



Crossing Among Sixteen Sweet Potato Parents for Establishing Base Populations Breeding

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ABSTRACT

The base - population of the controlled cross breeding is one of the important factors to develop a new improved cultivar. Since the incompatible nature of sweet potato remains a barrier for genetic improvement, therefore it requires a lot of crossed pairs. This study aimed to determine the level of incompatibility among crossing line between high yielding and micronutrient content cultivars. The field experiment conducted at Brawijaya University Research Station, Jatikerto-Malang, during February to August 2015. The North Carolina Design II was applied to sixty pairs controlled cross breeding and their sixty reciprocal pairs of six cultivars for micronutrient content enrichment with ten high yielding cultivars. The observations were made to the cross flowers number, capsules, fruit sets, and seeds number. The level of incompatibility between crossed pairs was determined by the level of fruit set. The result showed that most pairs were compatible (fruit set > 20%) and only few were incompatible (fruit set < 10%). Among six parents with micronutrient content enrichment, two of them, have a high compatibility as female parents, to all the high yielding cultivars, i.e. BIS OP-61 and Cangkuang. Positioning as a female parent can improve the effectiveness of its selection scheme.

INTRODUCTION

Sweet potatoes are the second most important root crops after cassava and widely cultivated in tropical and sub-tropical areas, especially Asia, Africa and the Pacific (El Sheikha & Ray, 2017; Truong, Avula, Pecota, & Yencho, 2018). In the sweet potato breeding program, improvement in yields and introducing quality traits such as higher micronutrient content are essential for human health (Bouis, Hotz, McClafferty, Meenakshi, & Pfeiffer, 2011; Islam, Nusrat, Begum, & Ahsan, 2016; Mayer, Pfeiffer, & Beyer, 2008; Waized, Ndyetabula, Temu, Robinson, & Henson, 2015). This time, micronutrient malnutrition (*Hidden Hunger*) has been reported to affect more than half the world's population, especially women and preschool children in developing countries (Bouis, Hotz, McClafferty, Meenakshi, & Pfeiffer, 2011; Pfeiffer & McClafferty, 2007). Therefore, developing improved sweet potato

varieties that are rich in micronutrient content become an alternative option to solve the global problem.

The development to improve sweet potato varieties can be obtained in three ways, first by evaluating local germplasm collection, second by introducing cultivars, and third by developing cultivars through hybridization (Baafi et al., 2016; Mbusa et al., 2018). Establishing base population of sweet potato through hybridization in breeding program involves many sweet potato parents that have many numbers of flowers and cross-compatible nature to each other in order to produce many seeds set (Lestari, 2010; Mbusa et al., 2018; Mwanga et al., 2017). In sweet potato, open cross as well as controlled cross breeding produced hybrids with high heterozygosity levels (Grüneberg et al., 2015; Truong, Avula, Pecota, & Yencho, 2018).

The sweet potato improvement program requires many new seedlings from true seeds to

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evaluate and select based on the preferred traits, for instance, high yield and rich in micronutrients. However, the ability of sweet potato produced true seeds are low due to the strain of *Ipomoea batatas* that has genomeBBBBBB were found self-sterile and high cross-incompatible. In this case the self-sterile in question is self-incompatible. Gurmu, Hussein, & Laing (2013) also reported that sweet potato has the inherent nature of self- and cross-incompatible, highly heterozygous, and a large of small chromosome number ($2n = 6x = 90$), make their genetic improvement complicated (Baafi et al., 2016). According to Sattler, Carvalho, & Clarindo (2016), sweet potato is a hexaploid, and the polyploid often results in reduced fertility due to meiotic errors, allowing the production of seedless varieties.

The genetic improvement activities involve sexual reproduction process of recombining desirable traits and the traits are often scattered in several clones. Fortunately, the morphological nature of sweet potato flowers easily crosses to each other and produces the seeds (Lestari, 2010). A self-incompatibility nature in sweet potato can be used to facilitate the hybridization process without emasculation. Trellising in sweet potato induced flowering (Afolabi, Carey, & Akoroda, 2014). Therefore, in hybridization blocks, trellising for inducing flowering and crosses without emasculation commonly used to improve hybrid seed production. The sweet potato seeds that produced in polycross mating as well as controlled crossed mating are the hybrid seeds with high heterozygosity levels (Grüneberg et al., 2015; Truong, Avula, Pecota, & Yencho, 2018).

The methods to overcome their cross incompatibilities are by using random polycross with diverse genotypes and also making many controlled cross combinations (Grüneberg et al., 2015). The ability to cross among sweet potato clones or cultivars ranges from zero to 100 % and crosses between compatible parents rarely produced four seeds per capsule. In fact, they produce one or two seeds per capsule (Lestari, 2010). Therefore, it is needed to evaluate degrees of incompatibility crosses among many cultivars of sweet potato for establishing the base population.

MATERIALS AND METHODS

Experimental Materials

Sixteen cultivars were used in the experiment consist of ten high yielding cultivars and the other six cultivars for micronutrient (iron

or zinc) content enrichment. High yielding cultivars are (1) Cilembu, (2) Sari, (3) Sukuh, (4) 73-6/2, (5) Boko, (6) Sawentar, (7) Kuningan Merah, (8) Kuningan Putih, (9) Beta 1, and (10) Beniazuma; whereas six cultivars for a parent with micronutrient content enrichment, are (11) BIS OP-61, (12) Papua Solossa, (13) Beta 2, (14) D67, (15) Cangkuang, and (16) Jago. The four among the six cultivars have iron content ranges from 83-106 mg Fe/kg, i.e. BIS OP-61, Papua Solossa, Beta 2, and Jago; while two other cultivars (Cangkuang and D67) have Zn content ranges from 6-12 mg Zn/kg in dry weight basis.

Establishing Hybridization Block

Hybridization blocks established at the Brawijaya University Research Station, located in Jatikerto, Kromengan, Malang Regency. The altitude is at 350 m above sea level with Inceptisol soil type. The hybridization was carried out for six months, from February to August 2015.

Mating Design Used and Methods of Hybridization

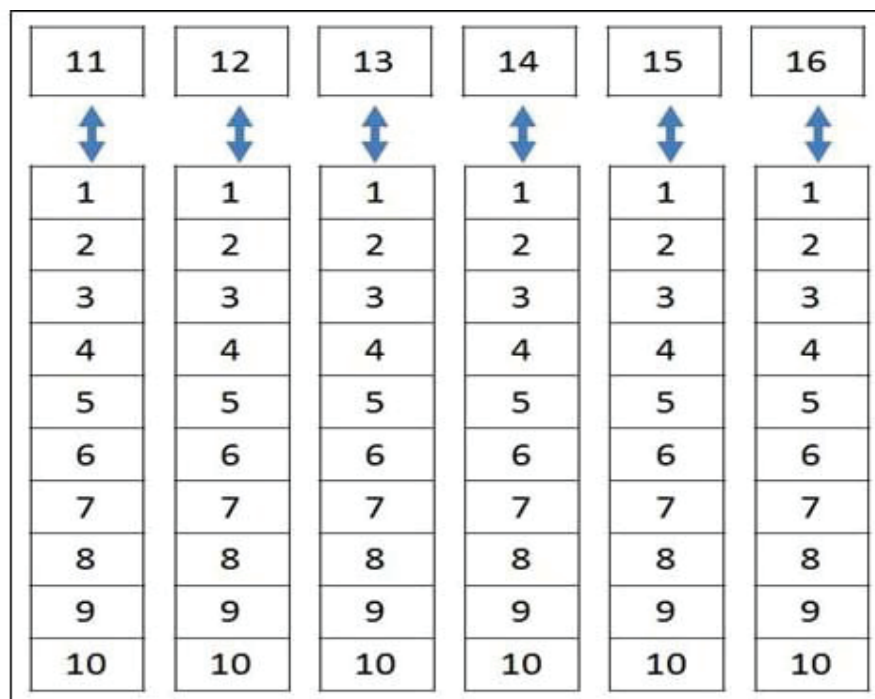
In the field, the combinations of the crossing designed is presented in Table 1. All combinations also conducted in their reciprocal crosses. All cultivars (ten cultivars of high yielding, with the serial number 1 to 10 and six cultivars for micronutrient enrichment with serial number 11 to 16) planted on plot size 1.20 m x 2.5 m, per plot consisted of double rows and five cuttings per row. The preparation of plots and factorial mating of cultivars implemented by North Carolina Design II, the schematic design was made as seen in Fig. 1, following Acquaah (2007). Each double row plot planted with five cuttings on each row as mentioned earlier, so that each plot consisted of a combination of the two cultivars. To enhance the flowers of each cultivar, their main vines trained upon stakes measuring 2 m in height, since trellising induced flowering (Afolabi, Carey, & Akoroda, 2014).

Cross breeding was conducted using hand-pollination breeding methods (controlled cross breeding), by transferring pollen from a male parent to the stigma of a female parent or vice versa (reciprocal). The crossing was done as follows: to avoid contamination of pollens from one parent to the others, the flowers bind with a cotton thread in the afternoon, a day before pollination was done to prevent it did not open and out-crossing by insects.

Table 1. The all of crossing pairs and their reciprocals

High micronu- trient content cultivar		High yielding cultivar									
		1	2	3	4	5	6	7	8	9	10
11	♂	1 x 11	2 x 11	3 x 11	4 x 11	5 x 11	6 x 11	7 x 11	8 x 11	9 x 11	10 x 11
	♀	11 x 1	11 x 2	11 x 3	11 x 4	11 x 5	11 x 6	11 x 7	11 x 8	11 x 9	11 x 10
12	♂	1 x 12	2 x 12	3 x 12	4 x 12	5 x 12	6 x 12	7 x 12	8 x 12	9 x 12	10 x 12
	♀	12 x 1	12 x 2	12 x 3	12 x 4	12 x 5	12 x 6	12 x 7	12 x 8	12 x 9	12 x 10
13	♂	1 x 13	2 x 13	3 x 13	4 x 13	5 x 13	6 x 13	7 x 13	8 x 13	9 x 13	10 x 13
	♀	13 x 1	13 x 2	13 x 3	13 x 4	13 x 5	13 x 6	13 x 7	13 x 8	13 x 9	13 x 10
14	♂	1 x 14	2 x 14	3 x 14	4 x 14	5 x 14	6 x 14	7 x 14	8 x 14	9 x 14	10 x 14
	♀	14 x 1	14 x 2	14 x 3	14 x 4	14 x 5	14 x 6	14 x 7	14 x 8	14 x 9	14 x 10
15	♂	1 x 15	2 x 15	3 x 15	4 x 15	5 x 15	6 x 15	7 x 15	8 x 15	9 x 15	10 x 15
	♀	15 x 1	15 x 2	15 x 3	15 x 4	15 x 5	15 x 6	15 x 7	15 x 8	15 x 9	15 x 10
16	♂	1 x 16	2 x 16	3 x 16	4 x 16	5 x 16	6 x 16	7 x 16	8 x 16	9 x 16	10 x 16
	♀	16 x 1	16 x 2	16 x 3	16 x 4	16 x 5	16 x 6	16 x 7	16 x 8	16 x 9	16 x 10

Remarks: 1 = Cilembu, 2 = Sari, 3 = Suku, 4 = 73-6/2, 5 = Boko, 6 = Sawentar, 7 = Kuningan Merah, 8 = Kuningan Putih, 9 = Beta 1, 10 = Beniazuma, 11 = BIS OP-61, 12 = Papua Solossa, 13 = Beta 2, 14 = D67, 15 = Cangkuang, 16 = Jago; ♀ = the cultivar of 11, 12, 13, 14, 15, or 16 as a female parent, and their reciprocal cross, the same of cultivars as a male parent (♂)



Remarks: 1 = Cilembu, 2 = Sari, 3 = Suku, 4 = 73-6/2, 5 = Boko, 6 = Sawentar, 7 = Kuningan Merah, 8 = Kuningan Putih, 9 = Beta 1, 10 = Beniazuma, 11 = BIS OP-61, 12 = Papua Solossa, 13 = Beta 2, 14 = D67, 15 = Cangkuang, 16 = Jago, each plot size 1.20 m x 2.5 m

Fig. 1. Mating Design with North Carolina Design II

Since, the level of self-incompatibility in sweet potato is almost 100% (Afolabi, Carey, & Akoroda, 2014; Lestari, 2010), it is not necessary to emasculate before pollination. At the time of pollination, the corolla opened, pollinated and tied again after pollination, to avoid insect contamination. Hand-pollination was conducted in the morning from sunrise (around 06.00 AM to 09.00 AM). It started in the sunrise because the anthesis started after sunrise and ended at 09.00 AM. Due to the passing of time likely to occur, fertilization has decreased. After the female parent had pollinated, the flowers tied again with the cotton thread.

Within three days after pollination, the cross was already seen whether it produced a seed set or not. When the flower stalk remains green, it means the pollinations are successful, but if the flower stalk discolored, yellow or pale green, it means the pollinations have failed and in three to four days, the flower and its stalk drop off. The capsule was harvested after the skin dries, approximately three weeks after the pollination. Then the capsule dried again in the sun for 3 days or until the seeds dry. And then, the seeds were grouped by their crossed pairs. The number of flowers crossed on each parent depending on the number of flower blooms every day.

Collecting and Presenting Data

The crossed flowers number, capsules number, fruit set, seed number, seed number per capsule, level of incompatibility, and germination rates were determined. The harvesting capsules were done periodically when their capsules dried up for three days in the sun, and subsequently

calculated the number of the capsules. Fruit set was calculated as the ratio of the capsule number to the number of pollinated flowers that expressed as a percentage. The seed germination rate was calculated based on the number of seedlings against a number of sowing seeds. Every seed planted in a plastic bag that filled with 100 g of soil. Prior to sowing the seeds were immersed in a concentrated sulfuric acid solution for 20 minutes, then washed with tap water until clean. After 30 days old, the seedlings transplanted in a nursery block. A mating pair is considered compatible if they have fruit set percentages greater than 20%, while partially incompatible if their fruit set of 10 - 20%, and then it is full incompatible when less than 10%.

RESULTS AND DISCUSSION

The Level of Compatibility

The compatibility level of all the mating pairs in sweet potato crops was evaluated in this study. There were 60 mating pairs and their reciprocal (120 mating pairs), involving 10 high yield cultivars paired with 6 cultivars which had high micronutrient content (Table 1). In each mating group, a cultivar as a female (♀) or a male parent (♂), observed based on fruit set percentages. A mating pair is considered compatible if they have fruit set percentages greater than 20%, while partially incompatible if their fruit set of 10 - 20%, and full incompatible when less than 10% (Lestari, 2010).

Table 2 shows that BIS OP-61 cultivar was only incompatible to Sukuh in one direction (unilateral) when the cultivar acted as a male parent, on the contrary, their reciprocal crossing was compatible.

Table 2. The compatibility status of BIS OP-61 on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x BIS OP-61	46	26	56.52	C	28	24	85.71	C
2.	Sari x BIS OP-61	30	15	50.00	C	51	20	39.22	C
3.	Sukuh x BIS OP-61	15	1	6.67	I	21	12	57.14	C
4.	73-6/2 x BIS OP-61	49	18	36.73	C	78	67	85.90	C
5.	Boko x BIS OP-61	94	48	51.06	C	57	52	91.23	C
6.	Sawentar x BIS OP-61	58	18	31.03	C	49	29	59.18	C
7.	K Merah x BIS OP-61	70	69	98.57	C	61	31	50.82	C
8.	K Putih x BIS OP-61	32	28	87.50	C	63	41	65.08	C
9.	Beta 1 x BIS OP-61	82	52	63.41	C	95	75	78.95	C
10.	Beniazuma x BIS OP-61	56	43	76.79	C	47	23	48.94	C

Remarks: C = compatible; I = incompatible

Another cultivar, such as Papua Solossa, had incompatible in two directions with Sukuh, partially incompatible to fully incompatible in one direction with Sari, Kuningan Putih and 73-6/2 (Table 3).

Cultivar Beta 2 also had an incompatible nature in two or one directions with Sari and Sukuh (Table 4). Similarly, with D67, Canguang and

Jago, had incompatibility in unilateral or reciprocal with some high yielding cultivars (Table 5, Table 6 and Table 7). Therefore, on all crossing pairs were found reciprocal compatibility, unilateral compatibility, and reciprocal incompatibility. However, they were dominated by compatible pairs, and only a small portion was partially incompatible to fully incompatible.

Table 3. The compatibility status of P Solossa on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x P Solossa	26	17	65.38	C	24	22	91.67	C
2.	Sari x P Solossa	28	3	10.71	PI	41	38	92.68	C
3.	Sukuh x P Solossa	0	0	0.00	I	2	0	0.00	I
4.	73-6/2 x P Solossa	20	0	0.00	I	52	34	65.38	C
5.	Boko x P Solossa	59	31	52.54	C	51	37	72.55	C
6.	Sawentar x P Solossa	59	16	27.12	C	35	29	82.86	C
7.	K Merah x P Solossa	67	35	52.24	C	58	48	82.76	C
8.	K Putih x P Solossa	11	2	18.18	PI	51	16	31.37	C
9.	Beta 1 x P Solossa	50	42	84.00	C	78	44	56.41	C
10.	Beniazuma x P Solossa	87	56	64.37	C	33	29	87.88	C

Remarks: C = compatible; I = incompatible; PI = partially incompatible

Table 4. The compatibility status of Beta 2 on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x Beta 2	50	39	78.00	C	20	10	50.00	C
2.	Sari x Beta 2	7	0	0.00	I	17	0	0.00	I
3.	Sukuh x Beta 2	14	10	71.43	C	6	0	0.00	I
4.	73-6/2 x Beta 2	28	11	39.29	C	39	36	92.31	C
5.	Boko x Beta 2	48	25	52.08	C	26	15	57.69	C
6.	Sawentar x Beta 2	40	32	80.00	C	7	4	57.14	C
7.	K Merah x Beta 2	38	17	44.74	C	23	8	34.78	C
8.	K Putih x Beta 2	30	20	66.67	C	52	47	90.38	C
9.	Beta 1 x Beta 2	57	46	80.70	C	27	25	92.59	C
10.	Beniazuma x Beta 2	65	50	76.92	C	35	26	74.29	C

Remarks: C = compatible; I = incompatible

Table 5. The compatibility status of D67 on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x 2136	46	25	54.35	C	27	18	66.67	C
2.	Sari x D67	39	0	0.00	I	27	4	14.81	PI
3.	Sukuh x D67	8	0	0.00	I	20	0	0.00	I
4.	73-6/2 x D67	45	19	42.22	C	47	10	21.28	C
5.	Boko x D67	76	36	47.37	C	52	25	48.08	C
6.	Sawentar x D67	61	9	14.75	PI	33	17	51.52	C
7.	K Merah x D67	83	39	46.99	C	58	21	36.21	C
8.	K Putih x D67	48	33	68.75	C	50	36	72.00	C
9.	Beta 1 x D67	99	32	32.32	C	45	21	46.67	C
10.	Beniazuma x D67	82	60	73.17	C	51	35	68.63	C

Remarks: C = compatible; I = incompatible ; PI = partially incompatible

Table 6. The compatibility status of Cangkuang on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x Cangkuang	41	7	17.07	PI	61	20	32.79	C
2.	Sari x Cangkuang	33	12	36.36	C	39	32	82.05	C
3.	Sukuh x Cangkuang	4	1	25.00	C	14	8	57.14	C
4.	73-6/2 x Cangkuang	50	16	32.00	C	79	27	34.18	C
5.	Boko x Cangkuang	68	20	29.41	C	89	26	29.21	C
6.	Sawentar x Cangkuang	62	1	1.61	I	79	25	31.65	C
7.	K Merah x Cangkuang	72	57	79.17	C	87	47	54.02	C
8.	K Putih x Cangkuang	35	23	65.71	C	77	43	55.84	C
9.	Beta 1 x Cangkuang	68	50	73.53	C	47	36	76.60	C
10.	Beniazuma x Cangkuang	85	61	71.76	C	71	55	77.46	C

Remarks: C = compatible; I = incompatible ; PI = partially incompatible

Table 7. The compatibility status of Jago on the crossing pairs and reciprocal

No.	Mating pairs	Crossing				Reciprocal			
		Flower number	Capsule number	Fruit set (%)	Compati-bility level	Flower number	Capsule number	Fruit set (%)	Compati-bility level
1.	Cilembu x Jago	57	8	14.04	C	47	43	91.49	C
2.	Sari x Jago	35	0	0.00	I	44	15	34.09	C
3.	Sukuh x Jago	14	5	35.71	C	20	0	0.00	I
4.	73-6/2 x Jago	56	42	75.00	C	50	47	94.00	C
5.	Boko x Jago	59	14	23.73	C	42	0	0.00	I
6.	Sawentar x Jago	71	22	30.99	C	38	24	63.16	C
7.	K Merah x Jago	47	37	78.72	C	40	23	57.50	C
8.	K Putih x Jago	47	13	27.66	C	65	39	60.00	C
9.	Beta 1 x Jago	71	30	42.25	C	35	22	62.86	C
10.	Beniazuma x Jago	48	8	16.67	C	52	46	88.46	C

Remarks: C = compatible; I = incompatible ; PI = partially incompatible

Some studies have shown similar results as in this study (Afolabi, Carey, & Akoroda, 2014; Baafi *et al.*, 2016; Indriani, Ashari, Basuki, & Jusuf, 2017; Rahajeng & Rahayuningsih, 2013; Sseruwu, Shanahan, Melis, & Ssemakula, 2016).

The compatible pairs as many as 100 pairs, had fruit set range between 21.28 - 98.57%, while the partial incompatible pairs consisted of 6 pairs with fruit set range between 14.01 - 18.18%, and the incompatible pairs consisted of 14 pairs with fruit set range between 0 - 6.67% (Table 2 to Table 7). For the grouping based on six cultivars as a female or a male parent respectively that classified as compatible, partially compatible and fully incompatible are presented in Table 8.

The grouping on BIS-OP-61 cultivar as a female parent showed that all of the mating pairs were compatible with the 10 high yielding cultivars, but on their reciprocal crossing had an incompatible to Sukuh cultivar (Table 2). Thus, the crossing between BIS OP-61 with Sukuh had only unilateral compatibility. On another grouping, there were many reciprocals compatible pairs and some unilateral incompatible to ten high yielding cultivars. The D67 and Papua Solossa had reciprocal incompatibility against Sukuh, and another crossing between Sari against D67 and Beta 2 cultivar had reciprocal partially to fully incompatibility (Table 3, Table 4, Table 5). Thus, only two of the mating pairs with BIS OP-61 and Cangkuang had highly compatible against ten high yielding cultivars, when both acted as a female parent (Table 8). Although there were two laterals or unilateral incompatibility in some sweet potato cultivars and produced few seeds only, due to many numbers cross recombination to be done, so many seeds could still be produced. This study used diverse genotypes and making many

controlled crosses to resolve cross-incompatibility in sweet potato. The results of this study are in line with the findings of Baafi *et al.* (2016).

Producing Many Seed Numbers

All the mating pairs of each parent group as a female or a male parent, based on fruit set percentages were compatible dominance, only a small portion of partially incompatible or fully incompatible (Table 8). Using many parents in controlled cross breeding nurseries with the North Carolina II Mating Design could produce many true seeds (Table 9).

The crossed flowers and capsules numbers produced by each parent in-group ranges from 252 to 643 flowers and 171 to 374 capsules respectively (Table 9). Each parent in question also had an average fruit set percentages ranged from 35 to 87% (Table 8). The seed number per capsule was less than two seeds, due to the large number of crosses done could produce many numbers of seeds, ranged between 297 to 557 seeds. Sweet potato seed number per capsule was lower, less than two seeds, due to their large ploidy and chromosome number of sweet potatoes. According to Sattler, Carvalho, & Clarindo (2016) a large number of small chromosomes in sweet potato often resulted in reduced fertility due to meiotic errors, allowing the low seed production.

The hand pollination among ten cultivars of high yielding with six cultivars as a breeding parent for iron and zinc content enrichment produced a lot of capsules and seeds, using many flowers number of each cultivar (Table 9). All the cultivars included in the hand pollination program had many numbers of flowers. For sexual reproduction, flowering is a prerequisite.

Table 8. Compatibility status of six cultivars to high yielding cultivars for establishing a base population in sweet potato breeding

Cultivar	Fruit set (%)		Compatible		Partially incompatible		Fully incompatible	
	♀	♂	♀	♂	♀	♂	♀	♂
BIS OP-61	68.00	87.36	10	9	0	0	0	1
Papua Solossa	69.88	49.63	9	6	0	2	1	2
Beta 2	67.86	66.31	8	9	0	0	2	1
D67	45.61	43.10	8	7	1	1	1	2
Cangkuang	49.61	47.88	10	8	0	1	0	1
Jago	59.82	35.45	8	8	0	1	2	1

Remarks: ♀ = a female parent; ♂ = a male parent

Table 9. The number of flowers, capsules, seeds, and seed number per capsule from six cultivars as a female (♀) or a male (♂) parent for establishing a base population in sweet potato breeding

Cultivar	Flowers number		Capsules number		Seeds number		Seeds number per capsule	
	♀	♂	♀	♂	♀	♂	♀	♂
BIS OP-61	550	532	374	318	451	479	1.21	1.51
Papua Solossa	425	407	297	202	557	248	1.88	1.23
Beta 2	252	377	171	250	297	335	1.74	1.34
D67	410	587	187	253	249	498	1.33	1.97
Cangkuang	643	518	319	248	438	299	1.37	1.21
Jago	433	505	259	179	415	291	1.60	1.63

Remarks: ♀ = a female parent; ♂ = a male parent

Table 10. Seeds number, number of seeds sown, seedling number, and germination rate (%) at the female or male parent of each cultivar for establishing a base population in sweet potato breeding

Cultivar	Sample of number seeds sown		Seedling number (genotypes)		Germination rate (%)		Seedlings produced estimation	
	♀	♂	♀	♂	♀	♂	♀	♂
BIS OP-61	40	40	35	28	87.50	70.00	395	335
Papua Solossa	40	40	30	35	75.00	87.50	418	217
Beta 2	40	40	30	23	75.00	57.50	223	193
D67	40	40	28	34	70.00	85.00	174	423
Cangkuang	40	40	27	40	67.50	100.00	296	299
Jago	80	40	77	35	96.25	87.50	399	255

Remarks: ♀ = a female parent; ♂ = a male parent

In the research location, especially in dry season some genotypes flowered easily, including all sixteen cultivars mentioned above. Grüneberg et al. (2015) stated that for recombining genotypes in a nursery of polycross as well as controlled cross breeding, the genotypes must have readily and balanced flowering. In this research, clone of Beta 2 has the number of cross flowers ranging from 252 - 377 comes from 50 plants, the lowest among the 6 parent clones (BIS OP-61, Papua Solossa, Jago, Beta 2, D67 and Cangkuang) in the crossing block. The other cultivars had crossed flowers ranging from 407 - 643 flowers from the same number of plants (Table 9). From many cultivars and plants/cultivar, it could be obtained a lot of true seeds (297 - 557 hybrid seeds). The large numbers of seedlings were raised from true seeds and evaluated for base population.

Germination Rate and Seedling Produced for Base Population

The seed number produced by sixteen parents of sweet potato crosses amounted 4557

seeds, 2407 seeds from female parents and 2150 seeds from male parents. Each of the mating pair from the female parent group and males took some true seeds sample (of total 520 seeds consist of 280 and 240 seeds respectively) as presented in Table 10 for sowing to produce seedlings. They had high germination rates (78 - 81%), produced 227 and 195 new seedlings respectively. When all the seeds (4557 seeds) were sown, it can be expected to produce many seedlings for the base population of improved sweet potato program. Every seed of sweet potato is a hybrid seedling, since its genetic nature is highly heterozygous hexaploid hybrid as stated by Grüneberg et al. (2015).

The new seedlings from the true seeds are very indispensable for the sweet potato improvement program. Producing true seeds, certainly involving sexual reproduction activity process, for recombining desirable traits and the traits are frequently dispersed in several clones. The high yielding trait is spreading among ten cultivars, namely: Cilembu, Sari, Sukuh, 73 6/2, Boko, Sawentar, Kuningan

Merah, Kuningan Putih, Beta 1, and Beniazuma (Table 1 and Fig. 1). For iron content trait scatters on four cultivars (BIS OP-61, Papua Solossa, Beta 2, and Jago), while for Zinc content spread on Cangkuang, and D67. Traits recombination through controlled/hand crosses between 10 high yielding parent clones and the other 6 clones of parental for micronutrient enrichment using North Carolina Design II (Acquaah, 2007), generated 60 mating pairs and 60 their reciprocal (Table 2 to Table 7). The whole mating pairs produced many compatible pairs and many seeds or seedlings for base population breeding. This is in line with the research of Ngailo, Shimelis, Sibiya, Mtunda, & Mashilo (2019) and Rukundo, Shimelis, Laing, & Gahakwa (2017) that reported on a recombination through sexual reproduction can bring four new characters with a worthy combination of significant traits and a single seed can give rise to a potentially commercial variety.

CONCLUSION AND SUGGESTION

In conclusion, the result showed that most pairs were compatible and only few in each group were partial to full incompatible. Many true seeds produced high germination rates and generated many new seedlings from the sixteen parents, could develop a base population. Similarly, the crossing involved many cultivars can overcome the constraints of the low number of seeds and cross-incompatibilities in sweet potato crossing. Among six parents for micronutrient content enrichment, two of them, had a general compatible ability as a female parent against to all the high yielding cultivars i.e. BIS OP-61 and Cangkuang.

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