Mulberry Breeding, Cultivation and Utilization in Japan

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Mulberry Genetic Resources and Breeding

Mulberry species and its distribution in Japan

Mulberry belongs to the genus *Morus* of the family Moraceae. Koidzumi (1917) classified the genus *Morus* into 24 species and one subspecies. Mulberry is distributed in a wide area of tropical, subtropical, temperate and sub-arctic zones. Most of mulberry varieties cultivated in Japan belong to *Morus bombysis* Koidz, *M. alba* and *M. latifolia* Poiret. Varieties belonging to *M. bombysis* are primarily cultivated in cold regions, such as Tohoku district. *M. latifolia* varieties are mainly cultivated in warm places, such as Kyushu district. However, varieties of *M. alba* are cultivated in a wide area, from Kyushu district to Tohoku district, since it has middle traits of these two species. Besides, *M. acidosa* Griff. grows naturally and is cultivated in south-west islands including Okinawa islands. *M. kagayamae* Koidz. and *M. boninensis* Koidz. are indigenous to the remote islands of Hachijoujima and Ogasawara, respectively.

Ploidy of mulberry

Generally, mulberry is a diploid plant with 28 chromosomes (2n=28). However, it is rich in ploidy and a lot of triploid varieties have been found especially among *Morus bombysis* Koidz. It is

said that *M. cathayana* Hemsl. has tetraploid, pentaploid and hexaploid varieties. Both *M. serrata* Roxb., indigenous to India, and *M. tiliaefolia* Makino, originally from Japan and Korea, are known to be hexaploid. *M. boninensis* Koidz. is a tetraploid being endangered due to cross contamination with *M. acidosa* Griff. *M. nigra* L. is dexoploid (2n=308), the largest number of chromosomes among phanerogams.

Inflorescence of mulberry

Mulberry has different varieties with male, female or androgynous flowers. Among the varieties with androgynous flowers, there are predominantly staminated, predominantly pistillated and even hermaphrodite types. Mulberry plants having anemophilous flowers cross each other easily and naturally.

Mulberry genetic resources

The National Institute of Sericultural and Entomological Science (NISES) of Japan has collected and maintained 1,300 accessions of both indigenous and exotic origin (Machii *et al.*, 1999). In order to utilize these genetic resources efficiently in breeding programs, morphological traits necessary for classification and identification, agronomic traits responsible for the resistance against diseases and pests, and commercial traits related to productivity and quality, are investigated. The information on these traits is very useful for achieving breeding targets.

Mulberry breeding method

It takes many years (approximately 15 – 20) to develop a new variety because mulberry is a perennial woody plant. Breeding targets should be set with a long-term view. So far, breeding

targets have been such as high yield, high nutritional value and resistance against diseases and pests. But nowadays, new targets have been added to cope with changes in the sericultural system such as large numbers of silkworm reared and adaptability to densely planted fields suitable for mechanical harvesting.

Crossing is the major breeding method adopted for the development of new mulberry varieties. In this method, the choice of parent selection plays a vital role of in achieving the objective. For example, the variety "Shin-ichinose" was selected from the F_1 generation of "Ichinose" x "Kokuso 21". This combination aimed to develop a variety showing high quality, high yield and resistance against lodging, considering that "Ichinose" shows good quality and high yield and that "Kokuso 21" has vigorous growth and an erect tree type. Two other varieties, "Tokiyutaka" and "Oyutaka" were also developed and released from this crossing. Besides, "Ichinose" and "Kokuso 21" have been used as parents for other varieties. One of the major reasons why "Ichinose" and "Kokuso 21" have been selected as parents is that "Ichinose" is female and "Kokuso 21" is male. They have desirable traits, and crossing is easy and simple.

A lot of indigenous, natural triploid varieties, such as "Ichibei", "Fukushima Oha", "Akagi" and "Tagowase" have been distributed, especially in Tohoku area, northern part of Japan. Since the 1960's, polyploidy breeding has been produced artificially by colchicine, which is capable of doubling chromosome number. The significance of polyploidy breeding is that 1) the leaves of triploids are larger than diploids and the yield is expected to be higher, 2) crossing between different ploids accumulates more genes than crossing between diploids, which is expected to yield more heterotic effect, and 3) triploids show good leaf quality and resistant against coldness (Tojo, 1985). Up to date, five triploid varieties, "Shinkenmochi", "Aobanezumi", "Mitsushigeri", "Yukimasari" and "Yukiasahi" have been developed and released using the polyploid breeding method.

Mulberry breeding system

In Japan, mulberry breeding started at the government Sericultural Experiment Station in 1916, and two varieties, "Kokuso 13" and "Kokuso 70" were released to farmers in 1922. After that, with the wave of post-war economic recovery planning, three varieties, "Kokuso 20", "Kokuso 21" and "Kokuso 27" were released in 1949. However, these varieties were not popularized very much, despite their high leaf productivity, because they were rather sensitive to dwarf disease, which causes the most serious growth damage, and of slightly poor quality.

In 1958, a field trial was initiated in four, climatically different, regions (cold, snowy, temperate and warm) and 13 prefecture sericulture experiment stations. In 1971, a dwarf disease resistance test was added to the program. When a selected strain is officially recognized to have excellent characteristics, it is commercially released as a new variety. Up to now, 19 varieties have been released, including "Shinichinose", "Yukishinogi", "Minamisakari", "Shinkenmochi", "Hayatesakari", "Aobanezumi", "Mitsuminami", and "Senshin". Such a system is believed to be indispensable to allow the Japan's breeding network to release a new mulberry variety to farmers.

Mulberry varieties

Generally speaking, varieties belonging to *M. bombysis*, have lobed and shallow bottom leaves. Branches are brown or gray, and the winter buds are oval and sharp-pointed. Varieties of *M. alba* have lobed/unlobed leaves with whitish-gray or grayish-brown branches. *M. latifolia* varieties have large, unlobed, lustrous leaves and greenish-gray or whitish-gray branches. "Ichinose" and "Kairyo-nezumigaeshi" most widely cultivated in Japan, are *M. alba* varieties, and "Kenmochi", intensively cultivated in cold areas, is a variety of *M. bombysis.*

As mentioned above, 19 varieties were registered and released from 1971 to 1998 by the Ministry of Agriculture, Forestry and Fisheries (MAFF). Out of them, six varieties, “Minamisakari”, “Hayatesakari”, “Mitsuminami”, “Hinosakari”, “Mitsusakari” and “Senshin”, are suitable for warm areas such as the Kyushu and Shikoku regions. Four varieties, “Shin-ichinose”, “Tokiyutaka”, “Oyutaka” and “Tachimidori”, are suitable for temperate areas, such as the Kanto region. Five varieties, “Shin-kenmochi”, “Aobanezumi”, “Mitsushigeri”, “Hachinose” and “Waseyutaka”, are adaptable to cold areas, such as the Tohoku region. Four varieties, “Yukishinogi”, “Yukishirazu”, “Yukimasari” and “Yukiasahi”, are adaptable to snowy areas, such as Niigata prefecture. There are some varieties, like “Hayatesakari”, which have been dispersed into the Tohoku from the Kyushu area, which was its place of origin.

Physiology and Cultivation of Mulberry

Specialty of mulberry leaf production

The growth of mulberry is generally divided into three stages; new shoot development, growth and storage (Ohyama, 1970). New shoot development is a stage in which new shoots develop using reserves stored in stump or root the previous year. Growth stage is when carbohydrates and other substances are produced for vegetative growth by means of photosynthesis in leaves. Storage stage is when most photosynthetic substances are stored for next year's growth. In cultivated mulberry plants, however, photosynthetic organs are removed/harvested by pruning and leaf picking disrupting the growth stage. The exploited mulberry plants resume growth using the remaining storage substances.

Table 1. Amino acid content in mulberry leaf and minimum requirement for silkworm (mg/g DM).

Amino acid	Content	(%)	S.D.	C.V.	Minimum requirement**
Asp	20.49	(10.0)	3.63	17.72	
Thr	10.52	(5.2)	1.75	16.63	7
Ser	10.12	(5.0)	1.60	15.79	
Glu	23.23	(11.3)	3.96	17.03	
Pro	10.93	(5.4)	3.73	34.10	
Gly	12.02	(5.9)	1.95	16.22	
Ala	15.75	(7.7)	2.90	18.44	
Val	12.83	(6.3)	2.17	16.92	8
Cys	1.17	(0.6)	0.25	21.72	
Met	2.99	(1.5)	0.61	20.48	4
Ileu	10.04	(4.9)	1.88	18.68	8
Leu	19.45	(9.5)	3.10	15.93	8
Tyr	7.40	(3.6)	1.39	18.74	
Phe	12.26	(6.0)	2.06	16.78	8
GABA	2.26	(1.1)	0.69	30.70	
NH3	2.89	(1.4)	0.54	18.70	
Lys	12.33	(6.0)	2.58	20.91	8
His	4.61	(2.3)	0.82	17.78	5
Arg	12.96	(6.3)	2.72	20.95	8
Total	204.25	(100.0)			
N(%)	4.36		0.42	9.63	

* Mean value of 119 varieties tested.

**Minimum quantity required for silkworm growth (Arai and Ito, 1967).

Nutritive value of mulberry leaves

The silkworm eats only mulberry leaves to make its cocoon, producing the silk. Mulberry leaves are rich in protein and amino acids (Table 1; Machii, 1989). It is known that there is high correlation between leaf protein level and production efficiency of

cocoon shell, which means cocoon shell weight to the total amount of mulberry leaves consumed by the silkworm (Figure 1. Machii and Katagiri, 1991). Therefore, an increase in protein level of mulberry leaves may lead to improvements in cocoon productivity.

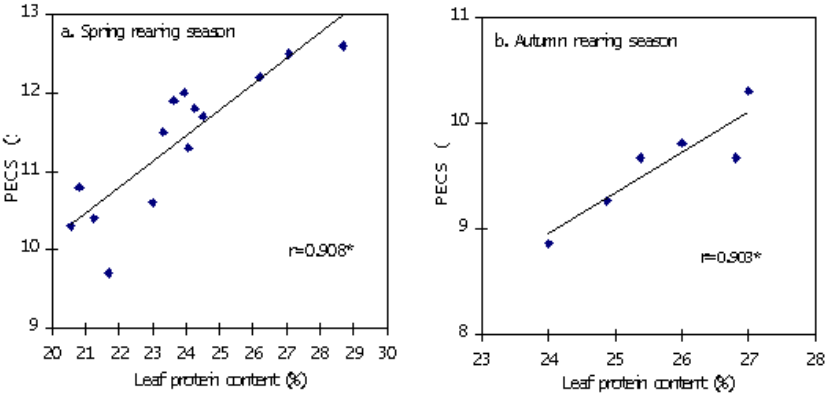

Fig 1. Correlation between leaf protein content and production efficiency of cocoon shell (PECS) in Mulberry varieties.

Cultivation

According to the 1996 statistical data of Japanese sericulture, the area of mulberry gardens was 14,884 ha, including 1,172 ha of densely planted fields. Regarding planting density of mulberry gardens, normal planting with 600 - 1,000 plants per 10a is common. In case of densely planted field, aiming at early high yield and machinery harvesting, more than 2,500 plants/10ha are used.

Standard application of chemical fertilizer to mulberry garden is 30kg of N, 14kg of phosphate and 12kgof potassium/10a for alluvial soil, and 30kg of N, 16kg of phosphate and 20kg of

potassium/10a for volcanic ash soil. In either case, application of at least 1,500kg of compost per 10a is recommended.

Training and harvesting

There are various training forms in mulberry cultivation according to various purposes. Maintenance of stump height is one of the typical forms of training. Based on the height from the soil surface: low cut (at the height of 15 – 30cm from soil surface), medium low cut (30 – 50cm) and medium cut (50 – 100cm) are under practice. The second one is a fist shape training method: if the plant is pruned at the fold every time, from where the shoots emerge, a fist is formed. Meanwhile, if it is pruned slightly above it, leaving a definite bud, the plant height goes up gradually and a fist is not formed. This is called a non-fist shape training method. The third one is a lateral branch training method developed in the Yamanashi Prefecture: branches adjacent to plants within a row are held down and tied up with a wire and the shoots emerge from the buds of the lying branches.

Harvesting methods vary with the rearing scale and frequency. Basically there are two methods, spring pruning (for summer-autumn rearing season) and summer pruning (for both spring rearing and late autumn rearing seasons). There are also circle harvesting method (spring pruning and summer pruning alternatively every year) and alternative harvesting method (alternating spring and summer pruning to half of the same plant). These two methods are adopted to secure enough yield by sustaining the tree vigor. Meanwhile, in densely planted fields, mechanical harvesting is so essential that low pruning, at a point near the ground to prevent stump formation, is desirable.

Propagation

Mulberry propagation is generally carried out by grafting and by cutting methods. Root grafting prevails because it is easy to handle and the grafted saplings have a high survivability. The cutting method can be with hard wood (using the branches grown in the previous year) and soft wood (using the spring sprouted shoots). In case of mulberry varieties of poor rooting ability, treatment with plant hormone is advised to stimulate rooting. Recently, tissue culture derived saplings are also being produced.

Other Utilization

Mulberry was originally cultivated in Japan, as well as in other countries, for sericulture. Recently, however, mulberry has being re-evaluated due to its functional characteristics and being utilized for various purposes:

- Fruit. Mulberry fruit changes the color from green to black purple through red with maturity. Some varieties introduced from mid Asia have white fruit. On average, the sugar content is about 12 %, but in some varieties it is more than 20 %. Mulberry fruit is consumed fresh, made into jam or liquor (mulberry wine). Very recently, it was found that mulberry fruit has an anti-oxidative property.

- Medicinal uses. Mulberry has been used as medicine from ancient times and especially the root bark has been used as an herbal medicine due to its properties to reduce high blood pressure. Mulberry leaf is rich in gamma-aminobutylic acid, effective against high blood pressure, and in alanine, effective against hangover (Machii, 1989, 1990). Moreover, it was found that deoxynojirimycin, which is said to have an effect to lower the blood-sugar level closely related to diabetes, is abundant in mulberry leaf. That is why nowadays, mulberry tea is considered as a health food.

- Paper production. Mulberry grows faster than other woody plants and is said to be suitable for high biomass production. Mulberry branches are being used as raw material for paper production.
- Mushroom production. Mulberry stem and stem powder are found to be good source of media for mushroom production.
- Animal feed. The use of mulberry for animal production in Japan, is being reported in other articles on this E-conference.

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