PRODUCTION OF AND RESEARCH ON STRAWBERRY IN JAPAN

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ABSTRACT

Japan is one of the major countries that produce strawberry, next to the United States. Since the end of the nineteenth century, many varieties have been introduced from the United States or Europe, and Japan itself has released a large number of new varieties by crossing the foreign ones. The most popular cropping type here is forcing culture, in which plants with flower buds are transplanted in vinyl houses and harvested from the beginning of December to April in the following year. In forcing culture it is important to induce flower buds at the proper time and to continue harvesting. Various techniques such as low temperature treatment for flower bud induction, CO_2 application for continuous harvesting and nutrient film technique for easing the farmer's work have been developed. The first new variety developed in Japan is 'Fukuba', which was released in 1899.

This variety has been cultivated for almost fifty years and used many times as parents. After World War II, public agricultural experimental stations bred new varieties for the fresh market consumption. Among them 'Hokowase', 'Harunoka' and 'Reiko' had been leading varieties until a few years ago. But recently the new varieties, 'Nyoho' and 'Toyonoka', have overtaken them due to their improved marketable characteristics. Future varieties are expected to have larger fruits with increased earliness and complex resistance to various diseases.

Introduction

The cultivated strawberry, *Fragaria* x *ananassa*, originates from natural hybridization between two native American species, *F. chiloensis* and *F. virginiana* carried out in Europe almost 300 years ago. Because of its good flavour, good taste and high nutritive value, strawberry has been the most preferred fruit worldwide. World production amounts to about two million metric tons and Japan is one of the major countries that produce strawberry, next to the United States and Poland (FAO Production Year Book, 1986).

The strawberry was introduced to Japan first from Holland early in the Edo era. It was not cultivated for commercial use, but only for a limited number of rich people. In the Meiji era, at the end of the nineteenth century, many varieties were introduced from the United States or Europe, and also in Japan a new variety 'Fukuba' was released by selection of the seedlings of 'General Chanzy' in 1899 by Fukuba. This variety, which had been cultured for fifty years after that time, played a major role in the advancement of forcing culture and strawberry breeding in Japan. Strawberry is considered as a vegetable in Japan, because the cultivation methods are similar to those for other vegetables. The most popular cropping type for strawberry is forcing culture. Even in the 1960s forcing culture accounted for about 40% of total cultivation. Since the Oil Crisis in 1973 the cultivation of strawberry has increased and replaced that of tomato or cucumber because strawberry tolerates low temperatures. Now forcing culture of strawberry accounts for more than over 80% of all strawberry cultivation. In the 1980s the area

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cultivated with strawberry amounted to about 10,000 ha and the production exceeded 200,000 tons. Most fruits are aimed at fresh market consumption in Japan. while they are used mainly for preserves or frozen in other countries.

Characteristics of strawberry production

1 Cropping type

As it gets warmer and the daylength becomes longer in spring, strawberry recovers from dormancy, flowering starts, fruits are set and at the same time a large number of runners are generated for reproduction. In autumn when it gets colder and the daylength becomes horter, strawberry differentiates flower buds and in winter it undergoes dwarfing and enters the dormancy period without flowering. Basic cropping type of strawberry consists of open field culture according to the natural pattern of growth described before. Most of the strawberry production in the world except in Japan is carried out though open field culture.

There are many kinds of cropping patterns developed in Japan : forcing culture, semi-forcing culture, retarded culture and open field culture. Among these types forcing culture is the most popular, as reflected by the monthly trend of consumer prices.

In forcing culture, daughter plants are cut from their mother plants in June and grown in nursery beds or in small vinyl pots. Usually the differentiation of flower buds is accelerated by the decrease in nitrogen supply, low temperature or short day treatment. Daughter plants with flower buds are transplanted in the middle of September and covered with vinyl material in October to promote their growth. Harvest starts from December and continues until next April or May. In winter, heating, gibberellic acid treatment and long day treatment are adopted sometimes to prevent dormancy.

In semi-forcing culture, daughter plants are cut from their mother plants in August and grown in nursery beds. They are transplanted in the field in October. They are covered with vinyl material in December after the dormancy is already broken. Harvest starts from February or March and continnes until May. In winter, the same techniques as those applied in forcing culture are adopted to promote the growth of the plants.

In retarded culture, daughter plants are grown in nursery beds. They are dug up from January until March and stored in a refrigerator at near 0°C. After the dormancy is broken during storage, they are transplanted in the field in August or September. Harvest starts from September or November and continues until November or January. Sometimes harvest starts from March again and continues until May. This pattern is referred to as two season-harvesting type.

In open field culture, daughter plants are grown in nursery beds and transplanted in the field in October. No treatments are applied to promote the growth of plants. In spring, plants recover from dormancy and start flowering. Harvest continues from May until June.

2 Varieties

The new variety first released in Japan was 'Fukuba', which was selected from seedlings of 'General Chanzy' in 1899 by Fukuba. This variety had been grown in forcing culture for fifty years and used many times as parents directly or indirectly (Fig. 1). After World War II, public agricultural experimental stations have made great efforts to release new varieties for forcing culture and among them 'Hokowase' bred in 1960 from the cross between 'Yakumo' (Kogyoku) and 'Tahoe', 'Harunoka' bred in 1967 from the cross between 'Sokusei No 2' and 'Donner', and 'Reiko' bred in 1978 from the cross of each selfed line of 'Harunoka' and 'Fukuba' were the leading varieties until a few years ago. But recently 'Nyoho' and 'Toyonoka' have overtaken them due to their superiority in taste, transportability and appearance.

'Nyoho' was bred in 1985 at the Tochigi Branch of Tochigi Agricultural Experimental

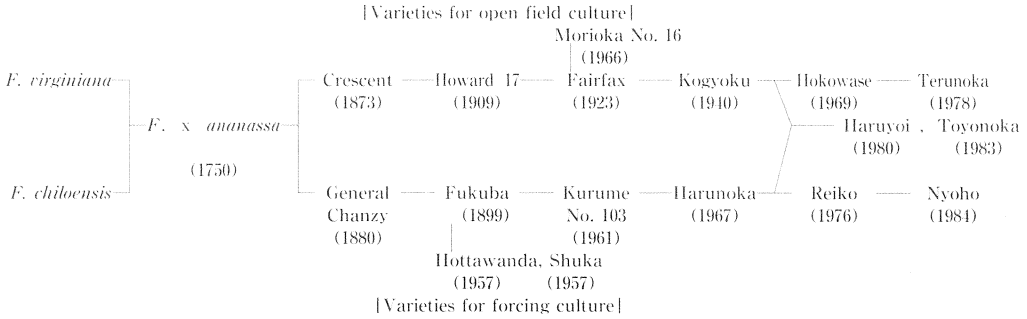

Fig. 1 Series of Japanese varieties for open field and forcing culture
Note : Figures in brackets indicate the year when the varieties had been released.

Station from three way crossing, i. e. 'Donner', 'Harunoka' and 'Reiko' (Akagi *et al.*, 1985). It is an earlymaturing variety and has beautiful fruits with a conical shape and red color. Taste and storage quality are relatively good. It is not resistant to diseases and insects, especially it is susceptible to crown rot and mite. This variety is spreading rapidly in the northern part of Japan (from Kanto to Kinki) and tends to replace 'Hokowase' or 'Reiko'.

'Toyonoka' was bred in 1983 at the Kurume Branch of the Vegetables and Ornamental Crops Research Station from a cross between 'Himiko' and 'Harunoka' (Honda *et al.*, 1985). It is earlymaturing and has large conical fruits with a bright red color. Its taste, flavour and storage quality are fairly good. It is comparatively resistant to Fusarium wilt and Verticillium wilt, but susceptible to powdery mildew. This variety was cultivated only in Kyushu at first, but presently it is being disseminated in the southern part of Japan (from Kyushu to Kinki) and tends to replace 'Horunoka' or 'Hokowase'.

For semi-forcing or open field culture which are not important now in Japan, foreign varieties such as 'Victoria' and 'Marshall' used to be popular before World War II. After the war 'Kogyoku' bred by Tamari in 1940 from seedlings of 'Fairfax' and 'Donner' introduced from the United States became very popular. From the late 1960s to now 'Donner', 'Hokowase' and 'Morioka No. 16' bred in 1970 by three-way crossing, i. e. 'Fairfax', 'Etasburg' and 'Chiyoda' are the main varieties for semi-forcing or open field culture.

Research work on cultivation

1 Nutrient film techniques

Forcing culture of strawberry requires 2,000 hours of hard work per ten ares as farmers have to bend their bodies during the operations and harvest.

Nutrient film technique (NFT) is one of the type of hydroponics invented by Cooper in 1973. In Japan NFT with long supporting poles has been developed especially for strawberry to alleviate farmer's hard work.

Daughter plants are grown in nursery beds with nutrient film or in pots which contain rock wool or baked husks instead of soil for two months. It is recommended not to use plants grown in soil in order to avoid soil diseases such as Fusarium wilt. In using pots or NFT for the nursery period it is easy to promote the differentiation of the flower buds by limiting nitrogen application or cooling the root system. These treatments are usually started one month before transplanting.

The major components of various solutions for NFT are listed in Table 1.

The concentration of the NFT solution which is expressed as electric current (EC) is adjusted depending on the varieties, growth stage, degree of flower bud initiation, etc. (Table 2, Udagawa, 1987). At low concentrations the leaf color becomes light green, especially the color between leaf veins turns remarkably pale. On the other hand, at high concentrations the growth of the roots is poor, and leaf burn and abnormal flowers occur very often due to calcium deficiency.

The pH of the solution tends to change from 4.5 to 7.5 depending on the growth stage of strawberry. During the growing season the pH increases, and at the time of harvest or during the resting season the pH decreases. Although the suitable pH for strawberry ranges from 5.5 to 6.5, it is difficult to adjust it by addition of acid or alkali. It is preferable to change the solution when the pH decreases below 4.5 or exceeds 7.5.

The temperature of the solution varies from 23°C to 30°C in summer and from 11°C to 20°C in winter. Cooling the solution may be necessary in summer when the temperature exceeds 30°C. Warming the solution up to 16°C in winter can improve the quality of fruits.

The amount of the solution supplied to plants ranges from 0.2 to 2.0 l/min/100 plants. Excessive supply causes growth delay and decreases the yield.

The yield and quality of the fruits produced by the application of NFT are not different from those obtained by cultivation in soil.

2 Flower bud induction techniques

It is known that low temperature, short day and limitation of nitrogen absorption can accelerate the differentiation of flower buds in strawberry. Pot nursery for reduced nitrogen application and nursery period in mountainous area for cooling had already applied in forcing culture, when harvesting started from the end of November or the beginning of December. However since for the market it is important to harvest fruits as early as possible, new techniques for premature induction of flower bud by cooling and short day treatment have been developed recently.

The most popular method for cooling is the use of large refrigerators. Daughter plants

Table 1 Major components of various solutions used for strawberry in Nutrition Film Technique (Udagawa, 1987)

(EC 1.8 ms/cm)

Name of solution	Component of solution (meq / l)								Amount of application (g / 1000l)			
	NO_3-N	NH_4-N	T-N	P_2O_5-P	K	Ca	Mg	SO_4-S	KNO_3	Ca $(NO_3)_2$	$MgSO_4$	$NH_4H_2PO_4$
Chiba	11.0	1.0	12.0	3.0	6.0	5.0	4.0	4.0	606	590	492	114
Yamazaki	12.0	1.2	13.2	3.6	7.2	4.8	2.4	2.4	727	566	295	137
Enshi	12.0	1.0	13.0	3.0	6.0	6.0	3.0	3.0	606	798	369	114

Table 2 Varietal and seasonal differences in concentration of solution in Nutrition Film Technique for strawberry (Udagawa, 1987)

Group	Name of variety	Suitable concentration of solution (ms/cm)			
		Just after transplanting	Before covering	Before flowering	After flowering
A	Hokowase, Terunoka, Haruyoi, Nyoho, Toyonoka	0.4	0.8–1.0	1.2	1.6–1.8
B	Hogyoku, Nagasakiqueen, Shizutakara, Meiho, Reiko	0.8	1.2–1.6	1.8	2.0–2.4
C	Chizuru, Osuzu	1.0	1.4–1.8	2.0	2.2–2.6

are put into them at temperatures ranging from 12°C to 15°C for two weeks. These plants are nursed in pots and the crown size exceeds 10 mm while the nitrogen content of the petioles is maintained at a lower value differing among the varieties, for example : a value of less than 110 ppm for 'Toyonoka' (Fig. 2, Furuya *et al.*, 1988).

The main emphasis to achieve high and early yield by using these techniques is to generate runners as early as possible and to obtain large daughter plants before the treatment. For this purpose it is important to use a vinyl tunnel and to spray gibberellic acid (50 to 100 ppm) on the mother plants (Table 3).

3 CO_2 application techniques

In forcing culture of strawberry the concentration of CO_2 in the vinyl house reaches a peak at 1000 ppm just before sunrise and decreases to 150 ppm in the morning, when photosynthesis is suppressed. When the vinyl house is open, the concentration increases to the same level as that outdoors (250 ppm). The vinyl house remains closed during cold days in order to maintain a high temperature. Therefore the CO_2 concentration becomes low during the daytime.

Kawashima (1987) showed that the application of CO_2 in the daytime is very effective for increasing the yield and promoting the growth of strawberry. In 'Hokowase' the yield increased by 50 to 100%, the growth was accelerated by one week and the secondary clusters developed well. However the fruit size decreased as abnormal fruits were obtained due to the lack of fertilization (Table 4). Liquid CO_2 was applied, the concentration was controlled by infrared rays analyzers at 750 ± 100 ppm and the temperature in the daytime was controlled from 25°C to 28°C, which is higher than the usual temperature in a vinyl house.

A total amount of 4,000 kg/10 a of CO_2 was applied for 7 months from November to

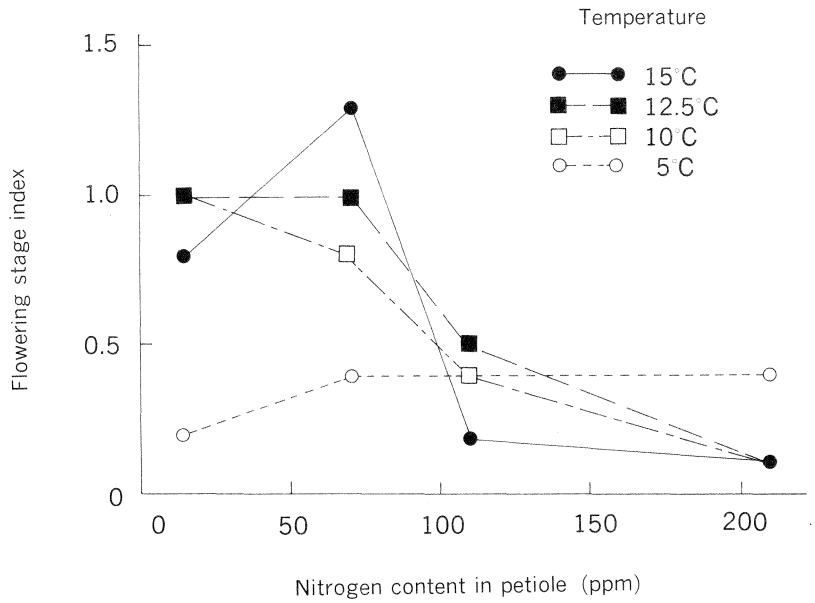

Fig. 2 Effect of nitrogen content and temperature on flower bud initiation (Furuya, 1988)
Note : Flowering stage index=Σ(Stage number × Number of plants)/Total number of plants.

May. The cost was ¥ 360,000 and additional initial cost necessary for the facility was ¥ 320,000.

Research work on breeding

1 Varieties for early harvest

As mentioned before, it is essential to get fruits early. Though various techniques for flower bud induction have been developed recently, they are labour-intensive and costly. Therefore it is desirable to breed very early bearing types of varieties, in which flower buds can be differentiated without any artificial treatment even in summer under high temperature and long daylength condition. Fruiting habit is classified into two main types, single crop or "June" fruiting and everbearing including day-neutral type. Early bearing type among the former varieties is used in forcing culture and the later type of varieties is used in open field culture for harvest from spring to summer in the mountainous areas.

Regarding the inheritance of everbearing characteristics, Power (1954) suggested the presence of two or more dominant genes of unequal potency acting complementarily and at least four dominant genes governing the expression of the character in octaploid cultivars. Brown and Wareing (1965) studied the everbearing character in diploid wild types and showed that this character was governed by a single recessive gene.

Table 3 Effect of temperature, daylength, gibberrellic acid treatment on runner generation (Fukuoka Agr. Exp. Stn.)

Treatment	Harunoka		Hokowase		Himiko	
	No. of runners	No. of daughter plants	No. of runners	No. of daughter plants	No. of runners	No. of daughter plants
Temperature						
Heating	2.13	9.38	0.68	3.08	0.81	3.75
No-heating	1.69	7.63	0.50	2.79	0.94	3.63
Daylength						
Long (16 hours)	1.88	8.63	0.68	3.44	0.94	3.81
Natural	1.94	8.38	0.50	2.44	0.81	3.56
GA treatment						
50 ppm	2.81	10.94	1.17	4.71	1.19	4.50
No-GA	1.00	6.06	0.00	1.17	0.56	2.88

Note : No. of runners was estimated on April 15 and No. of daughter plants was estimated on May 13.

Table 4 Effect of CO_2 application on yield and fruit size in forcing culture of strawberry cultivar 'Hokowase' (Kawashima, 1987)

Year	Treatment of CO_2	Temperature in daytime	Yield							Fruit size			Diseases and abnormalities	
			December	January	February	March	April	May	Total	L	M	S	D	A
	(ppm)	(C)	kg/a	kg/a	kg/a	kg/a	kg/a	kg/a	kg/a	%	%	%	%	%
1986	no	23	55	100	93	22	172	117	560	38	28	34	0	—
	750	30	105	135	145	43	232	138	799	35	27	38	1	—
1987	no	23	102	113	65	36	138	26	482	32	26	36	0	2
	375	23	100	151	124	42	185	52	652	38	26	36	1	1
	750	28	163	113	141	112	216	125	869	30	26	44	1	21

Oishi had started breeding the everbearing type of strawberry for the first time in Japan. He released 'Oishishikinari No. 1' in 1954 and 'Oishishikinari' in 1970 by using foreign varieties as parents. 'Fukuba' also has been used to breed everbearing varieties. From crossing with this variety, 'Hottawanda' was released in 1957 and 'Shuka' in 1975. In the near future, we plan to breed very early bearing varieties by crossing the everbearing type and early bearing one.

2 Large fruiting varieties

Varieties with large fruits are important from two points of view. 1) To save farmer's labour. Half of the total time, i. e. about 1,000 hours is spent on picking and packing. Prototype picking machine for harvesting at one time has already been developed in foreign countries. This machine is useful for the varieties for processing use, but it is still difficult to harvest strawberries for fresh market consumption by using this machine. 2) Although large fruits have a higher value than small ones for fresh market consumption, this does not apply to strawberries for cakes.

Many studies have shown that the fruit size is inherited quantitatively and part of its genetic variance is epistatic, whereas the small fruit size is a partially dominant character (Scott, 1959 and Scott *et al.*, 1972). Though the heritability of fruit size is considered to be fairly high, decrease in fruit size due to the fruit position and high temperature has been recognized (Fig. 3, Noguchi and Yamakawa, 1989). This fact suggests that the fruit size should be selected for the same harvesting time and on the basis of the same position on the same cluster.

Considerable improvement in fruit size has been achieved by breeders in recent years. 'Aiberry' and 'Toyonoka' are varieties which are notable for their large fruits. Especially 'Aiberry' has the largest fruits, 70 g maximum and 25 g on an average. On the other hand 'Toyonoka' has fruits weighting 45 g at the maximum and 15 g on the average. 'Aiberry' was released in 1983 by a private company from a cross between one seedling of 'Reiko' and 'Hokowase'. The fruits of this variety have a good appearance with a bright red skin color and good taste with a high sugar content in addition to the large size. However this

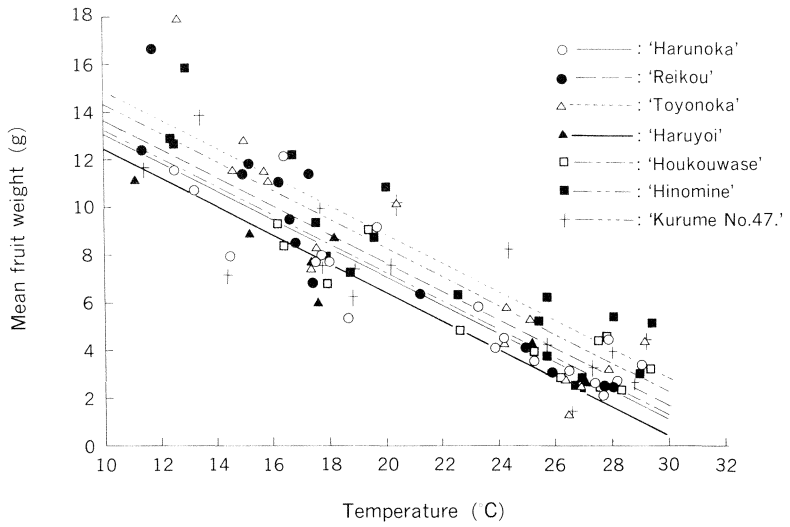

Fig. 3 Relationship between mean fruit weight and mean temperature during ripening (Noguchi and Yamakawa, 1988)

variety exhibits a large number of disadvantages, for example, late harvest and low resistance to many diseases. We have selfed 'Aiberry' to select its seedlings for early harvest and disease resistance, and crossed these selected lines with 'Toyonoka'. As many progenies with large fruits have been selected from this cross, 'Aiberry' appears to be a good breeding material to develop large fruiting varieties.

3 Disease-resistant varieties

Three main diseases will be considered : powdery mildew (*Sphaerotheca humuli*), Fusarium wilt (*Fusarium oxysporum*), and crown rot (*Colletotricum fragariae*). Powdery mildew infects not only the leaves but also the fruits in very susceptible varieties. Regarding the mode of inheritance of the resistance to powdery mildew, non-additive variance was found to be more important than the additive one and considerable epistatic variance was found to be present (Hsu *et al*., 1969). Resistancce in diploid *F. vesca* is controlled by two genes (Harland and King, 1957). Generally speaking, the varieties derived from 'Hokowase' and 'Kogyoku' are resistant whereas the varieties derived from 'Fukuba' and 'Harunoka' are susceptible. The test for the resistance to this disease is taken under natural infection conditions in the field where susceptible varieties and lines to be tested are planted alternatively. When all the susceptible varieties show symptoms, estimation starts.

Fusarium wilt is a soil-borne disease which induces the formation of distinct reddish brown crown lesions. As the disease advances, the lower crown tissues and leaves die rapidly. The mode of inheritance of the resistance to this disease is not clear. Generally the varieties derived from 'Fukuba' and 'Yachiyo' are resistant and the varieties derived from 'Hokowase' are susceptible. The resistance test for this disease is taken in contaminated fields where susceptible varieties and lines to be tested are planted in summer. When all the susceptible varieties are dead, estimation may start. It is difficult to breed varieties resistant to both powdery mildew and Fusarium wilt, simultaneously. However, in 1987 a new variety 'Hinomine' has been released from a cross between 'Terunoka' and 'Harunoka'. This variety displays a strong resistance to powdery mildew and is relatively resistant to Fusarium wilt (Honda *et al*., 1988).

Crown rot is a relatively new disease here in Japan, which was discovered about twenty years ago. As this disease occurs under hot and humid conditions, it is a serious problem in fields for the production of summer daughter plants. The disease affects leaves, runners and crown, and the plants eventually die when the crown is infected. The mode of inheritance of the resistance to this disease is not clear, but the disease seems to be inherited quantitatively. There are no Japanese varieties resistant to the disease. 'Hokowase' and 'Harunoka' are relatively resistant, and 'Fukuba' and 'Oishishikinari' are susceptible (Noguchi *et al* ., 1987). The test of resistance to this disease is taken by artificial inoculation to plants in pots. Within two or three weeks after inoculation, the disease index can be evaluated based on the length and extent of the lesion on the petioles (Bryan and Milholland, 1980).

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