apomuden produced one seed, which was sterile and failed to germinate. Self-fertilization in sweetpotato is rare (Jill et al., 1989). Although sweetpotato is almost always self-incompatible, self-compatible clones may be observed (Tumana and Kesavan, 1987). Some of the crosses also did not produce seeds. Most sweetpotato genotypes used in a previous study were self- and cross-incompatible and therefore, were not able to produce viable seeds through self- or cross-pollination (Vimala and Hariprakash, 2011). Self-incompatibility is genetically controlled by a single multi-allelic locus, the S-locus. The S-locus has been shown to encode at least two distinct genes, the pollen and pistil determinant genes, which are responsible for the self-incompatible reaction (Takayam and Isogali, 2005; Mcclure and Franklin-Tong, 2006). There are two types of self-incompatibilities in plants and these are heteromorphic and homomorphic (Acquaah, 2011). The self-incompatibility observed in this work was homomorphic because there was no difference between the relative heights of the stamen and the style. However, further work is needed to determine whether homomorphic self-incompatibility observed is gametophytic or sporopytic. Cross-incompatibility is presumed to result from pollination between parents with the same self-incompatibility phenotype (Kowyama et al., 2008). If cross-pollination takes place and the cross is compatible, then pollen germination occurs on the stigma in about 10 - 20 minutes after pollination (Kowyama et al., 2000). Therefore, out-crosses that failed to produce viable seeds such as crosses between Beauregard and CIP 442850, and CIP 443035 and Resisto, indicates existence of cross-incompatibilities among the sweetpotato genotypes studied. As a result, there will be difficulty in using such cross combinations for genetic studies. According to Charles et al. (1973) and Vimala (1989), cross-incompatibility among different varieties hinder targeted breeding especially when the parents with desirable traits of interest belong to the same incompatibility group. Fekadu et al. (2013), identified three types of cross compatibilities which are distinguished by the success of fertility (i.e. germinability of the pollen and differences with respect to stimulation of pollen itself and by the style). These were reciprocal fertility (fertility occurs in both directions), reciprocal incompatibility (incompatibility in both directions) and unilateral incompatibility (fertility occurs only when the genotype is used as female and not when used as male or vice versa). All these types were observed in this study. For example, crosses Histarch × Apomuden, Histarch × Ogyefo, Ogyefo × Apomuden, Faara × Histarch, and Faara × Apomuden exhibited reciprocal fertility while crosses CIP 442896 × Beauregard, Ouagadougou 03 × CIP 443035, Ouagadougou 03 × Resisto, and Ouagadougou 03 × Beauregard showed evidence of reciprocal incompatibility. Unilateral incompatibility was also observed for the crosses Histarch × CIP 442850 and Ogyefo × CIP 442850.

Table 5. Number of crosses conducted in the field to generate F_1 population (sugar content study).

Parents	S50	S48	S43	S113	S82	S15	S109	S75	S61#	S87#	S97#	S31#	S64#	S72#	S74#
S50	*				102	4	81		112	143	1	53	3	74	
S48		*								4					
S43			*						35	423		6		13	
S113				*					13	4		1		7	
S82	35				*		13		20	42		2			
S15						*			57	145		72		37	
S109	20				6		*		6	22					
S75								*	54	37		38		1	
S61#	29		3		25	27	14	8	*	29					
S87#		6	203	24	142	315	37	31	137	*				12	
S97#											*				
S31#	6			4		5	3	10	3	3		*			
S64#													*		
S72#	19						1	4	1					*	
S74#															*

#Low sugar parents. S50 (Apomuden), S48 (CIP 440071), S43 (Paga 01), S113 (Ukerewe), S82 (Beauregard), S15 (B/Faso 002), S109 (CIP 442850), S75 (B/Faso 001), S61 (Ogyefo), S87 (Histarch), S97 (Ehiamankyene 01), S31 (CIP 440095), S64 (CIP 442264), S72 (AAT 03-025), S74 (Ouagadougou 02).

Table 6. Number of seeds harvested from field for the generation of F_1 population (Sugar content study).

Parents	S50	S48	S43	S113	S82	S15	S109	S75	S61#	S87#	S97#	S31#	S64#	S72#	S74#
S50	*								63	17		3		27	
S48		*													
S43			*						30	25				6	
S113				*					5						
S82	13				*		1		5	3					
S15						*			56					48	
S109	3				4		*		4	5					
S75								*	39	1					
S61#	53		2		14	25	11	7	*	26					
S87#	180		2		13			1	139	*				6	
S97#											*				
S31#	7						1					*			
S64#													*		
S72#	8					2	1	2						*	
S74#															*

#Low sugar parents. S50 (Apomuden), S48 (CIP 440071), S43 (Paga 01), S113 (Ukerewe), S82 (Beauregard), S15 (B/Faso 002), S109 (CIP 442850), S75 (B/Faso 001), S61 (Ogyefo), S87 (Histarch), S97 (Ehiamankyene 01), S31 (CIP 440095), S64 (CIP 442264), S72 (AAT 03-025), S74 (Ouagadougou 02).

Table 7. Success rate and seed viability of the selected crosses.

Cross	Number of crosses	Number of capsule	Success rate (%)	number of Seeds harvested	Seeds per capsule	Seeds sown	Seeds germinated	Percent germination (%)
[+]61 × 87	27	14	51.9	26	1.86	21	20	95.2
[$]61 × 50	29	15	51.7	53	3.53	25	22	88.0
[$]61 × 82	25	13	52.0	14	1.08	6	6	100.0
[+]64 × 87	5	3	60.0	4	1.33	4	4	100.0
[+]87 × 61	137	69	50.4	139	2.01	89	80	89.9
[+]87 × 64	5	3	60.0	2	0.67	2	2	100.0
[$]87 × 50	157	79	50.3	186	2.35	40	38	95.0
[$]87 × 82	145	73	50.3	31	0.42	23	22	95.7
[+]87 × 72	12	6	50.0	5	0.83	5	5	100.0
[$]50 × 61	112	56	50.0	63	1.13	36	35	97.2
[$]50 × 87	143	72	50.4	18	0.25	15	13	86.7
*50 × 109	81	41	50.6	16	0.39	14	13	92.9
*50 × 79	31	16	51.6	4	0.25	4	4	100.0
*50 × 21	22	11	50.0	4	0.36	5	4	80.0
*50 × 82	102	51	50.0	13	0.25	14	13	92.9
*109 × 50	20	10	50.0	3	0.30	2	2	100.0
*109 × 82	6	3	50.0	4	1.33	4	4	100.0
*79 × 50	10	5	50.0	15	3.00	16	16	100.0
*79 × 109	1	1	100.0	3	3.00	3	3	100.0
*79 × 21	21	11	52.4	2	0.18	2	2	100.0
*79 × 82	2	1	50.0	4	4.00	11	10	90.9
*21 × 50	12	6	50.0	3	0.50	3	3	100.0
[$]82 × 61	20	10	50.0	5	0.50	4	4	100.0
[$]82 × 87	42	21	50.0	15	0.71	13	13	100.0
*82 × 50	35	18	72.0	31	1.72	32	31	96.9
*82 × 109	13	7	53.9	1	0.14	1	1	100.0
*82 × 79	11	6	54.5	4	0.67	4	4	100.0
Mean	45.41	22.70	54.10	24.74	1.21	14.74	13.85	96.30

[+]Crosses involving low sugar parents; [*]Crosses involving high beta-carotene parents; [$] crosses involving contrasting parents. [87=Histarch; 61=Ogyefo; 50=Apomuden; 82=Beauregard; 64=CIP 442264; 72=AAT 03-025; 79=CIP 443035; 109=CIP 442850; 21=Resisto].

Table 8. Climatic condition over the period of the crossing blocks in the screen house.

MONTHLY	April 2012	May 2012	June2012	July2012	August 2012
Total Rainfall (mm)	152.60	170.40	204.00	43.60	4.60
Relative Humidity (%)	83.24	85.29	89.52	89.12	86.74
Temperature (Min) °C	22.47	22.16	21.96	21.67	21.28
Temperature (Max) °C	32.63	31.57	29.65	28.44	28.42
Mean Temperature °C	27.51	26.83	25.80	25.04	24.93

Table 9. Climatic condition over the period of the crossing blocks in the field.

MONTHLY	October 2012	November 2012	December 2012	January 2013	February 2013
Total Rainfall (mm)	215.20	41.40	40.80	3.00	0.00
Relative Humidity (%)	88.42	85.17	80.10	56.63	61.26
Temperature (Min) °C	20.13	20.51	16.30	15.68	18.27
Temperature (Max) °C	33.65	34.39	34.57	37.34	37.02
Temperature Mean °C	23.34	26.17	25.90	26.51	28.18

Higher success rate was attained in this study because the 54% mean success rate observed exceeds 1 – 48% reported. The success rate normally varies from 1% to 47% for different female parents and an average success of 35% should be considered good (Jones, 1980). Jill et al. (1989), reported that in the Tongan programme, about 48% of the flowers pollinated developed into capsules with an average of two seeds in each capsule. The mean number of seeds per capsule found in this study (1.21) is in the range 1.1 to 1.7 reported by Jones (1980), but lower than what was reported by Jill et al. (1989). The differences, according to Jill et al. (1989), may be attributed to the weather, health of the plant, parents used and skill of pollinating staff. Sterilities, incompatibilities and environmental conditions all affect capsule set percentages (Jones et al., 1977). The higher germination rates of the seeds and the seedling vigour observed may suggest either the absence of sterility or lower sterility among the parents used in this study.

Materials and Methods

Plant materials

Twenty-one sweetpotato genotypes were used (Tables 1 and 2). The genotypes were selection from 115 sweetpotato accessions collected from local accessions (32), local improved accessions (13), exotic and local accessions in National Agricultural Research Systems (43), and exotic accessions from CIP, Ghana germplasm (27). The accessions were evaluated under rain-fed conditions in two replications at Fumesua (Forest ecozone) and Pokuase (Coastal Savanna ecozone) in the major and minor cropping seasons in 2011. Planting distance was 0.3 × 1 m making a total of 12 plants per ridge. The genotypes were selected based on high beta-carotene, high dry matter and low sugar content for the development of varieties that combined these traits in one genetic background. They are made up of four released varieties (Apomuden, Faara, Histarch and Ogyefo) and 17 breeding lines. The breeding lines were CIP 442264, CIP 4442896, CIP 443035, CIP 442850, CIP 440071, CIP 440095, AAT 03-025, Beauregard, BOT-03-020, Resisto, Ukerewe, Ouagadougou 03, B/Faso 002, Paga 01, B/Faso001, Ehiamankyene 01 and Ouagadougou 02.

Establishment of hybridization blocks

Hybridization blocks were established at the research fields of the Council for Scientific and Industrial Research-Crops Research Institute (CSIR-CRI), Fumesua in 2012 using the 21 genotypes selected. Two crossing blocks were established. One for beta-carotene and dry matter content and the other for sugar content. The hybridization blocks were first established in the screen house in pots and later re-established in the field. Planting distance in the field was 0.3 × 1m.

Mating design used and management of the hybridization blocks

The full diallel mating design was used. Flowers ready for pollination the next morning were tied the previous afternoon using a piece of drinking straw to prevent out-crossing by insects. At the time of pollination, the corolla was carefully opened, pollinated and carefully tied again afterwards to avoid insect contamination after pollination. Although self-fertilization occurs only rarely in sweetpotato (Jill et al., 1989), emasculation was done on the female parents to eliminate the possibility.

Data collection

Harvesting of the 115 sweetpotato accessions was at three and half months after planting. The 10 central plants were harvested and one large, one medium, and one small storage roots were selected randomly for determination of beta-carotene, dry matter and sugar content. Storage roots used for observations were approximately 3 cm in diameter or more, without cracks, insect damage or rotten parts (Ekanayake et al., 1990). Beta-carotene and sugar content were determined using the near-infrared reflectance spectroscopy (NIRS) analysis. Fifty grams fresh sample was used and was freeze dried for 72 hrs. Dry matter content was determined as ratio of the weight of the freeze dried sample to that of the fresh sample expressed as a percentage. For the crossing blocks, observations were made on parents that either produced flowers or not. Number of crosses made, number of capsules and number seeds harvested per cross were recorded. Success rate of the crosses was calculated as the ratio of number of capsules harvested to the number of crosses made expressed as a percentage. In addition, number of seeds per capsule was also determined as the ratio of number of seeds harvested to number of capsule harvested. Data were also taken on the number of seeds sown and number of seeds germinated. Germination rate was computed as the ratio of number of seeds sown to the number of seeds germinated expressed as percentage. Means for number of crosses made, number of capsules harvested, success rate, number of seeds harvested, number of seeds per capsule, number of seeds sown, number of seeds germinated, and percent germination were also computed. These computations were done using MS Excel 2013. Meteorological data for the study site during the period of the work were sourced from the CSIR-Crops Research Institute Weather Station at Fumesua. The data included minimum temperature, maximum temperature, mean temperature, total rainfall, and relative humidity.

Data analysis

Data for 102 out of the 115 accessions were analyzed due to missing information. Minor cropping season data for Pokuase was also excluded due to experiment failure as a result erratic rainfall. Data were subjected to Analysis of Variance (ANOVA) using Genstat statistical package (Genstat, 2007). Relative efficiency (RE) of alpha lattice design over randomized complete block design (RCBD) was not significant. Hence, RCBD was used to analyze the data. The RE was determined as the ratio of error means square due to RCBD to the error means square due to alpha lattice design. RE is significant if the ratio is >1 and vice versa. In the case of the hybridization blocks data, means, rate and percentages were computed using MS Excel 2013.

Conclusion

Breeding progress in sweetpotato is affected by many genetic and physiological factors. Some major ones are flowering prolificacy, polyploidy and the large chromosome number, coupled with self- and cross-incompatibilities among different genotypes. These slow down breeding progress of the crop. This study suggests that lack of flowering or poor flowering and self- or cross-incompatibility are major constraints to sweetpotato breeding in Ghana. In spite of this, crosses among four parents (Histarch, Ogyefo, Apomuden and Beauregard) were good and can be used to study genetic control of beta-carotene, dry matter and sugar content in sweetpotato. In addition, Histarch and Ogyefo are

recommended for the development of non-sweet, high dry matter sweetpotato varieties which are the preferred cultivars in Ghana due to their low sugar content and good cross ability. The study revealed that the best period to establish hybridization blocks in the forest ecozone of Ghana is the minor cropping season.

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References

Acquaah G (2011) Principles of plant genetics and breeding. Blackwell Publishing Ltd, Carlton, Australia.

Baafi E (2014) Development of end-user preferred sweetpotato varieties in Ghana. PhD thesis. West Africa Centre for Crop Improvement (WACCI), University of Ghana.

Baafi E, Manu-Aduening J, Carey EE, Ofori K, Blay ET and Gracen VE (2015) Constraints and breeding priorities for increased sweetpotato utilization in Ghana. Sustain Agric Res. 4(4) 1-16.

Campbell GM, Hernandez TP and Miller JC (1963) The effect of temperature, photoperiod and other related treatments on flowering in *Ipomoea batatas.* Proc Am Soc Hortic Sci. 83**:**618-622.

Charles WB, Hoskin DG and Cave PJ (1973) Overcoming self and cross incompatibilities in *Ipomoea batatas* (L.) Lam and *Ipomoea trichoara elliot*. In: Proc 3rd ISTRC. Ibadan, Nigeria. IITA. p. 17.

Dar SH, Rather AG, Ahanger MA, Sofi NR and Talib S (2014) Gene action and combining ability studies for yield and component traits in rice (*Oryza sativa* L.): A review. J Plant Pest Sci. 1 (3):110-127.

Edmond JB and Martin JA (1946) The flowering and fruiting of the sweetpotato under greenhouse conditions. In: Proc Am Soc Hortic Sci. 47**:**391-399.

Ekanayake IJ, Malagamba P and Midmore DJ (1990) Effect of water stress on yield indices of sweetpotatoes. In: Howeler RH (ed) Proc 8th ISTRC. Bangkok, Thailand. 724pp.

Fekadu G, Shimelis H and Mark L (2013) Self- and cross-incompatibilities in sweetpotato and their implications on breeding. Aust J Crop Sci. 7**:**2074-2078.

Folquer F (1974) Varietal efficiency in the spring production of sweetpotato seeds (*Ipomoea batatas* (L) Lam.). Field Crop Abstr. 29**:**881.

Genstat. 2007. For windows release 9.2.0.152. Genstat-ninth edition @ 2007, Lowes Agricultural Trust.

Jill EW, Finau SP, Nicole EJMS, Pita T, Kim DR, Carl IE, E. DO and Shirley T (1989) Agro-facts crops. Sweetpotato (*Ipomoea batatas*) breeding. University of the South Pacific Institute for Research, Extension and Training in Agriculture (IRETA).

Jones A (1980) Sweetpotato. In: Hybridization of crop plants. American Society of Agronomy. Crop Science Society of America, 677. S. Segoe Road, Madison, WI 53711.

Jones A, Dukes PD and Cuthbert Jr FP (1977) Pesticides increase true seed production of sweetpotato. Hortscience 12:165-167.

Kays SJ and Horvat RJ (1983) A comparison of the volatile constituents and sugars of representative Asian, Central American and North American sweetpotatoes. In: Proc 6th ISTRC. Lima, Peru. pp. 557-586.

Kowyama Y, Tsuchiya T and Kakeda K (2000) Sporophytic self-incompatibility in *Ipomoea trifida*, a close relative of sweetpotato. Ann Bot. (London) 85:191-196.

Kowyama Y, Tsuchiya T and Kakeda K (2008) Molecular genetics of sporophytic self-incompatibility in *Ipomoea,* a member of the convolvulaceae. In: Veronica E Franklin-Tong (ed) self-incompatibility in flowering plants: Evolution, diversity, and mechanisms. pp. 259-274.

Lebot V (2009) Tropical root and tuber crops – cassava, sweetpotato, yams and aroids. Wallingford, UK: Cabi Publishing Group.

Martin FW (1967) The sterility incompatibility complex of the sweetpotato. In: Tai EA (ed) Proc 1st ISTRC. St. Augustine, Trinidad. University of West Indies. pp. 3-15

Martin FW (1988) Genetic and physiological basis for breeding and improving the sweetpotato. In: Degras, L (ed.) Proc 7th ISTRC. Institute de la Reserche Agronomique (INRA), Paris France. pp 749-762.

Martin FW and Cabanillas E (1966) Post-pollen-germination barriers to seed set in sweet potato. Euphytica 15:404-411.

Martin FW and Cabanillas E (1968) Classification of sweetpotato varieties for incompatibility and sterility. Proc Am Soc Hortic Sci. 93:502-511.

Mcclure BA and Franklin-Tong V (2006) Gametophytic self-incompatibility: understanding the cellular mechanisms involved in "self" pollen tube inhibition. Planta. 224:233-245.

Miller JC (1937) Inducing the sweetpotato to bloom and set seed. J Hered. 28**:**347-349.

Missah A and Kissiedu AFK (1994). Effect of time of harvesting on the yield and pest incidence of two sweetpotato varieties in the forest zone of Ghana. In: Proc 5th ISTRC, AB. pp 276-280.

Montelaro J and Miller JC (1951) A study of some factors affecting seed setting in the sweetpotato. Proc Am Soc Hortic Sci. 57**:**329-334.

Ray RC and Tomlins KI (2010) Sweetpotato: postharvest aspects in food, feed and industry, New York: Nova Science publishers Inc.

Sam J and Dapaah H (2009) West Africa Agricultural Productivity Programme (WAAPP), Ghana baseline survey report. October, 2009.

Sharma RK and Mani SC (2008) Analysis of gene action and combining ability for yield and its component characters in rice, Oryza 45:94-97.

Takayam S and Isogali A (2005) Self-incompatibility in plants. Annu Rev Plant Biol. 56:467- 489.

Thottappilly G (2009) Introductory remarks. In: The sweetpotato. Loebenstein, GG and Thottappilly, G (eds). Pp 1-7 springer science+business media b.V. 2009.

Tumana CW and Kesavan V (1987) The evaluation of hybrids of sweetpotato. In: Chang, WN and Opena, RT (eds) the breeding of horticultural crops. Food and fertilizer technology centre for the Asian and Pacific region, Taiwan. pp. 59-63.

Tumwegamire S, Kapinga R, Zhang D, Crissman C and Agili S (2004) Opportunities for promoting orange-fleshed sweetpotato as a mechanism for combat vitamin A-deficiency in sub-saharan Africa. Afr Crop Sci J. 12: 241-252.

Vimala B (1989) Fertility and incompatibility in sweetpotato (*Ipomoea batatas* L.). Ann Agr Res. 10:109-114.

Vimala B and Hariprakash B (2011) Variability of morphological characters and dry matter content in the hybrid progenies of sweetpotato [*Ipomoea batatas* (L.) Lam.]. Geneconserve. 10:65-86.

Wang H (1982) The breeding of sweetpotatoes for human consumption. In: Villareal RL and Griggs TD (eds) Sweetpotato. AVRDC 82-172:297–311.

Williams DB and Cope FW (1967) Notes on self-incompatibility in the genus *Ipomoea L.* In: Tai EA (ed) Proc 1st ISTRC. St. Augustine, Trinidad. University of West Indies. pp 16-30.