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Actinidia Germplasm Resources and Kiwifruit Industry In China

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Kiwifruit is native to China, and today's cultivated kiwifruit are the large-fruited and good-flavored selections of two commercially developed *Actinidia* species: *A. deliciosa* C.F. Liang et A.R. Ferguson and *A. chinensis* Planch. The genus *Actinidia* Lindl. comprises 66 species and about 118 taxa, with a remarkably wide natural range extending from the tropics (latitude 0°) to cold temperate regions (50° N). With the exception of four species native to neighboring countries (*A. strigosa* Hook & Thoms. in Nepal, *A. petelotii* Diels in Vietnam, *A. hypoleuca* Nakai and *A. rufa* (Sieb. et Zucc.) Planch ex Miq. in Japan), all other 62 species, about 45 varieties, and 7 forms occur naturally in China (Cui, 1993; Ferguson, 1990; Huang et al., 2000; Liang, 1983). Such an unusually wide range of variation of species diversity and rich genetic resources provides tremendous potential for cultivar improvement and sustainability enhancement of the world kiwifruit industry. It is impossible therefore to ignore the value of *Actinidia* genetic resources in China, which occurs both naturally in the wild and is conserved in field repositories (Huang, 2003).

The economic potential of *A. deliciosa* was exploited following the first seed introduction from China in 1904 and the first commercial vineyard appeared in New Zealand in 1930 (Ferguson and Bollard, 1990). Since the 1970s, an international kiwifruit industry of >100,000 ha has been developed with annual production of 1×10^6 t (Huang and Ferguson, 2001). The successful development of kiwifruit industries, first in New Zealand and then in other countries, has stimulated China's interest in the potential of native *Actinidia* species, although China has a long history of local consumption of the *Actinidia* as fresh fruit, functional foods, Chinese herbal medicines, and as much as 150,000 t fresh fruit per year were collected from the wild (Cui, 1993). This wild harvesting has occurred for centuries, but until about 20 years ago, only very few sporadic attempts at cultivation have been made (Ferguson, 2001). A nationwide selection program was initiated by the Chinese government in 1977–78. The program resulted in >1400 superior genotypes being selected from wild populations of *A. chinensis*, *A. deliciosa,* and *A. arguta* (Sieb. et Zucc.) Planch et Miq. Most of these selections were topworked at research stations and evaluated. Subsequently, experimental trials, regional tests, and replicated trials of commercial scale resulted in 57 cultivars and a large number of selections (Cui, 1993). The outcome of this program made a unique situation for the Chinese kiwifruit industry with a different cultivar structure from the rest of the world. Since 1978 when commercial kiwifruit vineyards were first established in Hubei and Sichuan provinces using 'Hayward' (developed in New Zealand), commercial plantings have continuously increased to the present 57,396 ha. China now has >40% of all the planted kiwifruit in the world. Production likewise increased rapidly from 5,000 t in 1990 to 291,450 t in 2001. It is estimated that in 2002, the total production of kiwifruit in China was about 340,420 t. China has now surpassed New Zealand and Italy and has become the largest kiwifruit producer in the world (Huang and Ferguson, 2001). The current rapid growth of the world kiwifruit industry and its future sustainability will depend to a large extent on a thorough and continuous exploitation of the rich genetic resources and a sound management and conservation strategy for the germplasm. Since the late 1970s, extensive research has been conducted exploring genetic resources in China and has generated a wealth of information on the extent of genetic variation that exists. Our enhanced understanding of many basic aspects for further germplasm exploitation will lead us toward the development of a sustainable kiwifruit industry in China. Unfortunately, little of this basic information has been published in western languages. In this paper, we provide an overall review of the basic information that has been gathered on *Actinidia* germplasm and the development of Chinese kiwifruit industry over the past 2 decades.

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GENETIC DIVERSITY AND GERMPLASM RESOURECES OF GENUS *ACTINIDIA*

Morphological Variation for Horticulturally Important Traits

Tremendous phenotypic variations at both the interspecific and intraspecific level were observed in fruit traits (Table 1). For fruit weight, the interspecific variation ranges from 0.6 g in *A. maloides* Li to 240 g in *A. deliciosa*. The two most commercially important species, *A. deliciosa* and *A. chinensis*, have the largest fruit, but significant variation in fruit weight is also observed within both species. *A. chinensis* fruit weight ranges from 20 to 120 g, while that of *A. deliciosa* ranges from 30 to 200 g. In general, all fruit are oval and spherical in shape. There are at least 15 different fruit shapes that have been identified: ovate-globose, flat globose, oblong, near globose, ellipsoid, short cylindric, cylindric, ovoid, long globose, ovate-cylindric, long cylindric, ovoid-cylindric, long cone, ovate-cone, and ovoid-globose. One of the main breeding goals has been to develop cultivars with lighter skin than 'Hayward'. Although intraspecific variation of skin color is very limited and hardly genetically manageable, interspecific variation is broad and genetically heritable in most species. The interspecific variation of the fruit skin color ranges from brown to green, yellow, orange, light red, and even purple (Table 1).

Most *Actinidia* species have fruit skin covered with unpleasant pubescence. The stiff and long hairs of 'Hayward', selected from *A. deliciosa*, are considered undesirable and should be improved by future breeding and selection. A wide range of interspecific variation in type and amount of pubescence exists within the genus. This variation provides the breeding potential to improve this trait, and even a smooth skinned apple-like fruit may be developed in the future. There exits a continuous variation in skin pubescence ranging from long, stiff hairs on *A. setosa* (Li) C.F. Liang et A.R. Ferguson to the smooth skinned apple-like fruit of *A. arguta*. *Actinidia arguta* has a nice glabrous skin, but is small in size. This species has been successfully used in interspecific breeding for creating large sized, smooth skinned fruit. *Actinidia macrosperma* C.F. Liang has smooth orange-colored skin when ripe, making it a suitable parent for breeding efforts. It has also been used to improve skin color and heat tolerance. *Actinidia* has a wide range of flesh color although commercial cultivars are either green or yellow-fleshed. Flesh color varies from light green to orange, dark red or purple. Flesh color has been considered a trait with strong gene × environment interactions. In most warmer climate regions, red flesh color (usually red color around fruit core ring) in some selections of both *A. deliciosa* and *A. chinensis* can be discovered in late spring to early summer, however, the red color becomes faded in midsummer. At high elevations where large day–night temperature fluctuations exist, red color can persist until maturity (Huang, personal observation). Most species produce edible fruit, but fruit taste varies considerably. The species with excellent palatable fruit are *A. chinensis, A. arguta, A. kolomikta* (Maxim. et Rupr.) Maxim., *A. callosa* Lindl., *A. chrysantha* Liang, and *A. hubeiensis* Sun et Huang. *A. polygama* (Sieb. et Zucc.) Maxim. is the least palatable with a mix of bitterness, astringency and a shocking mouth numbing effect. More detailed morphological variation of horticulturally important fruit characteristics are listed in Table 1.

Table1. Diversity of fruit characters in genus *Actinidia*[z].

Species	Fruit shape	Fruit wt (g)	Skin color	Skin hairs
A. arguta	Ovate-globose, flat globose oblong, near globose	4–20	Light red, purple	Glabrous and smooth
A. arisanensis	Near globose, ellipsoid	5–10	Brown	Coarse hairs but shed
A. callosa	Near globose, short cylindric	8–9	Green	Glabrous
A. chengkouensis	Near globose, cylindric	10–35	Brown	Brown tomentose
A. chinensis	Ellipsoid	20–120	Brown	Brown short-tomentose but readily shed
A. chrysantha	Short cylindric, ovoid long globose	10–30	Chestnut brown, brown-green	Glabrous
A. cinerascens	Ovate-cylindric	5–10		
A. cylindrica	Long cylindric	0.5–1	Dark green	Glabrous
A. deliciosa	Long cylindric	30–200	Brown-green	Dense with yellow-brown coarse hairs
A. eriantha	Long cylindric	10–40	Green	Dense with white villose
A. farinose	Ovoid-cylindric	1–2	Light green	Short-tomentose but readily shed
A. fasciculoides	Long cylindric		Dark green	
A. fortunatii	Long cylindric	1–2	Dark green	Yellow short-tomentose
A. fulvicoma	Near cylindric	3–4	Dark green	Yellow long-tomentose
A. glauco-callosa	Flat globose	10–15	Green, red-brown	Glabrous
A. glaucophylla	Slender cylindric	1–5	Brown	
A. globosa	Near globose	10–25	Brown	Glabrous
A. gracilis	Ovoid , cylindric	5–10	Brown	Glabrous
A. grandiflora	Cylindric, ellipsoid	20–60	Brown	Grayish white or yellow-brown downy hairs
A. guilinensis	Globose	10–25	Green	Glabrous but spotted distinctly
A. hemsleyana	Cylindric	16–30	Brown	Densely grayish yellowish brown setose
A. henanensis	Cylindric	15–23	Red	Glabrous and smooth
A. henryi	Near cylindric, long cone	2–8	Green	Glabrous but spotted distinctly
A. hubeiensis	Ovate-cone	5–9	Dark green	Glabrous but spotted distinctly
A. indochinensis	Short ellipsoid	6–8	Brown	Glabrous but spotted distinctly
A. jiangxiensis	Ovoid-globose	15–25	Yellow-green	Brown downy hairs only at apex
A. kolomikta	Long-cylindric or long-globose	2–10	Green and yellow-green	Glabrous and smooth
A. lanceolata	Long cylindric, globose ovoid	1	Light brown	Glabrous
A. latifolia	Cylindric	2–4	Brown-green	Glabrous but spotted distinctly
A. leptophylla	Short cylindric, short ellipsoid	1–5	Green	Brown short-tomentose
A. liangguangensis	Long cylindric	1–4	Green	Coarse short-tomentose
A. lijiangensis	Cylindric	20–35	Green	Densely brown spotted
A. macrosperma	Ovoid, ovoid-globose	15–25	Orange	Glabrous and smooth
A. maloides	Globose	0.5–0.7	Yellowish brown and green	Glabrous
A. melanandra	Near cylindric	10–20	Brown	Glabrous
A. melliana	Cylindric	1–4	Light green	Short and sparsely coarse hairs
A. obovata	Cylindric	8–23	Brown green	Densely with brown tomentose
A. persicina	Short cylindric	13–18	Brown green	Densely with brown tomentose
A. pilosula	Globose		Green	Glabrous
A. polygama	Near long flat-cylindric or flat cone	5–9	Green and yellow-green	Glabrous and smooth
A. rubricaulis	Long cylindric	0.8–1	Dark green	
A. rubus	Near globose	4–9	Green	Glabrous
A. rudis	Long cylindric	1	Green	Glabrous
A. rufotricha	Ovoid, cylindric	10–19		
A. sabiaefolia	Ovoid	12–25	Dark green	Glabrous
A. setosa	Near globose, ovoid	20–35	Brown	Densely with brown long strigose
A. sorbifolia	Long cylindric	9–15	Green	Densely with brown tomentose and fruit spots distinctly
A. styraciflia	Cylindric	2–4	Green	With green fruit spots
A. suberifolia	Near globose	10–20	Brown	Tea-brown tomentose
A. tetramera	Ovoid, ellipsoid	0.8–3.0	Brown	Glabrous
A. trichogyna	Near globose, ovoid, long cylindric	12–20	Dark green	Glabrous but spotted distinctly
A. truneatifolia	Ovoid, wide ovoid	4–8	Dark yellow	Sparsely tomentose or spotted
A. umbelloides	Ovoid, short ellipsoid	10–20	Green	Sparsely white tomentose
A. valvata	Ovoid	7–12	Orange	Glabrous and smooth
A. venosa	Near ovoid or short cylindric	2–8	Green	Sparsely light brown tomentose
A. vitifolia	Short cylindric	21–35	Brown	Brown tomentose
A. zhejiangensis	Near globose	15–25	Green-yellow	Silver white long tomentose

[z]Data source: 1980–85 provincial reports of *Actinidia* germplasm survey; Cui, Z. (eds.), 1993. *Actinidia* in China. Shandong Science and Technology Press; Database of *Actinidia* research center, Wuhan Institute of Botany, CAS.

Flesh color	Core	Seed size and no.	Juiciness	Flavor
Green, jade green	Large	Small and numerous	Juicy	Sweet, slight acid
Jade green	Small		Juicy	Optimum sweet acid
Green, yellow	Small	Medium large, numerous	Juicy	Sweet acid
Green, light green	Medium	Large and numerous	Juicy	Sweet acid
		Small		
Light jade-green	Small	Small medium		
Green	Large	Medium large, numerous	Juicy	Sweet acid
Jade green	Small	Less	Juicy	Acid
Green	Medium		Less juicy	Acid sweet
Dark green		Small and numerous		
Green		Small and numerous		Acid
Green	Large	Small		
Green	Medium large		Less juicy	Very acid
		Small		
Green	Medium	Small and numerous	Juicy	Very acid
Green	Large	med-large, numerous	Juicy	Acid
Yellow green or green		Small and numerous	Juicy	Acid sweet and very fragrant
Green with red core		Less		
Green		Numerous		Slight acid and mouth numbing
Dark green		Medium less	Less juicy	Sweet
Green, dark green		Numerous	Juicy	Acid sweet
Green				
Dark green	Small	Small	Juicy	Sweet acid and fragrant
Dark brown	Small		Less juicy	
Jade green	Small	Large and numerous	Medium juicy	
Green	Small		Medium juicy	Very acid
Dark green	Medium	Small and numerous	Less juicy	Acid
Jade green	Medium	Large	Less juicy	Light acid
Orange	Small	Large, about 4–5 cm	Less juicy	Spicy taste mouth numbing
Green	Small			
Green		Large but less		
Green	Medium		Less juicy	Acid
Light green	Small	Less	Juicy	Acid and numb
Green	Medium	Small	Juicy	Acid
	Small			
Apricot yellow	Large	Less	Juicy	Astringent and mouth numbing
Jade green		Small and numerous	Less juicy	Plain taste slight acid
Green	Small	Numerous	Less juicy	Very acid
		Large		
Yellow green	Small	Medium		
			Juicy	
		Small		
				Spicing taste
Green		Large and numerous	Less juicy	Very acid, slight mouth numbing
Light green	Large	Less		Acid, slight mouth numbing
Green		Large and less		

Variation of Nutritional and Chemical Constituents

When kiwifruit was in the early stages of commercialization, its nutritional value played an important role for commercial promotion in the fresh fruit market. The fruit has a high content of vitamin C, minerals and dietary fiber. The vitamin C content in commercially produced kiwifruit can be as high as >80 mg/100 g fresh fruit, about 2 to 3 times higher than oranges and 5 to10 times higher than apples. The kiwifruit was once called the king of fruit in China because of its high vitamin C content. A wide range of vitamin C was observed among species ranging from 5 mg/100 g in *A. rudis* Dunn to 2140 mg/100 g in *A. latifolia* (Gardn. et Champ.) Merr. The species with high vitamin C content include *A. latifolia* (671 to 2140 mg/100 g), *A. eriantha* Benth.(500 to 1379 mg/100 g), *A. styraciflia* C.F. Liang (642 mg/100 g), *A. zhejiangensis* C.F. Liang (289 to 371 mg/100 g), *A. persicina* Huang et Wang (314 mg/100 g), *A. cinerascens* C.F. Liang (50 to 420mg/100 g), *A. chinensis* (50 to 420 mg/100 g), and *A. grandiflora* C.F. Liang (56 to 214 mg/100 g). The most widely grown *A. deliciosa* cultivar—'Hayward'—has the following composition: vitamin C 50 to 150 mg/100 g, soluble solids 12% to 18%, total sugar 7% to 13%, titratable acidity 1.1% to 1.6%, protein 0.11% to 1.2%, major minerals of calcium, magnesium and phosphorous ranging from 0.01% to 0.03%, high potas-

Table 2. Variation of main nutritional constituents in genus *Actinidia* [z].

Species	Vitamin C (mg/100 g)	SSC [y] (%)	Titratable acidity (%)	Total sugars (%)	Amino acids (% W/W)
A. arguta	81–430	14–15	0.88–1.26	8.8–11	5.18
A. arguta var. *purpurea*	80.9	8	1.3	3.4	--- [x]
A. callosa var. *callosa*	50	14	2.3	4.91	---
A. callosa var. *discolor*	162	13	3.6	5.2	---
A. callosa var. *henryi*	15.5	11	1.0	7.4	---
A. chengkouensis	44.0	---	2.4	3.30	---
A. chinensis var. *chinensis*	50–420	7–19.2	0.9–2.2	4.5–11.5	3.2–5.8
A. chinensis var. *jinggangshanensis*	275	13.5	1.9	3.9	---
A. chinensis var. *rufopulpa*	119	16	1.6	10.6	---
A. chrysantha	57–71.7	11	1.3	4.5–8.3	---
A. cinerascens	50–420	7.0–19	0.9–2.2	4.5–11.5	---
A. cylindrica	30–100	7–13.2	1.1–1.3	4.5–6.1	6.6
A. deliciosa var. *deliciosa*	50–250	8–25	1.1–1.6	69–13.2	4.1–6.0
A. deliciosa var. *coloris*	80	11	1.5	8.6	---
A. deliciosa var. *chlorocarpa*	86	17	1.0	8.6-12.4	---
A. eriantha var. eriantha	500–137	5–16	1.3–2.9	9.7	7.93
A. eriantha var. *alba*	496	12.5	0.95	6.9	---
A. eriantha var. *brunea*	874	12	1.4	5.6	---
A. eriantha var. *calvescens*	433	8	1.2	7.3	---
A. farinose	10–20	---	1.8	---	---
A. fasciculoides	7–8	---	0.3	---	---
A. fulvicoma var. *fulvicoma*	30–117.8	9.5	1.0–1.4	2.6–5.3	---
A. fulvicoma var. *lanata*	35	10.0	0.5-1	2.3	---
A. fulvicoma var. *lanata* form *hirsuta*	157	10	1.0	2.6	---
A guilinensis	1320	13.5	1.4	6.9	---
A. glaucophylla	10–25	9	0.7–1	4.2	---
A. glaucophylla var. *asymmetrica*	54	12	---	6.5	---
A. globosa	15	9	1.5	---	---
A. grandiflora	56–214	4–15	1.2–2.4	4.5	5.62
A. hemsleyana	12–80	8–10	0.8–1.7	5.1	---
A. henanensis	25–29.7	5–16	1.3–1.7	3.2–11	---
A. henryi	4.4	6	0.8	---	---
A. hubeiensis	51-60	14	1.2	8.5	2.04
A. jiangxiensis	266	12	0.68	7	---
A. indochinensis	17–41.5	7–14	1.4–2.0	5.7–6.4	---
A. lanceolata	33	12	1.2	---	---
A. latifolia	671–2140	10	1.1–1.9	3.14	6.10
A. leptophylla	87	3.3	1.7	---	---
A. liangguangensis	10–56	7	1.0	2.2	---
A. lijiangensis	60	14	1.1	7.4	5.1
A. macrosperma	28.8	10	0.6–1	5.9	9.0
A. melanandra	203	14	0.9	7	8.9
A. melliana	45	8.5	2.5	1.5	---
A. persicina	314	14.5	1.6	5.4	4.2
A. polygama	58–87	11–17	0.2–1.1	11.2	---
A. rufotricha var. *glomerata*	42	6.5	1.2	2.2	---
A. rubricaulis	17	8	2.6	2.7	---
A. rubus	30	7	0.6	---	---
A. rudis	5	5	1.0	---	---
A. sabiaefolia	68	12.4	1.0	3.1	---
A. setosa	79	10.5	1.3	7.1	---
A. sorbifolia	42	11	1.8		
A. styraciflia	642	9	1.1	5.8	4.0
A. tetramera	107	11–15	0.2	7.8	---
A. truneatifolia	83	8	1.3	3.9	---
A. valvata	62–92	8	0.2–1.4	3.3–6	4.65
A. zhejiangensis	289–371	10–12	1.4–1.7	6.4	---

[z]Data source: computer database of *Actinidia* research center, Wuhan Institute of Botany, CAS.; Cui, Z. (eds.) 1993. *Actinidia in China.* Shandong Science and Technology Press.

[y]Soluble solids concentration.

[x]Data not available.

sium from 0.2% to 0.3%, and low sodium <0.002%. The medicinal or health benefit of the kiwifruit has also been shown in limited clinical studies. Preliminary evidence indicates that the fruit has laxative effect and medical benefits for enteric malfunctions (Cui, 1993). Limited studies analyzing vitamins A and B and various amino acids indicate that kiwifruit have relatively high contents of these health beneficial constituents. Table 2 lists major nutritional values important to horticulturists and breeders.

Ploidy Variation

Actinidia is one genus with tremendous interspecific and intraspecific variation in ploidy. A unique characteristic of this ploidy variation is the structured reticulate pattern including diploids, tetraploids, and hexaploids in diminishing frequency and rekindled to the geographic distribution of ploidy races (Ferguson et al., 1997; Xiong 1992; Yan et al., 1994). The basic chromosome number of 29 is widely accepted, although this could be of ancient polyploid origin (Huang et al., 1998; McNeilage and Considine, 1989). Of the 48 taxa studied so far, 40 contain diploids, 19 contain tetraploids, 5 contain hexaploids and 1 contains an octaploid (Table 3). The intra-taxon ploidy variation has been observed in 15 taxa. Ten taxa have diploid and tetraploid races: *A. callosa* var. *discolor* C.F. Liang, *A. callosa* var. *henryi* Maxim., *A. chinensis* var. *chinensis*, *A. cylindrica* var. *reticulata* C.F. Liang, *A. grandiflora*, *A. indochinensis* Merr., *A. kolomikta*, *A. polygama*, *A. rubricaulis* var. *rubricaulis* Dunn, and *A. sabiifolia* Dunn. Two taxa have tetraploid and hexaploid races: *A. deliciosa* var. *chlorocarpa* (C.F. Liang) C.F. Liang et A.R. Ferguson and *A. valvata* var. *valvata* Dunn. *A. arguta* var. *arguta* has the greatest intra-taxon variation including diploids, tetraploids and hexaploids. *A. arguta* var. *purpurea* (Rehd.) C.F. Liang contains tetraploids and octaploids. *A. arguta* contains all ploidy races, offering great potential for ploidy manipulation through breeding (Ferguson et al., 1996).

Due to the limited sampling of cytogenetic studies for ploidy analysis, the extent of both interspecific and intraspecific ploidy variation is expected to be changing when more samples are subjected to chromosome checking or even when more populations of certain taxa are studied. The intra-taxon ploidy variation has been investigated most extensively in *A. chinensis* when Xiong (1992) first reported large-fruited tetraploid plants with 116 chromosomes from southeast Hubei and north Jiangxi provinces, China. HortResearch, New Zealand, took a further step in screening >100 genotypes from 45 accessions of *A. chinensis* held in the HortResearch repository. They found that 60% of the genotypes were diploids and 40% were tetraploids (Yan et al., 1994). This led to the hypothesis that distribution of ploidy races is geographically oriented and that tetraploids of *A. chinensis* are primarily restricted to the mountainous areas of southeast Hubei, north Jiangxi and north Fujian, China (Ferguson et al., 1997). While it may be true that most large-fruit-sized selections of *A. chinensis* are tetraploids (Huang et al., 1997), a positive correlation between ploidy level and fruit size may exist. Although no obvious morphological difference has been established between the diploid and tetraploid *A. chinensis*, an experienced breeder can usually identify tetraploids from the diploids by variations in leaf thickness (Lowe, HortResearch, New Zealand, personal communication). The leaves of tetraploids are generally thicker and darker green in color than those of diploids (Huang, personal observation). Intrataxon ploidy variation poses difficulties to kiwifruit breeders who are forced to obtain ploidy information before hybridizations should be made. Before the discovery of intraspecific ploidy races, breeders were puzzled why crosses between two *A. chinensis* plants were less successful than when two different species, such as *A. chinensis* x *A. eriantha*, were crossed (Wang et al., 1989, 1994; Xiong, 1990). On the other hand, by precisely understanding ploidy variation involved, kiwifruit breeders have the opportunity to create new ploidy germplasm, novel breeding lines or even novel cultivars. With aid of embryo rescue technology and tissue culture methods (Mu et al., 1990, 1992), a continuous variation from diploid to octaploids and even aneuploids could possibly be created. Dodecaploid somaclones of *A. deliciosa* were found from leaf-derived callus tissue cultures (Boase and Hopping, 1995). Obtaining ploidy information before selecting breeding parents should be now considered a routine procedure

Table 3. Ploidy diversity in *Actinidia*[z].

Species	Ploidy	Chromosome no.
A. arguta var. *arguta*	2x, 4x, 6x	58, 116, 174
A. arguta var. *purpurea*	4x, 8x	116[y]
A. arisanensis	2x	58
A. callosa var. *discolor*	2x, 4x	58, 116
A. callosa var. *henryi*	2x, 4x	58, 116
A. callosa var. *strigosa*	4x	116
A. chinensis var. *chinensis*	2x, 4x	58, 116
A. chrysantha	4x	116
A. cylindrica var. *cylindrica*	2x	58
A. cylindrica var. *reticulata*	2x, 4x	58, 116
A. deliciosa var. *deliciosa*	6x	174
A. deliciosa var. *chlorocarpa*	4x, aneuploid?, 6x	116, 160?, 174
A. eriantha var. *eriantha*	2x	58
A. eriantha f. *alba*	2x	58
A. eriantha var. *brunea*	2x	58
A. eriantha var. *calvescens*	2x	58
A. farinose	2x	58
A. fulvicoma var. *fulvicoma*	2x	58
A. fulvicoma var. *lanata*	2x	58
A. glaucophylla var. *glaucophylla*	2x	58
A. glaucophylla var. *astymmetrica*	4x	116
A. grandiflora	2x, 4x	58, 116
A. guilinensis	2x	58
A. hemsleyana var. *hemsleyana*	2x	58
A. hubeiensis	2x	58
A. hypoleuca	2x	58
A. indochinensis	2x, 4x	58, 116
A. kolomikta	2x, 4x	58, 116
A. lanceolata	2x	58
A. latifolia var. *latifolia*	2x	58
A. liangguangensis	2x	58
A. lijiangensis	2x	58
A. macrosperma var. *macrosperma*	4x	116
A. macrosperma var. *mumoides*	4x	116
A. melanandra var. *melanandra*	2x, 4x	58, 116
A. melliana	2x	58
A. persicina	2x	58
A. polygama	2x, 4x	58, 116
A. rubricaulis var. *rubricaulis*	2x, 4x	58, 116
A. rubricaulis var. *coriacea*	2x	58
A. rufa	2x	58
A. rufotricha var. *glomerata*	2x	58
A. sabiifolia	2x, 4x	58, 116
A. setosa	2x	58
A. styraciflia	2x	58
A. tetramera	2x	58
A. valvata var. *valvata*	4x, 6x	116, 174
A. zhejiangensis	2x	58

[z]Data source: data from the computer database of *Actinidia* research center, Wuhan Institute of Botany, CAS., both male and female plants of most species were recently checked for chromosome numbers (including the published data on species by Xiong et al., 1985; Xiong and Huang, 1988), except *A. arguta* 6x, *A. arisanensis* 2x from Blanchet et al., 1992; *A. hypoleuca* 2x from McNeilage and Considine, 1989; and *A. arguta* var. *purpurea* 8x from Ferguson et al., 1997. Chromosome number was determined as follows: cell wall enzyme digesting, low osmotic pressure, slides flame drying, Giemsa dying and counting by Olympus-BH.

[y]Flow cytometry estimated.

in kiwifruit breeding. Manipulating ploidy variants may also enhance our understanding of ploidy nature, i.e., autopolyploidy vs. allopolyploidy. There is evidence indicating that the tetraploid *A. chinensis* is autotetraploid and hexaploid *A. deliciosa* is allohexaploid (Huang et al., 1997). Understanding the gamete tetrasomic segregation of the tetraploid *A. chinensis* in crosses would also be helpful for estimating ploidy genotype frequencies, progeny seedling survival rate and creating various ploidy genotypes.

Isozyme Genetic Variation

Although only a few studies have been conducted and limited information is available, all existing results suggest that the genetic diversity of *Actinidia* at the isozyme level is extraordinary high (Huang et al., 1997; Messina et al., 1991; Testolin and Ferguson, 1997). After examining 22 Chinese cultivars selected from the wild and 56 plants from 28 *Actinidia* taxa using 10 isozyme markers, Huang et al. (1997) observed a high level of isozyme variation and heterozygosity both in the cultivars and in the taxa. For example, in 22 cultivars examined, the isozymic heterozygosity of 10 isozyme loci ranged from 18% to 100% and average heterozygosity was 65.1%. A wide range of different isozymic heterozygosity was also observed in different taxa, ranging from 68% to 100%. It is reasonable to assume that the high isozymic heterozygosity observed within the genus is well in accordance with ploidy variation and other diverse characteristics of the *Actinidia*. It is also interesting to note that a high percentage of multi-allelic heterozygosity was found in many loci. For example, in the PGI locus, tetra-allelic, tri-allelic and diallelic heterozygotes were 18%, 27%, and 55%, respectively. The high percentage of di-, tri- or tetra-allelism found in allohexaploid *A. deliciosa* and autotetraploid *A. chinensis* suggested an effective maintenance of heterozygosity through polyploidy in *Actinidia* (Stebbins, 1950). Furthermore, higher tri- and tetra-allelic heterozygosity was observed in selected cultivars than in wild plants. This is apparently related to projected selection process, indicating that genetic heterozygosity should be an important objective in future breeding programs, particularly when mass or recurrent selection procedures are being used (Ferguson et al., 1996). When isozyme polymorphisms were used to study the taxonomic relationships among *Actinidia* taxa, *A. chinensis* was found to be the species most closely related to *A. deliciosa* by sharing 34 of 40 alleles. It is believed that *A. deliciosa* was derived by polyploidization solely from *A. chinensis* without any other *Actinidia* species being involved (Testolin and Ferguson, 1997).

Genetic Diversity at the DNA Level

The genome size (haploid) of *Actinidia* species is about 375 to 750 Mb (Weising et al., 1996). Although genetic diversity at the DNA level has not been subjected to extensive evaluation in *Actinidia*, evidence from available research data indicates that the genus has extremely high genetic diversity in both nuclear and cytoplasmic genomes. Weising et al. (1996) evaluated eight accessions of diploid *A. chinensis* using 16 microsatellite DNA markers and microsatellite heterozygosity ranged from 50% to 100%. They also observed a high variability of microsatellites across different species. Huang et al. (1998) evaluated four diploid and six tetraploid *A. chinensis* using 20 microsatellites and showed heterozygosity of 50% to 85% in diploids and 90% to 100% in tetraploids. The number of alleles per locus varied from 9 to 17, with an average of 12.4 alleles per locus in *A. chinensis*. The intra-locus heterozygosity revealed by microsatellites in tetraploids was found to be even higher than that by isozymes. This resulted in >60% of tri- and tetra-allelic heterozygosity in the 20 microsatellites, further demonstrating that the polyploidy maintains rich genetic diversity in *Actinidia* species. The genetic diversity was recently revealed by RAPDs (randomly amplified polymorphic DNA) for 39 taxa within genus *Actinidia* (Huang et al., 2002). Even when there were only three to five individual plants of each taxa evaluated, an average of 77% of polymorphic loci was revealed in species level and total of 91% at the genus level. Recently, Zheng et al. (2003) conducted an extensive genetic evaluation of 26 varieties of *A. chinensis* and 19 varieties of *A. deliciosa*, respectively, using 9 SSR markers. The gene diversity in *A. chinensis* was 89% while that in *A. deliciosa* 91%. Analysis of the distribution of genetic diversity showed that 97.83% and 2.17% genetic diversity occurred between and within species, respectively.

DEVELOPMENT OF KIWIFRUIT INDUSTRY IN CHINA

Early Efforts

In China, the early attempted efforts in introduction, evaluation and development of useful selections for vineyard cultivation were initiated by the Institute of Botany, The Chinese Academy of Sciences, in 1957. This pioneer program primarily emphasized on a survey of *Actinidia* germplasm in Taibai Mountain of the Qinling Mountain ranges, Shaanxi province, and Funiu Mountain, Henan province. *A. deliciosa* and *A. chinensis* were introduced of into the Beijing Botanical Garden for evaluation, selection and basic biological research. The program continued to introduce *A. arguta*, *A. kolomikta,* and *A. ploygama* into the botanical garden in 1960. These plants have been maintained for evaluation of growth and reproduction biology for >30 years and the program made many contributions to our basic understanding of *Actinidia* biology. A similar effort in germplasm survey and selection of superior genotypes was also attempted by Central China Agricultural College in Wudangshan Mountain, Hubei province, in 1958. Neither of these early programs resulted in any significant contribution to current cultivar development and China kiwifruit industry, but a wealth of useful information on basic biology, natural habitat, genetic resources and taxonomy were generated.

Selection from Natural Resources

A government organized, nationwide selection program was initiated in China in 1977–78. This program had two primary goals: 1) a national germplasm survey and inventory of *Actinidia* resources and 2) selection of superior genotypes for cultivar development. The latter goal was to develop new cultivars superior over the most widely grown 'Hayward' that was developed in New Zealand from an early introduction from China in 1904. As a result, a national cooperative group for *Actinidia* research was founded in August 1978, with governmental initiative funds and almost all central governmental and provincial agricultural research organizations and major agricultural universities participated. This cooperative group was later integrated into a cooperative organization for scientific research under the Ministry of Agriculture in 1993. This is probably the largest program in history for selecting cultivars directly from the wild. The progress of the program can be outlined by three significant contributions. First, 61 species, 43 varieties, and 7 forms in the genus *Actinidia* native to China were classified based on survey data from 27 provinces. Second, an inventory of natural genetic diversity, natural resources, and distribution data was established. The naturally wild fruit production of *A. chinensis* and *A. deliciosa* was estimated to be 150,000 t/year during 1980s, although a massive exploitation of using wild fruit for processed products without adequate measures of conservation strategy resulted in an equally massive damage to natural reserves since the mid-1980s. Third, >1400 superior genotypes were selected from wild populations of *A. chinensis*, *A. deliciosa,* and *A. arguta*. Most these went through the followup topworking in research stations followed by extensive evaluations, experimental trials, regional tests and replicated trials on a commercial scale. As a result, 57 cultivars and a large number of selections were developed. The outcome of this program was unique to the Chinese kiwifruit industry with a different cultivar structure from the rest of the world. Most of the newly released cultivars in China are selections from wild populations of *A. chinensis* and *A. deliciosa*. A few new cultivars of *A. arguta* were also selected from the wild but they are not yet widely accepted in commercial production and are not yet currently important to the China kiwifruit industry. The newly developed cultivars and selections show great diversity in many commercial traits, including large fruit size (average 80 to 100 g), high vitamin C content (250 to 350 mg/100 g fresh flesh), high soluble solids content (about 26%) and long life in cold storage (up to 120 d) or at room temperature (40 d). Some cultivars and selections are very precocious and set flowers the next year after grafting; others are early productive (17 kg/3-year-old plant), cold hardy, drought tolerant, and have wider adaptability. Some cultivars or selections are particularly valuable for traits such as different maturity dates, excellent new flavors and interesting tastes, various flesh colors and special appeal for processed products.

CURRENT KIWIFRUIT INDUSTRY IN CHINA

Acreage and Production

Over the past 2 decades there has been very extensive planting of kiwifruit in China, so that more kiwifruit are grown in China now than in any other country. Kiwifruit production in China is expanding rapidly and could soon have a significant impact on international kiwifruit industry (Huang and Ferguson, 2001). In the early phase of commercial development from 1978–91, commercial vineyards were first established in Hubei and Sichuan provinces in 1978, mainly using the A. deliciosa cultivar 'Hayward' from New Zealand. By 1990, the total area planted in China had expanded to 4,000 ha and the following year to 8,300 ha. From 1991–2002, commercial plantings increased very rapidly to the present 57,396 ha. Production likewise increased rapidly from 5,000 t in 1990 to 291,450 t in 2001. It is estimated that in 2002, the total production of kiwifruit in China was about 340,420 t. China has now surpassed Italy and New Zealand in kiwifruit production and become the largest producer in the world.

In 2001–02, the total area in kiwifruit production was comprised of about 80% *A. deliciosa* cultivars and 20% *A. chinensis*. One-third of the plantings were still very young and below cropping age in 2001. Most of the remaining area was in young vineyards, 4 to 7 years old and about 30 % of the total area was in vineyards that have reached cropping maturity. The young age of most plantings accounts in part for the low average production in China, <5 $t \cdot ha^{-1}$. Even if few new plantings are established, total kiwifruit production in China should increase markedly for the next 3 or 4 years. Yields in mature fruiting vineyards are still low, however, averaging about 9 $t \cdot ha^{-1}$. Such a rapid increase of Chinese kiwifruit production is largely due to the tremendous change of overall Chinese market economy in the past decade, private sector has been playing more important roles in economic driven of profitable agricultural industries. The Chinese kiwifruit industry is still young, profitable and rapidly developing industry, it is quite possible that as the vines age, as kiwifruit growers become more experienced with this new crop and as vine management improves, yields could approach the world average of about 15 $t \cdot ha^{-1}$.

Cultivars in Production

Kiwifruit plantings in China are very diverse. The *A. deliciosa* cultivar 'Qinmei' is the most extensively planted but still accounts for little more than 30% of the total plantings and no other cultivar accounts for even 15% of the total area. Although China is rich in *Actinidia* germplasm, the imported cultivar 'Hayward' is the second most extensively planted, and is often preferred for the quality of its fruit. Four cultivars of *A. deliciosa* ('Qinmei' 30.5%, 'Hayward' 13.2%, 'Miliang-1' 9.7%, and 'Jinkui' 4.0%) and four of *A. chinensis* ('Kuimi' 5.4%, 'Jinfeng' 4.7%, 'Zaoxian' 4.0%, and 'Hongyang' 3.8%) together account for just over 75% of the total area in kiwifruit.

The cultivars are generally restricted to one or two provinces and none is grown extensively in many provinces. The most obvious example is 'Qinmei': although the area planted in this cultivar is six times that planted of any other single cultivar, the plantings are largely confined (85%) to Shaanxi, the province where it was selected. 'Yate' was selected in and is almost exclusively grown in Shaanxi. Likewise, 'Hongyang' was selected in Sichuan and is mainly grown in that province. When a particular cultivar is grown in two or more provinces, these provinces are usually contiguous. Although cultivar choice may reflect climatic requirements and adaptation to a particular environment, it does seem that there is often a strong preference for local selections.

About 6% of the plantings are described as early maturing, i.e., harvested before mid-September. These would be almost entirely cultivars of *A. chinensis*. Another 30%, comprising cultivars of both *A. chinensis* and *A. deliciosa*, are midseason and are harvested between mid-September and early October. The remaining 64%, mainly of cultivars of *A. deliciosa*, are late maturing and harvested between mid-October and mid-November. The lack of cooling or storage facilities in many areas of China means that there is a preference for cultivars which can be harvested later in the season when temperatures are lower and fruit have less field heat. Until now, underground cellars for short-term storage is still a common practice in many kiwifruit production areas where modern cold-storage facilities are not available.

OPPORTUNITIES AND CHALLENGES

Opportunities

With increasing consumer awareness of the nutritional value of kiwifruit and its potential contribution to a healthy diet, the per capita consumption of kiwifruit will hopefully increase thus enhancing the future development of China kiwifruit industry. Further exploitation of kiwifruit's nutritional and functional food values should provide new incentive for promoting kiwifruit in the fresh fruit market.

A well-established infrastructure of germplasm repositories and active research programs in evaluation of the germplasm resources are continuously supporting the sustainable development of the industry.

Defined breeding goals and streamlining new releases of novel cultivars from main breeding programs in China will increase market share and develop new niches in world fresh fruit market.

There is an abundance of natural resources for any new genes useful for future consumer demands and production needs.

New developments in the breeding technology, orchard management, harvest and handling, storage and processing, etc., will be available for future development of the industry.

Challenges

The role of Chinese production in the international kiwifruit market needs to be defined, taking into account that three of the four main producing countries are dependent on exports. Many problems within the current Chinese kiwifruit production system, such as lack of market regulation, poor quality control, and high percentage loss in handling and storage, need to be improved. The infrastructure, such as establishing domestic and exporting trade centers also need to be enhanced for Chinese kiwifruit marketing capacity.

The danger exists for overproduction because of not enough efforts in market promotion, consumer education, and exploitation of new uses.

New products are needed for enhancing the consumption and production.

Serious genetic erosion of natural resources and challenges for rigid sampling and collecting from the wild, and better management strategies of germplasm resources need to be considered.

Worldwide coordination in efforts of germplasm evaluation and developing new cultivars and high quality products is required to meet consumers' preference.

We can anticipate that Chinese kiwifruit production will increase rapidly in next a few years. Total production may exceed 500,000 t by 2005 or 2006, producing more than half of the world kiwifruit. Until now Chinese kiwifruit export has been negligible in the world kiwifruit trade and essentially all kiwifruit produced in China have been consumed within China. Although many problems exist in the Chinese kiwifruit production and marketing system, China should soon be an important player in the international kiwifruit trade as storage facilities and marketing infrastructure are further improved.

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