Introduction and Use of Exotic Germplasm in the Chinese Sweetpotato Breeding Program

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Sweetpotato (*Ipomoea batatas*) was introduced to China over 400 years ago. Its high yield, wide adaptability, tolerance of abiotic stresses, and versatility have contributed to its traditional and continuing importance in Chinese agriculture. Sweetpotato ranks fourth among crops in planted area, about 5.6 million ha, with mean yields higher than those almost anywhere else in the world. In the 1950s and 1960s, the crop was used mostly for food and feed, with only 10% of total production going to starch extraction and food processing. In the 1990s, that has risen to about 45% of total production. Given the changes in use pattern, it is clear that high dry matter (DM) or high starch content is becoming more important. Most Chinese cultivars have low or moderate DM content of <30% (XSPRC, 1993). Over the last 20 years, many provincial breeding programs worked to increase DM content and yield with little success. Given the lack of progress, there appears to be a need for an infusion of new sources of genetic diversity.

Chinese Sweetpotato Breeding: Past and Present

Over the past 400 years, a number of local cultivars emerged due to selection pressure by farmers and environmental changes. Forty-eight were listed in the Catalog of Sweetpotato Cultivars in China (XSPRC, 1993), which contained 184 important cultivars. Those cultivars possess tolerance of biotic stress and resistance to abiotic stresses. They are still grown in small areas in South China. However, most of them had low yield and poor adaptability when planted away from their place of origin. That has been a serious constraint to the expansion of sweetpotato production. In 1938, Nancy Hall was introduced from the USA. Preliminary evaluations were conducted in Nanjing and Sichuan. In 1941, the Japanese cultivar Okinawa 100 was introduced and soon became the most widely grown in northern China. Nancy Hall and Okinawa 100 became important in both production and in breeding.

Modern breeding programs

Modern sweetpotato breeding began in the late 1940s and early 1950s when the population explosion and severe food shortages led the government to emphasize sweetpotato production. Major efforts were devoted to sweetpotato breeding in provinces with large sweetpotato planting areas. A number of new cultivars were developed using Okinawa 100, Nancy Hall, and some local cultivars as parents. Most of the new cultivars had medium to low DM content. Xushu 18 is the cultivar most widely grown, with a planted area of 1.5 million ha. Its DM content is about 25% (summer cropping in sandy loam soil in Xuzhou) and extractable starch content is 11-15% (XSPRC, 1993). Various institutes released many cultivars. One of most successful after Xushu 18 was Nanshu 88, which was released in 1988 by the Nanchong Agricultural Research Institute. It is, however, grown only in Sichuan Province.

To increase production and efficiency, key breeding units in China were organized into a national collaborative sweetpotato breeding project. Greatly improved collaboration among provincial- and city-level

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research units resulted. Conventional hybridization is still the principal approach for sweetpotato breeding. Since the late 1970s, Jiangsu Academy of Agricultural Sciences (AAS) and Shandong AAS paid more attention to collection, evaluation, and use of wild-relative species. Some newly developed cultivars, such as Sushu 2 and Pushu 83-91, were bred with the introgression of genes from wild relatives. New cultivars, Yi 306, Lushu 7, and Yushu 7, were selected from crosses with the Japanese cultivar Minamiyutaka, which has 12.5% of wild species genes in its pedigree. Mutation breeding with ^{60}Co radiation used to induce somaclonal variation has been used to improve sweetpotato. This work was done at Beijing Agricultural University. As a result, Nongda 601, highly resistant to black rot caused by *Ceratosystis fimbriata*, was selected from Xushu 18; and, Nongda 321-10, with resistance to stem nematode (or brown ring caused by *Ditylenchus destructor*), was selected from Ning 12-17. Yantai Institute of Agricultural Sciences selected a number of cultivars using fast neutron radiation. These selected cultivars are high yielding and have high vitamin C content. The Xuzhou Sweetpotato Research Center (XSPRC) selfed elite clones, and selected two superior clones, Xuzi 39 and Pengwei S_1-12-48. None of these efforts, however, resulted in a cultivar superior to Xushu 18.

In recent years, postharvest processing of sweetpotato has become an important way for farmers to increase their income. That requires a high-yielding sweetpotato high in DM content. Existing cultivars do not meet these demands. Disease-resistant cultivars with high starch content and high DM yield are urgently needed.

Inbreeding tendency in sweetpotato breeding

Nancy Hall and Okinawa 100 have been widely used as parental material since the beginning of the modern breeding program. According to Lu (1990), who analyzed the pedigree of cultivars listed in the Catalog of Sweetpotato Cultivars (1981), 41 cultivars have been released from crosses with Okinawa 100 as a parent, and 33 from Nancy Hall. Thirty-one cultivars were developed from cross combinations between the two, including important cultivars such as Lizixiang, Yiwohong, Fengshouhuang, and Huabei 52-45. Nancy Hall and Okinawa 100 were dominant among parents in breeding programs in Beijing and Nanjing. In Beijing, Huabei 117, Huabei 166, Beijing 553, Beijing 284, Beijing 169, and others were selected from crosses of these two parents. More than 70 cultivars were selected from the crosses of Nancy Hall and Okinawa 100 after provincial breeding units were established in the early 1950s. Some of them, such as Yiwohong, Beijing 553, and Lizixiang are still planted in some places.

In turn, Xushu 18, which has 75% of its genes from Nancy Hall and Okinawa 100, has been widely used as parental material.

Although the use of Nancy Hall and Okinawa 100 led to the development of many successful cultivars, the genetic background of sweetpotato has become narrow and limited. From 1986 to 1990, 21 of 23 cultivars released in China carried a substantial number of genes from Nancy Hall and Okinawa 100. Nanshu 88 and Ji 18-1 were the only two exceptions. Of 21 new cultivars registered from 1990 to 1995, only Sushu 4 and Sushu 6 were not genetically related to these two parents.

The General Seed Company of China (1989) listed 42 cultivars grown on more than 667 ha. Of these, 26 were considered closely related to Nancy Hall or Okinawa 100 or both, in that they have more than 12.5% of their genes in common.

Sweetpotato breeding programs all over China have extensively used Nancy Hall, Okinawa 100, Xushu 18, and other closely related cultivars as parents. This practice caused severe inbreeding during selection, and limited the release of new, promising cultivars, especially those with high DM content. Although more than 30 new cultivars have been released since 1990, none can replace Xushu 18. These new cultivars have low to medium DM content compared with many Japanese cultivars.

In recent years, more and more exotic germplasm has been introduced through international cooperation. The breeding strategy of CIP (Mok et al., 1998) strongly influenced sweetpotato breeding in China. Breeders paid more attention to broadening the genetic base by introducing exotic germplasm. With the introduction of superior germplasm from CIP and Japan, the inbreeding tendency can be reversed to achieve higher yields and DM content. Breeding materials from various sources, including those from South America and Africa, are expected to further broaden the genetic base to incorporate resistance to viruses and other diseases. The challenge is to introgress these new genetic resources into highly-adapted, high-yielding Chinese commercial cultivars. Obviously, cultivar introduction alone will not achieve these goals. There is a need for further breeding.

Material and Methods

Various sources of seed families have been evaluated in China. Seed families from CIP-Lima had high DM content with resistance to root-knot nematode (*Meloidogyne* spp.). CIP-Nairobi sent seed families of high DM content with sweetpotato virus disease resistance. Those from CIP-Bogor had high DM content with wide adaptability. Seeds were also received from the cooperative shuttle breeding project with Japan (Table 1). Seven advanced clones were introduced from CIP-Bogor. They had been selected at three sites in Indonesia: Bogor (humid tropics, poor soil, 200 m), Lembang (highland, cooler climate, 1600 m) and Malang (highly fertile soil, 700 m). These clones were initially selected based on yield, DM content, starch content, and adaptability to poor soils. Two clones (190070-1 and 194039-1) selected at Xuzhou from CIP-Lima seeds were included. Xushu 18 was used as a check.

Seedling evaluation was done at Xuzhou by planting during the first week of June. Advanced clones were multiplied at XSPRC and evaluated at Chengdu, Jinan, and Xuzhou. Clones were planted in random complete block design with three replications. The size of a single plot was 9.4 m^2. Cultivation was done according to the standard method of each provincial AAS. Harvest was 120 d after planting. DM content of storage root was measured using 200 g of longitudinally sliced strips. Drying oven temperature was set at 70^{o}C until the samples reached constant weight.

Results and Discussion

Botanical seed families from CIP have been introduced into China since 1990; more than 34,000 seeds have been evaluated. The number of families and their origin are listed in Table 1. Seeds introduced in the early 1990s had poor germination and low adaptability, resulting in a low selection

Table 1. Evaluation of botanical seeds introduced to XSPRC from CIP.

Year	Crosses	Seeds received	Seedlings planted	Clones selected	Origin
1992	33	1,700	600	12	CIP-Lima
1994	100	8,100	3,571	34	CIP-Lima, CIP-Bogor
1995	80	6,700	4,000	70	CIP-Lima, CIP-Bogor, CIP-Nairobi
1996	30	2,650	1,010	22	CIP-Lima, CIP-Bogor
1997	14	1,483	920	30	Shuttle-breeding families
1998	160	12,000	8,600	400	CIP-Lima, CIP-Bogor
1999	148	20,520			CIP-Lima, CIP-Bogor

ratio. Selected high-yielding clones such as 490074-2 (from CIP-Lima, 1992) and B0080-1 (from CIP-Bogor, 1994) had low DM content. These clones have already been discarded from the CIP breeding program.

In 1995, large quantities of seeds were introduced, most of them from crosses of high DM-content parents. Two clones from CIP-Lima were selected, 194038-3 and 194039-1. Both had high DM content, 35% for 194038-3 and 32% for 194039. They had higher dry matter content than that of Xushu 18 (25-26%). After initial selection at XSPRC, the 2 clones were sent to more than 10 breeding units around the country for further evaluation. Although the clones were not released as cultivars, they were used as parental material in many provinces. In 1996, 22 good clones were selected from CIP seed families. Of these, Kawa 090-1 had 30% DM content, 4% higher than Xushu 18. Further evaluation was done in 1998 with about 12,000 seeds, 9,600 of which came from CIP-Lima, 2,200 from CIP-Bogor, and 524 from the National Agriculture Research Center (NARC), Japan. The Japanese seeds were produced as a part of CIP-NARC's shuttle-breeding activity. With the adoption of improved seed germination methods, about 90% of seeds germinated. After inferior plants in the nursery were discarded, 8,600 seedlings were transplanted to the field. Finally, 400 good clones were selected from the first year seedling evaluation. Selection was based on good root shape and high DM content.

In 1998, seven clones were introduced from CIP-Bogor. Of these, enough planting material was produced to test three clones (Group I) in Xuzhou, Jinan, and Chengdu. Four clones (Group II) that did not produce enough cuttings were tested only in Xuzhou. The result of the evaluation of Group I is presented in Table 2, and that of Group II in Table 3. The results indicated that AB94001.8 (code name CIP-2) had high DM content and high yield. Fresh storage root yield of CIP-2 was almost the same as Xushu 18 (Table 2), but DM content was higher than Xushu 18 at all three sites. This clone will be tested in demonstration trials in 1999.

Clone AB94001.8 was initially selected in Indonesia from seed families obtained through shuttle breeding. In evaluations of various introductions from many countries, seed families from Japan were observed to produce progenies having very high DM content. The parental clones of these families also had high DM content in Japan (Tarumoto, 1989; Yamakawa, 1995).

Table 2. Multilocation trial of introduced high DM-content clones (Group I), China, 1998.

Clone	Xuzhou			Chengdu			Jinan			Mean		
	DM (%)	FY (t/ha)	DY (t/ha)	DM (%)	FY (t/ha)	DY (t/ha)	DM (%)	FY (t/ha)	DY (t/ha)	DM (%)	FY (t/ha)	DY (t/ha)
AB94001.8	30.2	19.5ab[a]	5.9a	32.3	28.4a	9.2a	39.4	11.2a	4.1ab	34.0	19.7	6.4
AB95002.3	30.4	8.5c	2.6 b	27.8	13.2 c	3.7 c	41.6	3.9 b	1.6 c	33.3	8.5	2.6
AB97001.1	28.2	14.4abc	4.1ab	28.3	13.2 c	3.7 c	38.5	6.2 b	2.4 bc	31.6	11.3	3.4
190070-1	31.8	12.1bc	3.8ab	33.3	13.5 c	4.5 bc	43.6	5.1 b	2.2 c	36.2	10.2	3.5
194039-1	30.2	21.2ab	6.4a	32.3	17.1 b	5.5 b	40.6	8.2ab	3.3abc	34.4	15.5	5.1
Xushu 18	24.4	24.2a	5.9a	30.3	30.7a	9.3a	35.1	12.4a	4.3a	29.9	22.4	6.5

DM = dry matter content, FY = fresh storage root yield, DY = dry matter yield.
a. Mean separation within columns by Duncan's multiple range test at P = 0.05.

Table 3. Single-location trial of introduced high DM-content clones (Group II), Xuzhou, China, 1998.

Clone	DM (%)	FY (t/ha)	DY (t/ha)
AB94002.7	29.7	4.9	1.46
AB95002.7	32.8	10.8	3.54
AB94078.1	33.7	13.8	4.65
AB95012.4	25.0	8.4	2.10
Xushu 18	24.0	20.6	4.94

DM = dry matter content, FY = fresh storage root yield, DY = dry matter yield.

Obtaining botanical seeds in quantity from Japan was difficult due to the cost of seed production. Moreover, all of the recently-released cultivars, which are frequently used for hybridization, are protected under the breeders' rights law in Japan. To overcome these limitations, shuttle breeding was suggested (Takagi, H., Japanese International Research Center for Agricultural Science and Komaki, K., National Agricultural Research Center, pers. comm.). CIP sent a trainee to NARC to learn hybridization techniques using high DM-content cultivars such as Minamiyutaka, Satsumahikari, and Hi-starch. *Ipomoea nil*, a dwarf morning glory, which had strong flowering induction ability, was used as grafting stock. Three trainees from developing countries were sent to Japan, one each in 1996, 1997, and 1998. Hybrid seeds produced were evaluated in China, Indonesia, and Vietnam. DM content in the breeding population was rapidly increased using these seed families.

Another clone, AB94078.1, was selected at CIP-Bogor from seed families of CIP-Lima. This clone had the highest DM content of all clones tested at Xuzhou (Tables 2 and 3), and also gave the highest DM content (39%) at three distinctively different environments in Indonesia (Mok et al., 1997a). This clone has already been distributed to other breeding units in China.

Two main selection criteria at CIP-Bogor were high DM content and wide adaptability (Mok et al., 1997b). These *AB series* clones, selected for wide adaptability in Indonesia, seemed to perform satisfactorily at the evaluation sites in China. Clones selected in Indonesia for high DM content almost always tested high for DM content in China. The heritability of DM content was 61.2% (Mok et al., 1997b). It is likely that this trait could have a small genotype by environment interaction.

Conclusion

In China, popular sweetpotato cultivars mostly have low to medium DM content. Two major reasons for this are the narrow genetic base and the high yield focus of breeding programs. Recent developments in starch processing from sweetpotato in China require cultivars with high DM content and high starch content. Collaborative research with CIP makes the exchange of genetic resources possible with unprecedented speed. As a result, a number of high DM clones have been selected and introduced. These materials are under evaluation in many provinces where sweetpotato is important. These preliminary results indicate it is possible to select cultivars for high DM content, high yield, and wide adaptability in China. This effort will have a major impact in many provinces where starch processing is a major source of farmers' income.

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