Mulberry Production and Research in Taiwan: from Sericulture to Horticulture and Human Health [1)]

Lan-Yen Chang [2)] Wan-Ling Wu [3)] Piyathida Aroonpong [4)]
Chen-Yu Chung [4)] Jer-Chia Chang [5)]

Keyword: multiple utility, classification, breeding, introduction

Summary

Mulberry (*Morus* spp.) production has contributed to the development of the sericulture industry in Taiwan for 300 years, but peaking during the 1970s. Since the 1990s, mulberry has been raised the issues concerning on horticultural, food industry and human health due to its multiple uses and functional components. For promoting industrial development through a breeding program to improve the existed varieties, studies focusing on reevaluation of taxonomical and genetic relationship, pest/disease resistance, cytogenetics, distant hybridization, marker-assisted selection (MAS) of genes linked to known phenotypic traits, the mapping of quantitative trait loci (QTL) and even functional genomic are being or soon to be undertaken. In addition, aspects in cultivation physiology and postharvest techniques are also being exploited to increase productivity and to extend the shelf-life of mulberries for fresh markets.

---

1) This manuscript has been oral presented in the 23rd International Congress on Sericultural and Silk Industry, 24-27 November, 2014, Bangalore, India, which was sponsored by Ministry of Science and Technology, Executive Yuan, Taiwan, ROC.

2) Assistant researcher, Tainan District Agricultural Research and Extension Station.
3) Assistant researcher, Taipei Branch Station, Taoyuan District Agricultural Research and Extension Station.
4) Graduate Student in Master Program, Department of Horticulture, National Chung Hsing University.
5) Assistant Professor, Department of Horticulture, National Chung Hsing University. Corresponding author.

Introduction

Mulberry (*Morus* spp.) is an economically important perennial plant. It was probably originated in western south China and the Himalaya foothills (Sànchez, 2000; Vijanyan *et al*., 2004). The domestication of the mulberry began thousands of years ago, and the worldwide spread of the plant began in 419 AD. Mulberry is now distributed at altitudes from 0 to 4000 m, and from between 50˚N to 10˚S, with large diversified populations in China, India, Japan and Turkey. Three main mulberry species, white (*Morus alba*), black (*M. nigra*) and red (*M. rubra*), are extensively cultivated (Minamizawa, 1976). The mulberry has been developed for various uses, such as the sole feeding food for silkworms in sericulture, the berry production for fresh/processing market, as the medical substitutes of drugs for diabetes (Asano *et al*., 1994) and as a sedative (Machii, 1990). Some varieties with fascinating canopies are also attractive for landscaping (Chang, 2006; Chang *et al*., 2014; Lin and Lu, 2001; Yamanouchi *et al*., 2009). This charming plant is likely soon to catch everyone’s eye once more.

Industrial history of the mulberry in Taiwan

In Taiwan, indigenous mulberry species grew wildly but they were not utilized until the 17th century. In AD 1661, people from China brought silkworm eggs to Taiwan and tried to produce silk. The first 'Alien' mulberry species was introduced from China in 1683 (Lien, 2009). However, successful cultivation of the plant was begun to feed silkworms in 1896 when Taiwan was ruled by the Japan. Due to its warm climate, Taiwan was a base for silk production and in the 1900s, the Taiwanese people were encouraged to feed the silkworms and plant the mulberry. The plantation area reached 700 hectares (Fig. 1).

Some wild mulberries were collected for their superior leaf yield and quality, such as 'Sakuma' ('Taisang No. 1'), a variety that was selected for foliage (Table 1). Some varieties were introduced from Japan for further breeding. However, the production was suspended in 1941 because of the Pacific War (Lin and Lu, 2001; Compilation Committee of Sericulture and Apiculture Experiment Station, 1997).

After the war, the government of Taiwan, the Republic of China took over the reconstruction of mulberry farms and the silk industry as part of its program of economic recovery. From 1963 to 1973, the increasing international demand for silk caused many people to enter the industry. The economical mulberry production area grew to 3000 ha and the amount of dried cocoons exports reached 466 tons a year (Fig. 1). Currently, the germplasm of mulberry in Taiwan includes 176 accessions for foliage and 62 for berry usages. Nowadays, there are 11 commercial cultivars for foliage, berry production and ornamental purposes are available, which were 3, 6 (Fig. 2) and 2 for each use mentioned above, respectively (Table 1). Potential cultivars for breeding were introduced from Japan, Australia, South Asia and Central America. Practices of orchard management have been improved and a breeding program to increase the efficiency of production has been established. However, owing to increasing labor costs and technical barriers to trade of Japan market in the 1980s, the production of both silk and leaf mulberry was limited (Lin and Lu, 2001; Compilation Committee of Sericulture and Apiculture Experiment Station, 1997). Fortunately, the industry has being moving toward more to versatile horticultural, food and human healthy purpose since 1995 (Chang, 2006). The area of mulberry production is now 100 hectares, but the demand for berry, processing products, and related functional healthy food is rising. To meet the need of nowadays leisure life, the ecological tourism and pick-your-own farm have also arisen from old mulberry farms. The rising of online shopping and home delivery services also accelerated the stream of ready-to-eat fresh mulberry products from farmers to custom (Fig. 3).

Some varieties were introduced from Japan for further breeding. However, the production was suspended in 1941 because of the Pacific War (Lin and Lu, 2001; Compilation Committee of Sericulture and Apiculture Experiment Station, 1997). Some varieties of mulberry with special canopies are used in landscaping and gardening. Functional compounds that found in mulberry fruits, leaves and even the whole tree are characterized to be involved in various bioactive pathways in human health and some of them are of great value in developing a potential therapy for diabetes, cardiovascular disease and cancer (Asano *et al*., 1994; Chen *et al*., 2006; Machii, 1990) The mulberry industry in Taiwan is entering a new era.

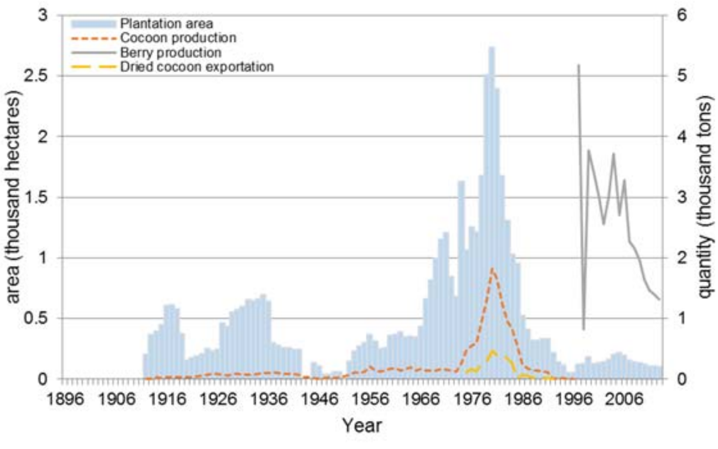

Fig. 1. Mulberry plantation area, the amount of cocoon production, dried cocoon exportation and berry production in 1896 to 2013.

Table 1. Origin and traits of main cultivated mulberry varieties in Taiwan

Variety name	Use*	Origin (year/originator)	sex	Yield / tree	Traits	Year of release
'Taisang No. 1' ('Sakuma')	F	1919/selected from wild	male	815 g	evergreen	renamed as 'Taisang No. 1' since1945
'Taisang No. 2'	F	1967/bred by Chung-Chih Hsieh 44C005×46C022	female	1667 g	evergreen	1978
'Taisang No. 3'	F	1967/bred by Chung-Chih Hsieh 44C005×46C020	male	1492 g	evergreen	1978
'Taisang No. 19'	B	1957/selected in Taipei	female	18.9 Kg	Fruit with purple black, weight: 5g; soluble solids 5ºBrix, acidity: 0.9%	Commercially available
'Miaoli No. 1'	B	1983/selected in Dahu, Miaoli by Ming-Wen Chang/bred by Jer-Chia Chang	female	21.4 Kg	Fruit with purple black, weight: 6.1 g; 7.7 ºBrix, acidity: 0.8 %	2006
'Elongated fruit No. 1'	B	1981/indirectly introduced from south Africa by Deng-Jen Wu	female	5.6 Kg	Fruit with purple red, weight: 6.5 g; 20.3 ºBrix, acidity: 0.7%	Commercially available
'Shiaying'	B	2004/Selected in Shiaying, Tainan by Jer-Chia Chang	female	19.5 Kg	Fruit with purple black, weight: 5.8 g; 14 ºBrix, acidity: 0.7%	Commercially available
'Miaoli No. 2'	B	1985/ bred by Jinn-Tsair Lin Taisang No. 19×Taisang No. 3	female	High yield	Fruit with purple black, weight: 5.1g; 10.9 ºBrix, acidity: 0.6%	2012
'Black diamond'	B	2000/Selected by Jeng-Yuan Huang in Shuilin, Yunlin	female	High yield	Fruit with purple black, weight: 6.7 g; 8 ºBrix, acidity: 0.6%	Commercially available
'Shidareguwa'	L	1980/ from Japan	female	-	Small fruit (2-3g); soft and weeping canopy	Commercially available
'Unryuu'	L	1985/ from Japan	male	-	z-bending canopy	Commercially available

*Eleven commercialized accessions and their uses in Taiwan were specifically indicated according to Chang (2006, 2008); Chang *et al*. (2008); Chang and Chang (2010); Chang *et al*. (2014). Note: F, Foliage; B, berry; L, Landscaping and gardening.

Fig. 2. Commercial available accessions for berry production in Taiwan: 'Elongated fruit No. 1', 'Taisang No. 19', 'Miaoli No. 1', 'Shiaying' (Left) and 'Black Diamond' (right).

Fig. 3. The package and storage procedures for berries after harvest.

Research advances in mulberry

Mulberry is a wind-pollinated and highly heterozygous plant that evolved a complex population and has easily been domesticated to suit various environments. Over 68 species have been identified, but confusions of nomenclature and classification have occurred, thus resulting in an impact on breeding programs. Carl von Linné (1753) started the study of scientific classification and scholars worked hard to make the system morphologically (Koidzume, 1917; Hotta, 1954; Chang, 2006) and molecularly (Hirano, 1982; Sharma *et al*., 2000; Vijayan *et al*., 2004; Zhao *et al*., 2007) consistent. Recently, a breakthrough in classification using vegetative traits and chilling requirements has helped to construct a new unbiased key for identifying different sexual patterns of mulberry in Taiwan (Table 2; Chang *et al*., 2014).

Table 2. A key for indentifying *Morus* spp. in Taiwan using vegetative characters and chilling requirement as identification traits. (Chang *et al*., 2014)

A. Ovate acute-like bud during the dormant period, arrow-like bud during vegetative growth; wider petiole, leaf length/width ratio greater than 1.4, densely acute margin, dark green leaf, higher chilling requirement.

………***M. laevigata***

AA. Longideltoid bud during the dormant period, arrow-like bud during vegetative growth, leaf length/width ratio greater than 1.4, longer leaf blade.

B. Light green leaf with serrate margin, acuminate apex; medium chilling requirement.

………***M. atropurpurea***

BB. Dark green leaf with serrate margin, caudate to long caudate apex.

C. Higher chilling requirement.

………***M. bombycis***

CC. No chilling requirement, evergreen.

D. Green growing bud.

………***M. australis***

DD. Red to purple growing bud.

………***M. formosensis***

AAA. Orthodeltoid bud during dormant period, rosette bud during vegetative growth; leaf length/width ratio less than 1.4; round leaf blade, acute or obtuse apex; higher chilling requirement.

E. Thin leaf blade, obtuse margin, shallowly or deeply cordate base.

………**M. alba**

EE. Thick leaf blade, crenate margin, deeply cordate base.

………**M. latifolia**

Nowadays, mulberry species in Taiwan are classified to (1) *Morus laevigata*; (2) *M. atropurpurea*, *M. bombycis*, *M. australis* and *M. formosensis*; (3) *M. alba* and *M. latifolia*. The result were supported by previous studies that have used traditional classification system (Lin and Lu, 2001; Chang, 2006) and the genetic diversity analysis using RAPD and ISSR marker (Lu *et al*., 2008). However, the diversity of mulberry species in Taiwan is relatively low.

Researches into cytogenetics, micropropagation, and the modification of sexual expression have been performed to increase the efficiency of breeding. Chang *et al.* (2008) demonstrated that most mulberry accessions in Taiwan are diploids, but 'Elongated fruit No. 1' (*M. laevigata*) is a triploidy. Tissue culture systems of *Morus latifolia* and *M. laevigata* were established from axillary buds (Lu, 2002; Lu, 2003), and later the progress in *M. alba* var 'Shidareguwa' showed preliminary results (Aroonpong, 2014). In the research of functional components, berry of mulberry contains high levels of anthocyanins and has the greatest capacity of antioxidation among the fruits in Taiwan (Chen *et al*., 2004). The alkaloid in leaves, 1-deoxyjirimycin (1-DNJ), showed its potential in diabetes control (Asano *et al*., 1994) and skin-whitening (Vijayan *et al*., 2011).

Other researches have focused on solving problems in the production, such as, (1) the lack of excellent varieties for fresh market and long shelf-life of berries; (2) the need for integrated pest and disease management, especially for mulberry longhorn beetle (*Apriona* spp.) and popcorn disease (*Ciboria shirana*); (3) the need for low cost labor to solve the problem of grower aging and (4) the need for the postharvest techniques that prolong shelf-life of table berries, such as 'Shiaying' and 'Elongated fruit No. 1'. Mulberry is the fruit with high respiration rate and moderate ethylene production rate after harvest. Lower the storage temperature helps to extend the fruit quality. Decay was also the major factor of the yield loss after harvest. Fruits radiated ultraviolet-C (UV-C) with 2.40 $kJ \cdot m^{-2}$ reduced postharvest decay (Tseng *et al*., 2013). We hope the research results are helpful to boost the development of mulberry into a promising condition and to attract young people to the industry in the future.

Future Prospects

In Taiwan, 11 cultivars are now commercially cultivated for the berry, foliage, and landscaping purposes (Table 1). An outstanding variety that produces superior berries with high yield or has a high resistance to popcorn disease and mulberry longhorn beetles is still needed. Owing to the limited gene pool, we attempt to introduce legally promising species to satisfy various breeding purposes. In addition, advances in breeding program, such as distant hybridization, mutation, quantitative trait loci (QTL) mapping, marker-assisted selection (MAS) and even the functional genomic of superior horticultural traits, pest/disease resistance, and high level of functional compounds, are also being made. Other research is dedicated to the improvement of cultivation and postharvest techniques for production of high-quality berries. We are looking forward to preceding an international cooperation project for a better future for the mulberry industry.

Reference

Asano, N., E. Oseki, E. Tomioka, H. Kizu, and K. Matsui. 1994. N-containing sugars from *Morus alba* and their glycosidase inhibitory activities. Carbohydr. Res. 259: 243-255.

Aroonpong, P. 2014. Studies on propagation of tissue culture seedlings in mulberry (*Morus alba* var. Shidareguwa). Master dissertation, National Chung Hsing University.

Chang L. Y., K. T. Li, W. J. Yang, J. C. Chang, and M. W Chang. 2014. Phenotypic classification of mulberry (*Morus*) species in Taiwan using numerical taxonomic analysis through the characterization of vegetative traits and chilling requirements. Sci. Hort. 176: 208-217.

Chang, L. Y., J. C. Chang, M. C. Chung, W. J. Yang, K. T. Li, and M. W. Chang. 2008. Determining genome size and ploidy in *Morus* by flow cytometry, The first Asian Horticultural Congress, abstract pp.56., Dec. 10-13, Seoul, Korea.

Chang, J. C. 2006. Taxonomy and cultivar improvement of mulberry in Taiwan. J. Taiwan Soc. Hort. Sci. 52: 377-392. (in Chinese with English summary)

Chang, J. C. 2008. 'Miaoli No. 1' mulberry: a new cultivar for berry production. HortScience 43: 1594-1595.

Chang, J. C. and M. W. Chang. 2010. 'Elongated fruit No. 1' mulberry: an elite cultivar for fresh consumption. J. Am. Pomol. Soc. 64: 101-105.

Chang, J. C., M. W. Chang, and L. Y. Chang. 2014. 'Shiaying' mulberry: a promising cultivar for fresh consumption and processing. J. Am. Pomol. Soc. 68: 33-39.

Chen, P. N., S. C. Chu, H. L. Chiou, W. H. Kuo, C. L. Chiang, and Y. S. Hsieh. 2006. Mulberry anthocyanins, cyanidin 3-rutinoside and cyanidin 3-glucoside, exhibited an inhibitory effect on the migration and invasion of a human lung cancer cell line. Cancer Letters 235: 248-259.

Chen, T. Y., N. S. Shaw, W. J. Yang, and T. S. Lin. 2004. Research on the antioxidant activity of fruits produced in Taiwan. J. Chinese Soc. Hort. Sci. 50: 592 (Abstract).

Compilation committee of sericulture and apiculture experiment station. 1997. The history of sericulture and apiculture experiment station. p.89-90. Sericulture and apiculture experiment station, Gongguan, Miaoli.

Hirano, H. 1982. Varietal difference of leaf protein profiles in mulberry. Phytochemistry 21: 1513-1518.

Lien, H. 2009. General history of Taiwan. (5th edition) Department of Economic Research (ed.), Jong Wen Books Co., Taipei.

Linné, C. 1753. *Morus.* In: C. Linné (ed.), Species plantarum. Vol. 2. Stockholm, Sweden. pp. 968.

Lin J. T. and H. S. Lu. 2001. Study on mulberry production in Taiwan. Sci. Agri. 49: 281-287. (Chinese)

Lu, M. J. 2002. Micropropagation of *Morus latifolia* Poilet using axillary buds from mature trees. Sci. Hort. 96: 329-341.

Lu, M. J. 2003. Tissu culture of *Morus laevigata* Wall using axillary buds. J. Taiwan Soc. Hort. Sci. 49: 251-258. (with English abstract)

Lu, M. J., X. M. Lin, Y. B. Wang, and T. E. Dai. 2008. Identification of genus relationship of mulberry by using RAPD and ISSR analysis, p.11, 2008 AgBio exhibition, Taipei, Taiwan. (abstract)

Machii, H., A. Koyama, and H. Yamanouchi. 2000. FAO electronic conference: Mulberry for animal production. <http://www.fao.org/livestock/agap/frg/mulberry>

Minamizawa, K. 1976. Moriculture: Basic and application. Houmeishia publishing, Tokyo, Japan. pp. 127-129.

Sànchez M. D. 2000. World distribution and utilization of mulberry, potential for animal feeding. FAO Electronic conference on mulberry for animal production. 21 Sep. 2014. <http://www.fao.org/livestock/agap/frg/mulberry/Papers/HTML/Intro.htm>

Sharma, A., R. Sharma, and H. Machii. 2000. Assessment of genetic in a *Morus* germplasm collection using fluorescence-based AFLP markers. Theor. Appl. Genet. 101: 1049-1055.

Tseng, W. B., T. T. Wang, Y. T. Liou, and C.T. Wu. 2013. Ultraviolet-C radiation elicits trans-resveratrol accumulation and reduces postharvest decay in 'Miaoli No. 1' mulberry fruit. J. Taiwan Soc. Hort. Sci. 59: 29-42. (with English abstract)

Vijayan K., P. P. Srivastava, and A. K. Awathi. 2004. Analysis of phylogenetic relationship among five mulberry (*Morus*) species using molecular markers. Genome 47: 439-448.

Vijayan, K., T. A. Tikader, W. Zhao, C. V. Nair, S. Ercisli, and C. H. Tsou. 2011. *Morus*. In: Kole, C. (ed.), Wild Crop Relatives: Genomic and Breeding Resources, Tropical and Subtropical Fruits. Springer-Verlag, Berlin/Heidelberg. pp. 75-95.

Yamanouchi, H., A. Koyama, H. Machii, T. Takyu, and N. Muramatsu. 2009. Inheritance of a weeping character and the low frequency of rooting from cuttings of the mulberry variety 'Shidareguwa'. Plant Breed. 128: 321-323.

Zhao, W., Y. Wang, T. Chen, G. Jia, X. Wang, J. Qi, Y. Pan, S. Wang, Z. Li, Y. Huang, Y. Pan, and Y. H. Yang. 2007. Genetic structure of mulberry from different ecotypes revealed by ISSRs in China: An implications for conservation of local mulberry varieties. Sci. Hort. 115: 47-55.

臺灣桑業發展歷程:從蠶桑、園藝到人體健康[1)]

張 嵐 雁[2)]　吳 婉 苓[3)]　彭 美 嘉[4)]
鍾 鎮 宇[4)]　張 哲 嘉[5)]

關鍵字：蠶桑、種原、分類、育種、品種

摘要：臺灣桑樹(*Morus* spp.)產業隨蠶業而起逾 300 年，於 1970 年代達到巔峰，惟 1990 年代起因政策及市場供需失衡之雙重壓力下而面臨轉型。桑樹全株皆可利用，並具多樣機能性物質，產業可朝向園藝(果用、觀賞用)、食品加工及機能性功能(藥用、養生及美白)等用途發展。為提昇產業競爭力，並達抗病蟲害、高機能性成份、多元用途、穩產及質優之育種目標，種原親緣分析、細胞遺傳、遠緣雜交、與優良性狀連鎖的分子標誌進行輔助育種(Marker-assisted Selection, MAS)，甚至探討數量性狀基因座定位(quantitative trait loci mapping, QTL mapping)等相關研究已陸續展開。此外，為提高鮮果品質、產量及延長貯架壽命，相關栽培生理及採後處理技術之試驗亦分別進行中。

---

1) 本文曾於第 23 屆國際蠶業研討會口頭宣讀 (2014 年 11 月，班加羅爾，印度)，並獲科技部經費之資助。
2) 行政院農業委員會臺南區農業改良場助理研究員。
3) 行政院農業委員會桃園區農業改良場台北分場助理研究員。
4) 國立中興大學園藝學系碩士班研究生。
5) 國立中興大學園藝學系助理教授，通訊作者。