ADVANCES IN TEA PLANT BREEDING IN CHINA

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Abstract

China is one of the major tea producing countries in the world, which has 305.9 million hectare tea field and produces 260.9 million tons of tea annually. Improved tea cultivars played an important role in the rapid development of China tea industry. There are now 134 registered national tea cultivars in China, which are suitable for processing green tea, black tea, oolong tea, white tea, yellow tea and dark green tea. Systematic tea breeding in China has started since early 1950s, which can be divided into four stages, i.e., high yield breeding stage, quality breeding stage, pest-resistance breeding stage and diversified breeding targets stage. The advances in tea breeding techniques including quality assessment, yield identification, germplasm resource innovation and molecular assistant selection also discussed in the present paper.

Keywords: *Camellia sinensis, tea cultivar, quality breeding, pest-resistance, germplasm, molecular assistant selection*

1. INTRODUCTION

China is the the most important tea producing countries in the world and it has 305.9 million hectare tea field and produces 260.9 million tons of tea annually, being 62.6% of global tea fields and 50.1% of global tea production volume, respectively. There are many factors leading to the rapid development of Chinese tea industry, including market demand and improvement of cultivation techniques and release of improved tea cultivars, among which improved tea cultivar played a key role. There have been now 134 registered national tea cultivars and more than 200 provincial level tea cultivars in China. These tea cultivars are suitable for processing green tea, black tea, oolong tea, white tea, yellow tea and dark green tea respectively (Li et al., 2017). Systematic tea breeding in China has started since early 1950s, which can be divided into four stages, i.e., high yield breeding stage, quality breeding stage, pest-resistance breeding stage and diversified breeding targets stage. This review summarizes the advances in tea breeding in China, and the advances in tea breeding techniques are also discussed.

2. METHODS

Published literatures regarding to tea breeding in China were searched from databases of Vip (http://qikan.cqvip.com/Qikan/Journal) and Web of Science (http://apps.webofknowledge.com) up to March 30th, 2019. The searching terms used were: “tea breeding” and “China”. We retrieved all the searched papers and removed the duplicate references by Endnote. Then, we read the titles and abstracts of the remaining papers to exclude those which were not related to the researched topic. The screened papers were then classified into high yield breeding, quality breeding, pest resistance breeding and diversity breeding targets, which will be cited in the corresponding subtitles.

3. RESULTS AND DISCUSSION

3.1. Development of tea breeding in China

The early tea breeding inn China can be traced back to 2000 years ago. An ancient book “Er Ya” reads that tea plants could be classified into arbor type and frutex type, which are now usually used for

processing black tea and green tea respectively. By the Tang Dynasty (618-907 AD), tea breeding became a routine operation for tea farmers in China (Liang & Feng, 2000). The tea farmers screened the tea cultivars based on the leaf color or shoot morphological characteristics. During Song Dynasty (960-1279 AD), tea cultivars were classified into seven groups according to plant type, leaf size and sprouting time in the spring season, i.e., white leaf group, oval leaf group, small leaf group, early sprouting group, late sprouting group, arbor group and frutex group (Liang & Liu, 1990; 1994). Modern tea breeding, with characteristics of clonal tea breeding, has started since 1950s and it can be divided into four stages.

3.1.1. High yield breeding stage

During 1950s – 1970s, almost all of Chinese tea was exported to earn foreign exchange, during which the demand of Chinese tea greatly exceeded the supply. Increasing production volume was the most important for the Chinese tea industry, in which there was an urgent need for high yield tea cultivars. High yield was the key target for tea breeders and many tea cultivars with high yield potential were bred. In 1965, twenty-one tea cultivars with high yield potential were recommended to be planted in all tea areas in China, which promoted rapid development of tea production (Bai et al., 2001; Chen & Zhou, 2005). During this stage, the most popular clonal tea cultivar propagated by cuttings was 'Fudingdabaicha' originated from Fujian Province and its dry tea yield reached 3000 kg per ha (Yao et al., 2008). And the most popular sexual tea variety propagated by seeds was 'Jiukeng' originated from Zhejiang Province and its dry tea yield reached 3750 kg per ha. In 1980, tea production volume in China was 304,000 tones, being more than 5 times of that in 1950.

3.1.2. Quality breeding stage

With the continuous increase in tea output and the decrease in tea export, the domestic market for black tea was gradually saturated in China in late 1980s. Domestic tea consumers mainly consume green tea, especially high-quality green tea. There was little demand for low-grade black teas. Therefore, the targeting of tea plant breeding was shifted from high-yield breeding to high-quality breeding. The propagation by tea seeds was abandoned completely because the tea plants propagated by tea seeds were genetically separated. All the bred tea cultivars were clonal ones in this stage. In order to meet the demand of the production of famous and quality green teas, most cultivars bred in this period had the characteristics of early sprouting in spring season, high level of amino acids and medium level of tea polyphenols. From 1984 to 1998, seventy-seven national level tea cultivars were released, i.e, 30 cultivars in 1984, 22 cultivars in 1987, 24 cultivars in 1994 and one cultivar in 1998. The most famous and popular tea cultivar released during this stage was 'Longjing-43' (Li et al., 2007), which was suitable for processing famous Longjing Tea in Hangzhou. The next popular tea cultivar in this stage was 'Zhenong-113', which was suitable for processing Maofeng green tea (Xu et al., 2011).

3.1.3. Pest and disease resistance breeding stage

With the awareness of pesticide pollution harmfulness to human health, it become very important to reduce pesticide application in tea fields and to control pesticide residues in tea products. It is the most effective way to control pesticides and fungicides by breeding and planting pest resistant tea cultivars. A few tea cultivars with resistance potential to pests such as *Empoasca vitis* and diseases such as anthracnose were screened from the existing tea germplasms by intrapopulation selection procedure. Radiation mutation breeding, biotechnology and genetic engineering methods have been also used in breeding pest-resistant tea cultivars (Liang & Shi, 2016). During 2000-2010, twenty national level tea cultivars were released (Table 1), among which 'Qianmei-809' is resistant to tea blister blight and *Lepidosaphes ume*, while 'Wannong-91' is resistant to *Aleurocanthus spiniferus* and *Empoasca flavescens*. New cultivar 'Zhongcha-108' is resistant to anthracnose (Liu et al., 2018).

3.1.4. Diverse targeting breeding stage

With the time entering 2010s, the demanding for tea products has becoming more and more diversified, including the diversification of sensory quality attributes (color, aroma, taste and appearance) and healthy functions. The tea breeding targeting high level EGCG (epigallocatechin gallate, the most

abundant component of antioxidant catechins), high level amino acids including functional theanine, high level methylated EGCG, high level anthocyanin, low level caffeine and colorful leaves has been lunched since early stage of twenty-first century, in which great progress was made, especially in breeding tea cultivars with traits of high level amino acids and albino leaves (Chen et al., 2009; Wu & Chen, 2011). Breeding targeting fragrant aroma and tea cultivars for harvesting both leaf and fruit is also lunched. Great progress has been made in breeding tea cultivars with high level of amino acids and albino leaves (Du et al, 2006; 2016).

Table 1. Registered national tea cultivars in China

No.	Cultivar Name	Registered in	Released by	Suitable for processing
1	**Fudingdabai**	1984	Fuding County, Fuajian Province	White tea, green tea
2	**Fudingdahao**	1984	Fuding County, Fuajian Province	White tea, green tea
3	**Fuandabaicha**	1984	Fuan County, Fuajian Province	White tea, green tea
4	**Meizhan**	1984	Anxi County, Fuajian Province	Oolong tea
5	**Zhenghedabai**	1984	Zhenghe County, Fuajian Province	White tea, black tea
6	**Maoxie**	1984	Anxi County, Fuajian Province	Oolong tea, green tea
7	**Tieguanyin**	1984	Anxi County, Fuajian Province	Oolong tea
8	**Huangdan**	1984	Anxi County, Fuajian Province	Oolong tea, black tea
9	**Wuyishuixian**	1984	Jianyang City, Fuajian Province	Oolong tea, black tea
10	**Benshan**	1984	Anxi County, Fuajian Province	Oolong tea
11	**Dayewulong**	1984	Anxi County, Fuajian Province	Oolong tea
12	**Mengkudaye**	1984	Shuangjiang County, Yunnan Province	Black tea, Puerh tea
13	**Fengqingdaye**	1984	Fengqing County, Yunnan Province	Black tea, Puerh tea
14	**Menghaidaye**	1984	Menghai County, Yunnan Province	Black tea, Puerh tea
15	**Lechangbaimao**	1984	Lechang County, Guangdong Province	Black tea
16	**Hainandaye**	1984	Wuzhi Mountains, Hainan Province	Black tea
17	**Fenghangshuixian**	1984	Chaoan County, Guangdong Province	Oolong tea, Black tea
18	**Damianbai**	1984	Shangrao County, Jiangxi Province	Green tea, Black tea
19	**Shangmeizhou**	1984	Wuyuan County, Jiangxi Province	Green tea
20	**Ningzhouzhong**	1984	Xiushui County, Jiangxi Province	Black tea, Green tea
21	**Huangshanzhong**	1984	Huangshan City, Anhui Province	Green tea
22	**Keemenzhong**	1984	Qimen County, Anhui Province	Black tea
23	**Jiukengzhong**	1984	Chunan County, Zhejiang Province	Green tea
24	**Yuntaishanzhong**	1984	Anhua County, Hunan Province	Black tea, Green tea
25	**Meitantaicha**	1984	Meitan County, Guizhou Province	Green tea
26	**Lingyunbaimaocha**	1984	Lingyun County, Guangxi Province	Green tea, Black tea
27	**Ziyangzhong**	1984	Ziyang County, Shaanxi Province	Green tea
28	**Zaobaijian**	1984	Yunlian County, Sichuan Province	Green tea
29	**Yichangdayecha**	1984	Yichang County, Hubei Province	Black tea, Green tea

30	**Yixingzhong**	1984	Yixing County, Jiangsu Province	Green tea
31	**Qianmei-419**	1987	Guizhou Tea Research Institute	Black tea
32	**Qianmei-502**	1987	Guizhou Tea Research Institute	Black tea
33	**Fuyun-6**	1987	Fujian Tea Research Institute	Green tea, White tea
34	**Fuyun-7**	1987	Fujian Tea Research Institute	Green tea, black tea
35	**Fuyun-10**	1987	Fujian Tea Research Institute	Black tea, Green tea
36	**Zhuyeqi**	1987	Hunan Tea Research Institute	Green tea, Black tea
37	**Longjing-43**	1987	Tea Research Institute of CAAS	Green tea
38	**Anhui-1**	1987	Anhui Tea Research Institute	Black tea, Green tea
39	**Anhui-3**	1987	Anhui Tea Research Institute	Black tea, Green tea
40	**Anhui-7**	1987	Anhui Tea Research Institute	Green tea
41	**Yingshuang**	1987	Hangzhou Tea Research Institute	Green tea
42	**Cuifeng**	1987	Hangzhou Tea Research Institute	Green tea
43	**Jingfeng**	1987	Hangzhou Tea Research Institute	Green tea
44	**Biyun**	1987	Tea Research Institute of CAAS	Green tea
45	**Zhenong-12**	1987	Zhejiang University	Green tea, Black tea
46	**Shuyong-1**	1987	Chongqing Tea Research Institute	Black tea
47	**Shuyong-2**	1987	Chongqing Tea Research Institute	Black tea
48	**Yinghong-1**	1987	Guangdong Tea Research Institute	Black tea
49	**Ningzhou-2**	1987	Jiujiang Tea Research Institute	Black tea
50	**Yunkang-10**	1987	Yunnan Tea Research Institute	Black tea, Green tea
51	**Yunkang-14**	1987	YunnanTea Research Institute	Black tea, Green tea
52	**Juhuachun**	1987	Tea Research Institute of CAAS	Green tea
53	**Guihong-3**	1994	Guilin Tea Research Institute	Black tea
54	**Guihong-4**	1994	Guilin Tea Research Institute	Black tea
55	**Yangshulin-783**	1994	Agricultural Bureau of Qimen County	Green tea
56	**Wannong-95**	1994	Anhui Agricultural University	Green tea, Black tea
57	**Xicha-5**	1994	Wixi Tea Research Institute	Green tea
58	**Xicha-11**	1994	Wixi Tea Research Institute	Black tea, Green tea
59	**Hanlu**	1994	Tea Research Institute of CAAS	Green tea
60	**Longjingchangye**	1994	Tea Research Institute of CAAS	Green tea
61	**Zhenong-113**	1994	Zhejiang University	Green tea
62	**Qingfeng**	1994	Hangzhou Tea Research Institute	Green tea
63	**Xinyang-10**	1994	Xinyang City	Green tea
64	**Baxiancha**	1994	Sci-Tech Committee of Shaoan County, Fujian Province	Oolong tea, green tea
65	**Qianmei-601**	1994	Guizhou tea Research Institute	Black tea
66	**Qianmei-701**	1994	Guizhou tea Research Institute	Black tea

67	**Gaoyaqi**	1994	Hunan Tea Research Institute	Black tea, Green tea
68	**Zhuyeqi-12**	1994	Hunan Tea Research Institute	Black tea, Green tea
69	**Baihaozao**	1994	Hunan Tea Research Institute	Green tea
70	**Jianbohuang-13**	1994	Hunan Tea Research Institute	Green tea
71	**Shuyong-703**	1994	Chongqing Tea Research Institute	Green tea
72	**Shuyong-808**	1994	Chongqing Tea Research Institute	Black tea
73	**Shuyong-307**	1994	Chongqing Tea Research Institute	Black tea
74	**Shuyong-401**	1994	Chongqing Tea Research Institute	Black tea
75	**Shuyong-3**	1994	Chongqing Tea Research Institute	Black tea
76	**Shuyong-906**	1994	Chongqing Tea Research Institute	Black tea, Green tea
77	**Echa-4**	1998	Hubei Yichang County	Green tea
78	**Fuzao-2**	2002	Qimen tea Research Institute	Black tea, Green tea
79	**Lingtoudancong**	2002	Raoping County, Guangdong Province	Oolong tea, Black tea, green tea
80	**Xiuhong**	2002	Guangdong Tea Research Institute	Black tea
81	**Wulinghong**	2002	Guangdong Tea Research Institute	Black tea
82	**Yundadanlu**	2002	Guangdong Tea Research Institute	Black tea
83	**Gancha-2**	2002	Wuyuan Tea Research Institute	Black tea
84	**Qianmei-809**	2002	Guizhou Tea Research Institute	Black tea, Green tea
85	**Shuchazao**	2002	Shucheng Agricultural Bureau	Green tea
86	**Wannong-111**	2002	Anhui agricultural University	Green tea
87	**Zaobaijian-5**	2002	Chongqing Tea Research Institute	Green tea, Black tea
88	**Nanjiang-2**	2002	Chongqing Tea Research Institute	Green tea
89	**Zhenong-21**	2002	Zhejiang University	Green tea, Black tea
90	**Echa-1**	2002	Hubei Agricultural Academy	Green tea
91	**Zhongcha-102**	2002	Tea Research Institute of CAAS	Green tea
92	**Huangguanyin**	2002	Fujian Tea Research Institute	Oolong tea, Green tea
93	**Yuemingxiang**	2002	Fujian Tea Research Institute	Oolong tea, Green tea
94	**Mingke-1**	2002	Fujian Tea Research Institute	Oolong tea, Green tea
95	**Huangqi**	2002	Fujian Tea Research Institute	Oolong tea, Green tea
96	**Guilu-1**	2004	Guilin Tea Research Institute	Green tea, Black tea
97	**Mingshanbaihao-131**	2006	Mingshan Tea Bureau, Sichuan	Green tea
98	**Xiaouchunbolu**	2010	Xiapu Tea Bureau, Fujian	Green tea, Black tea
99	**Chunyu-1**	2010	Wuyi Agricultural Bureau, Zhejiang	Green tea
100	**Chunyu-2**	2010	Wuyi Agricultural Bureau, Zhejiang	Green tea
101	**Maolu**	2010	Hangzhou Tea Research Institute	Green tea
102	**Nanjiang-1**	2010	Chongqing Tea Research Institute	Green tea
103	**Shifocui**	2010	Anqing Crop Plantation Bureau, Anhui	Green tea

104	**Wancha-91**	2010	Anhui Agricultural University	Green tea, Black tea
105	**Raoshanxiulu**	2010	Guilin Tea Research Institute	Green tea
106	**Guixiang-18**	2010	Guilin Tea Research Institute	Green tea, Black tea
107	**Yulu**	2010	Hunan Tea Research Institute	Green tea
108	**Zhenong-139**	2010	Zhejiang University	Green tea
109	**Zhenong-117**	2010	Zhejiang University	Black tea, Green tea
110	**Zhongcha-108**	2010	Tea Research Institute of CAAS	Green tea
111	**Zhongcha-302**	2010	Tea Research Institute of CAAS	Green tea
112	**Dangui**	2010	Fujian Tea Research Institute	Oolong tea, green tea, Black tea
113	**Chunlan**	2010	Fujian Tea Research Institute	Oolong tea, green tea, Black tea
114	**Ruixiang**	2010	Fujian Tea Research Institute	Oolong tea, green tea, Black tea
115	**Echa-5**	2010	Hubei Agricultural Academy	Green tea
116	**Hongyan-9**	2010	Guangdong Tea Research Institute	Green tea, Oolong tea
117	**Hongyan-12**	2010	Guangdong Tea Research Institute	Green tea, Oolong tea
118	**Hongyan-7**	2010	Guangdong Tea Research Institute	Green tea, Oolong tea
119	**Hongyan-1**	2010	Guangdong Tea Research Institute	Green tea, Oolong tea
120	**Baimao-1**	2010	Guangdong Tea Research Institute	Black tea, Green tea, Oolong tea
121	**Jinmudan**	2010	Fujian Tea Research Institute	Oolong tea, Green tea, Black tea
122	**Huangmeigui**	2010	Fujian Tea Research Institute	Oolong tea, Green tea, Black tea
123	**Zimudan**	2010	Fujian Tea Research Institute	Oolong tea
124	**Tezao-213**	2012	Mingshan Agricultural Bureau, Sichuan	Green tea
125	**Zhongcha-111**	2014	Tea Research Institute of CAAS	Green tea
126	**Qiancha-8**	2014	Guizhou Tea Research Institute	Green tea
127	**Anqing-8902**	2014	Tea Industry Association of Anqing , Anhui	Green tea
128	**Bayutezao**	2014	Agrotechnical extension station of Chongqing	Green tea
129	**Shanpolu**	2014	Tea Industry Association of Shucheng, Anhui	Green tea
130	**Sucha-120**	2014	Tea variety Research Institute of Wuxi, Jiangsu	Green tea
131	**Huaqiu-1**	2014	Huaqiu Tea Industry Co. Ltd. Sichuan	Green tea
132	**Tianfu-28**	2014	Sichuan Tea Research Institute	Green tea
133	**Xiangfeicui**	2014	Hunan Agricultural University	Green tea
134	**Hongyan-13**	2014	Guangdong Tea Research Institute	Oolong tea

3.2. The problems facing Chinese tea breeding and their countermeasures

3.2.1. Reforming breeding program to shorten breeding cycle

Based on the previous breeding program, it will take about 22 years to breed a registered national tea cultivar, i.e., taking 2 years for crossing and getting the hybrid seeds, 5 years for identifying hybrid offspring individuals, 5 years for strain comparison test, 5 years for provincial level regional adaptation test and 5 years for national level regional adaptation test (Figure 1). The breeding program is now reformed and the provincial and national regional adaptation tests can be carried out simultaneously. In this case, it will take 17 years to finish a breeding program cycle.

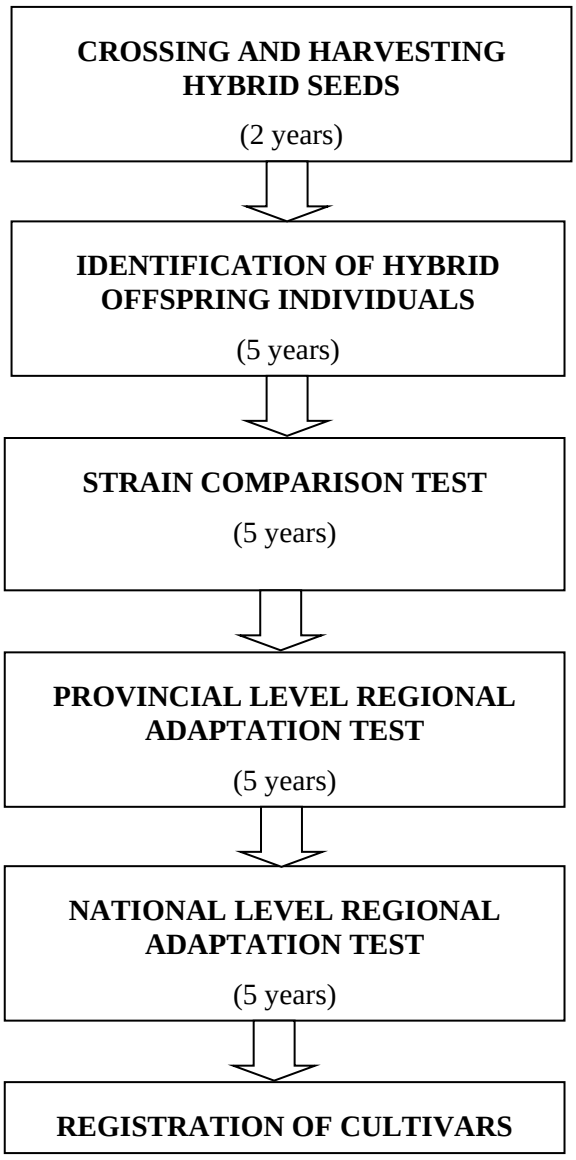

Figure 1. Breeding program of tea cultivars

3.2.2. Developing precision identifying techniques to accelerate hybrid individual screen

Sensory evaluation of made tea is usually used to assess quality of a tea cultivar. However, it usually takes hundreds of grams of fresh leaves to process a made tea sample, whose demand is very difficult to be met at the early stage of individual screening. Metabolomic technique is now used to precisely reveal the profiles of more than 100 chemical compounds in tea using a few grams of sample. We can predict the quality potential of a hybrid individual plant based on the chemical profiles. In this case, individuals with low quality potential will be abandoned quickly to accelerate the hybrid individual screening process.

3.2.3. Developing rapid propagation method to expend the population of a screened strain

When tea plant is propagated by cutting, it takes 16-18 months before the young plants can be transplanted to tea field. Therefore, 3-4 years are needed to expand from a hybrid individual to a population enough for strain comparison test (at least 200 plants in total). We developed a rapid propagation system in which the cut plants can be transplanted in 2-3 months and 200 plants can be propagated from a hybrid individual plant in 2 years.

3.2.4. Developing molecular markers for molecular assisted selection

Molecular markers are closely linked to the genes determining the target traits. Molecular marker-assisted breeding is to use molecular markers closely linked with the genes determining the target traits. By detecting molecular markers, the presence of the target genes can be detected and the target traits can be selected (Zhou et al., 2019). Molecular marker assisted selection shortens the breeding period, speeds up the breeding process, improves the breeding efficiency and overcomes the difficulties arisen in the conventional breeding methods (Yang et al., 2009; Yao et al., 2012; Tan et al., 2013; 2015;). The development of new molecular markers linked to disease resistance, insect resistance, drought resistance, high yield, and quality improvement (Chen et al., 2007; Tan et al., 2018) will accelerated the tea breeding procedures.

4. CONCLUSIONS

There are 134 registered national tea cultivars in China. The systematic tea breeding since 1950s can be divided into four stages, i.e., high yield breeding stage, quality breeding stage, pest-resistance breeding stage and diversified breeding target stage. Long breeding program period is a major problem facing the tea breeding field in China. China is taking a variety of management measures and technological measures to accelerate the tea plant breeding program cycle, including the reform of breeding procedures, the techniques for precisely identifying tea cultivar quality, rapid propagation techniques and molecular marker assisted breeding.

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