K. Sawamura, Y. Harada, and T. Kikuchi
Hirosaki University, Japan

J. M. Ogawa
University of California, Davis

The Apple Industry in Japan

A Historical Sketch and Diseases Specific to the Region

Japan produces about 1 million metric tons of apples (*Malus domestica* Borkh.) per year, or 27% of the annual production in the United States. In Japan, apples are important not only because of the size of the industry with respect to the population (125 million) but also because the large, highly colored fruit are prized as congratulatory gifts (Fig. 1). This article describes the introduction of apple cultivars into Japan, the changes in cultural techniques used to produce these cultivars, and the strategies developed to combat serious diseases endemic or introduced to the region.

The History of Apple Production in Japan

In 1868, the Meiji restoration period reopened Japan to foreign trade (13). Little is known about the introduction of apple trees into Japan before that time, although imported trees were planted in the garden of the *daimyo* (feudal lord) in Edo (now Tokyo) somewhat earlier. In 1871, a newly formed agency of the government imported 75 cultivars, principally from the United States, including Ralls Janet (Kokko). These cultivars of *M. domestica* served as examples of modern apples with superior size and flavor and also as breeding material for new cultivars. During the Meiji era (1868–1912), about 380 cultivars were introduced, mainly from the United States, although some of these had actually been selected in Europe (mostly France and Great Britain). Fewer than 10 of these cultivars introduced by the Agency of Hokkaido Development and by Japan's Ministry of the Interior were accepted as commercial cultivars before the turn of the century. Surprisingly, and for unknown reasons, the final selections were all American cultivars. New apple cultivars were not developed in Japan until the early 1930s.

Of great significance was an apple fruit brought to Japan from the United States by John Ing, a Christian minister and schoolteacher from Indiana. At a Christmas party in Hirosaki in 1875 he showed this large apple fruit to his invited guests. One of the guests planted seeds from the fruit, and a seedling he selected was named Indo, which, based on isozyme similarities (1), is believed to have been derived from White Winter Pearmain, of West Virginia origin. The Indo fruit was much larger and sweeter than the Asian apple called Waringo (*M. asiatica* Asami), which originated in China and had been introduced into Japan several centuries earlier. Indo was later crossed with Golden Delicious, giving rise to Mutsu, a triploid seedling tree that develops large, yellowish green fruit in midseason. Mutsu continues to be an important cultivar. In 1962, Fuji, a selection from a cross between Ralls Janet and Delicious, was introduced by the Horticultural Division of Tohoku Agricultural Experiment Station, Aomori Prefecture (now Morioka Branch of Fruit Tree Research Station) at Fujisaki City, and named after that city as well as Mount Fuji, Japan's highest mountain. This cultivar made a major impact on the Japanese apple industry in that about 50% of apple production in 1990 was Fuji. This cultivar is now being grown in other countries, including New Zealand, Brazil, Korea, and the United States.

Apple Production Today

The commercial production of apples is still centered in northern Japan between latitudes 36° and 44° north. The average rainfall in this region is 1,100–1,400 mm, and the relative humidity averages 70 to 80% during the summer months. The prefecture (*ken*) with the largest area in apple production is Aomori, followed by Nagano, Yamagata, Iwate, Fukushima, Akita, and Hokkaido (Fig. 2). About 50% of the total apple production in Japan is in Aomori, where the average growing season for different cultivars ranges from 136 to 178 days. Orchards average 0.9 ha and are owned by the growers, who, with their families, do essentially all of the work required to produce a crop.

Most orchards (80% of those in Japan and 90% of those in Aomori) have low-density planting, i.e., 150–200 trees per hectare, with trees pruned to a flat, open-center form and grown on Marubakaido rootstock (*M. prunifolia* (Willd.) Borkh.

Fig. 1. Apple cultivar Mutsu fruit bearing the design *kotobuki* ("happiness, congratulations") and packed in soft plastic netting to prevent bruising.

Much of the information in this article was presented at the Deciduous Tree Fruit (Apple) Disease Workshop at Hirosaki, Japan, held in conjunction with the Fifth International Congress of Plant Pathology, Kyoto, Japan, in 1988. This overview is based primarily on technical articles published in Japan, largely in Japanese print.

Dr. Ogawa's address is: Department of Plant Pathology, University of California, Davis, CA 95616.

var. *ringo* Asami). Plantings are square, with tree spacings of 7 × 7 m or 8 × 8 m to provide foliar canopies over more than 80% of the orchard floor. Tree height is restricted to about 4 m. An open-center tree has two or three primary scaffold branches 2.0–2.5 m long, each with two secondary scaffold branches 1–2 m long. Most lateral branches on which fruiting branches are borne develop on the secondary scaffold branches and are kept well away from the trunk (10). The fruit production in Fuji orchards averages about 30 t/ha, with yields up to 40–50 t/ha in well-managed orchards.

High-density planting (1,250 trees per hectare) was introduced into commercial orchards in 1973, with trees on M.26 rootstock and spacings of 4 × 2 m. The planting of high-density orchards is increasing gradually, but another decade or more may be needed to establish a specific type adapted to Japanese conditions. Just 30 years ago, the cultivars grown in Aomori were Ralls Janet (62%), Jonathan (25%), and Delicious (Starking and Richared) (4%); 20 years later, the leading cultivars were Starking Delicious (42%) and Fuji (31%). Today, Fuji occupies half of the Aomori production area, followed by Starking Delicious (10%), Tsugaru (8%), Orin (6%), Jonagold (6%), and Mutsu (5%). Ralls Janet and Jonathan, which had played such a large role, now comprise only 0.5 and 1%, respectively, of the hectarage.

Apples in northern Japan bloom in early to mid-May and are harvested from August through November. Fuji is harvested up to 15 November in Aomori, while in the southern regions of Nagano and Fukushima it often is harvested until the end of November without fear of freeze damage. Apples in cold storage are marketed within 1–5 months after harvest, while those stored in controlled atmosphere can be held for 6–8 months.

The Japanese market demands large fruit of the highest quality, with full red color and a minimum of russeting. To obtain large fruit with the desired pinkish red or yellow coloration, little russeting, and extended storage life, growers use intensive, expensive practices such as pollinating by hand or by a wild bee called *mamekobachi (Osmia cornifrons* Radoszkowski), which they raise; thinning fruit by hand from soon after bloom to early July; bagging individual fruit (*fukuro kake*); removing leaves; and harvesting by special techniques. The time spent in hand-labor—largely by the property owner, family members, and neighbors—totals about 2,600 hours, including 550–600 hours for the bagging operation.

Fruit bagged and uncovered become a bright pinkish red, a market requirement for their use primarily as a specialty gift item for various social events, including weddings. About 80% of the Fuji fruit grown in Aomori are bagged in order to enhance their redness and extend their storage life. Essentially all Mutsu fruit (normally greenish yellow) and varying percentages of other cultivars, including Tsugaru and Jonagold, are bagged to enhance their bright pinkish red coloration (2–4) or, as in the case of Golden Delicious, to reduce russeting (37). Bagging is more common in Aomori than in other prefectures, and the average worker bags about 2,000–2,500 fruit per day.

In the bagging process, individual young fruit formed from the king blossom are covered with a small paraffin-coated or newspaper bag; for Mutsu, this is done during the middle of June. The first bag is replaced in mid- to late July with a larger bag consisting of an outer layer of specially processed paper in green, yellow, blue, or tan or of regular newspaper with the underside colored black and sometimes with an inner waxed layer colored red, blue, or black (Fig. 3A). Manufacturers suggest bags for each cultivar, and growers appear to have their preferences. Bags are removed approximately 1 month before harvest, which is during late August to early September for Tsugaru and late September for Jonagold, Mutsu, and Fuji. The outer bag is removed first and the inner bag about 5 days later to prevent sunburn. This exposure of the noncolored fruit to sunlight (Fig. 3B) enhances the formation of anthocyanin pigments but not of chlorophyll.

Removal of 10–40% of the leaves (31) begins immediately after bags are removed and is repeated when the individual fruit are turned to expose noncolored areas to increased light for more uniform coloration. Another practice to improve coloration is placement of plastic, aluminum-coated reflecting sheets under the trees (Fig. 3C). Although not considered essential for marketing fruit, this technique is used by about 80% of the growers in Aomori.

The bagging practice initially was adopted to prevent damage to fruit from moths and weevils, but whether it had value in disease control is not recorded. Bagging was begun as early as the 1890s in Iwate Prefecture, and its rapid spread to Aomori Prefecture by 1905 probably was influenced by indications that bagging improved fruit quality and reduced surface blemishes. In the 1940s, appropriate timing of fruit bagging was found to convert an apple inherently green, such as Mutsu, to a bright pinkish red at harvest. Bagged fruits later were found to have slightly less flavor than those not bagged, but the enhanced color prompted earlier harvest, probably of less mature fruit. Cultivars with a green (Orin) or deep red color (Jonathan and Starking Delicious) are not bagged, while Golden Delicious is bagged to produce fruit with less russeting, especially at the stylar end. The practice of bagging apples is declining because it increases the cost of production. For long-term storage (6–7 months), however, the bagged, less mature fruit are preferred.

Harvesting involves placing 20–30 fruit in a picking basket, taking the fruit to the grading stand by hand or by vehicles with pneumatic tires to prevent mechanical injuries caused by bouncing, and grading by hand into 20-kg lots using wooden, or more recently, plastic boxes. The apples are hauled immediately to an agricultural cooperative (30% in Aomori and almost all in Nagano) or to a wholesaler for immediate sale, repackaging for

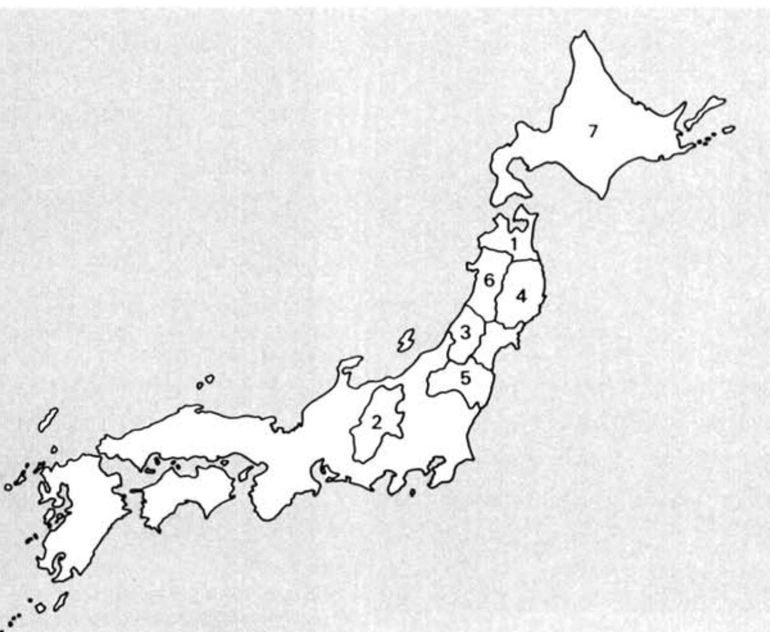

Fig. 2. Major apple-growing prefectures in Japan ranked according to production: 1 = Aomori, 2 = Nagano, 3 = Yamagata, 4 = Iwate, 5 = Fukushima, 6 = Akita, and 7 = Hokkaido.

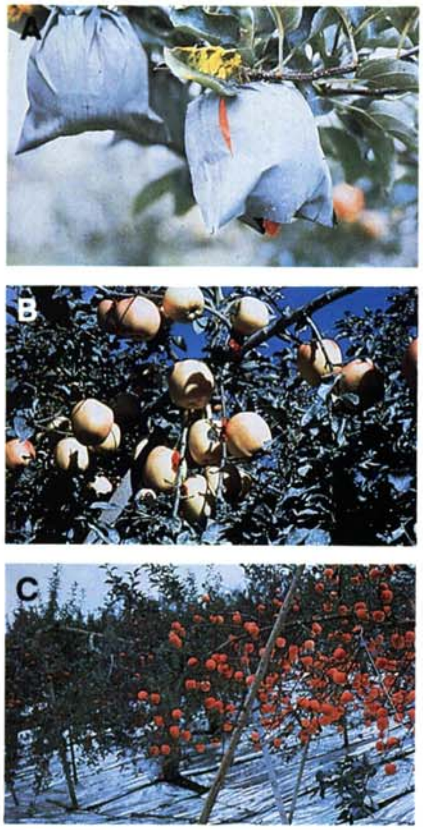

Fig. 3. (A) As the individually bagged fruit enlarges, the outer bag splits at a special seam; the inner red waxed liner continues to prevent the fruit from turning color. (B) After the bags are removed, the inner red lining acts as a pad to prevent mechanical injury of fruit in contact with a limb. (C) Plastic reflector sheets placed under the trees enhance coloration of the lower part of the fruit.

Fig. 4. ***Monilinia mali*** infection that has moved from the stigma down the style into the fruit; liquid is oozing from the decaying fruit.

retail markets, or storage in either cold or controlled-atmosphere units. For special packs, each fruit is placed into a soft, netted, plastic cup to prevent mechanical damage during marketing (Fig. 1). The bagged fruit generally command a higher price than those not bagged.

Apple Diseases in Japan

In the early years, researchers feared that the newly introduced, genetically different commercial apple cultivars and selections might promote rapid development of new or unknown diseases that could be difficult to control. Their fears were justified. Some diseases almost eliminated the culture of apples in Japan. Young scientists were challenged to quickly solve these devastating problems through correct identification of pathogens, description of disease cycles, and development of control measures.

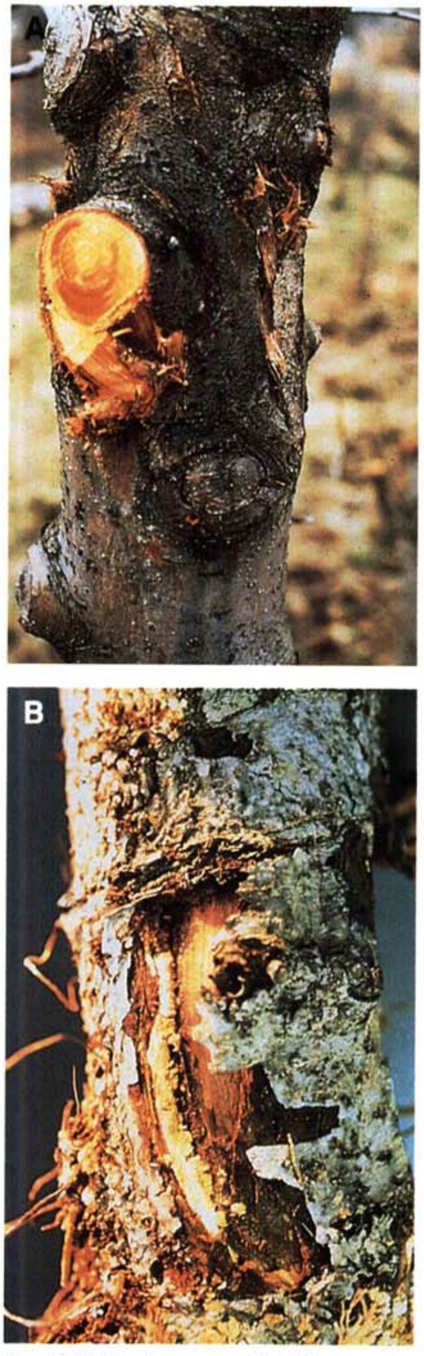

Fig. 5. (A) Canker caused by ***Valsa ceratosperma*** with abundance of black pycnidia on tree trunk before treatment with mud and plastic wrap. (B) After treatment, wound periderm indicates healing process.

Fruit production scientists before the turn of the century were located in institutions in apple production areas, i.e., Sapporo Agricultural College (now Hokkaido University) and the agricultural experiment stations in northern Japan. Distinguished were K. Miyabe and his students Y. Takahashi, G. Yamada, S. Ito, and M. Miura. At that time, teachers and students who were fortunate to have studied at the Sapporo Agricultural College, where all courses were taught in English under the leadership of W. S. Clark from the United States, were fluent in this second language. They traveled extensively to observe apple diseases in foreign countries to facilitate investigation of the serious problems facing Japan's fledgling apple industry. At first, each new disease epidemic was related to reported diseases in the United States or Europe and established control measures were tested. Lime sulfur was introduced in 1897 and Bordeaux mixture in 1907 to reduce blossom, foliage, and fruit diseases; copper fungicides are still widely used.

***Monilia* disease.** The report in 1894 (29) of a *Monilia* disease of apples followed observations of a wilt and blight of leaves and blossoms and rot of young fruit. Until the pathogen was identified as a new species, *Sclerotinia mali* Takahashi (= *Monilinia mali* (Takahashi) Whetzel), it was confused with *Monilinia fructigena* Honey in Whetzel and *M. laxa* (Aderhold & Ruhland) Honey, which were known to cause a blossom and twig blight disease. During 1925–1926, Shima (29,30), working with cultivars Jonathan, Ralls, and McIntosh, clearly showed that Monilia blossom blight was related to movement of the pathogen from infected leaves into the pedicel. He also demonstrated that fruit rot originated only through stigmatic infection and was correlated with the ability of the mycelium to grow faster than pollen tubes in penetration of stylar tissue (Fig. 4). Only ascospores infected young leaves, whereas both conidia and ascospores infected the stigma. Willetts and Harada (38), realizing the importance of apothecia production in nature, first defined the conditions required for their formation and produced apothecia under laboratory conditions. Prevention of apothecia production was attempted by spreading carbonized rice hulls and lime with carbon black on the orchard floor to hasten melting of snow and drying of the topsoil (16). Other approaches were hand-pollination of stigmas, which drastically reduced the percentage of diseased fruit, and use of a dust formulation of the antibiotic griseofulvin mixed with spores of *Lycopodium clavatum* L. and pollen grains (35). These procedures, however, could not assure disease control. A spray of lime sulfur during bloom was also tested but not only failed to protect the stigma from infection but injured the stigma and reduced pollen germination. Fungicides such as fluoromide and guazatine are applied to prevent leaf blight by the prepink stage, vinclozolin to suppress lesion development and conidia production, and thiophanate-methyl to prevent leaf and blossom blight.

Valsa canker. Valsa canker (*furan-byo*) also emerged near the turn of the century (1897). It almost destroyed the apple industry in Aomori and continues be a devastating, unsolved problem throughout the northern apple-producing prefectures. Neither the perennial nature of the canker nor the annual abundance of new lesions in which fruiting bodies quickly form (Fig. 5A) were anticipated. (Cytospora canker, a similar disease in other parts of the world, is serious in Japan only after severe stress caused by freezing or sunburn.) *Valsa ceratosperma* (Tode:Fr.) Maire (= *V. mali* Miyabe & Yamada), the organism causing Valsa canker, was equally pathogenic on all apple cultivars and could be controlled only by excision of cankers or removal of infected limbs—or even the whole tree.

The ingenuity of apple growers, as noted by Iwabuchi (8), was demonstrated by their development and use of a *doromaki-ho* (biological control) method as early as 1901. The curative treatment was to scrape off the affected tissue, spread soil on the cut surface, and wrap the area with rice straw, reed straw, or a straw mat. For protection, the trunk and large branches were also wrapped with something like rice straw or a straw mat. Presumably, the growers did not understand that this procedure involved the principle of eradication, i.e., reduction of the population of the pathogen. This was perhaps the first effective biological control measure for dealing with a plant disease. Growers have continued to trust in this control method because other techniques have not provided the desired level of protection.

The current *doromaki-ho* process involves taking wet soil from underneath the tree, placing it about 3 cm thick on the canker without removing the diseased tissue, and wrapping the trunk with vinyl film. Research has confirmed the early claim that this procedure is therapeutic (5,21,27); once wound periderm forms, the canker fails to expand (Fig. 5B).

The *doromaki-ho* process was effective. The disease was well controlled until the early 1930s but became devastating again in the mid-1960s and continues to spread. However, the disease is essentially nonexistent in prefectures south of Fukushima, where the winter climate is warmer. This suggests that winter injury could be involved in its epidemiology. The problem of control is complicated by the difficulty of detecting early infections and the ability of the pathogen to infect at many points—fruit scars, pruning wounds and other injuries, and limb crotch areas throughout the tree. Without concerted effort at control, this disease will continue to be a serious factor in apple production. Chemicals being investigated for treatment are guazatine, benomyl, and thiophanate-methyl.

Rust. The rust pathogen, *Gymnosporangium yamadae* Miyabe:Yamada, resembles the American apple rust or cedar apple rust fungus, *G. juniperi-virginianae* Schwein., with the exception that the telial horn is bi- or triennial. As with the American apple rust fungus, the aecial stage is found only on species of *Malus* (6). This pathogen is endemic in Asia on *Malus* species as aecial hosts (Fig. 6) and species of *Juniperus sabina* L. as telial hosts. *Juniperus* spp. are popular as landscape trees, both as overstory for Japanese gardens and as dwarf (bonsai) trees. Protective treatments include the sterol biosynthesis inhibitors as well as mancozeb, thiram, and ziram.

As early as 1900, the Aomori prefectural government stated that eradication of *Juniperus* was required for disease control. Spread of one or more of the nine recognized species of *Gymnosporangium* onto the new apple introductions was expected but not realized until the severe outbreak of rust (*akahoshi-byo*)

Fig. 6. Leaves of apple with yellowish orange spots caused by the rust pathogen, *Gymnosporangium yamadae*.

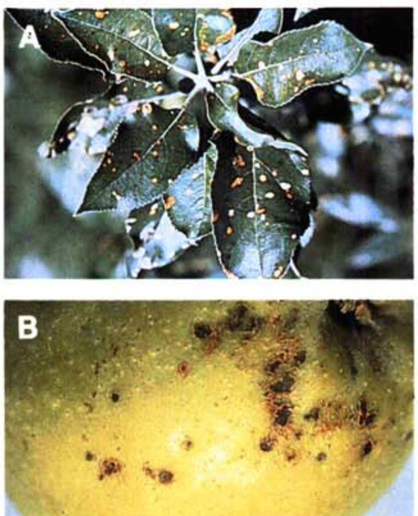

Fig. 7. Alternaria blotch of apple cv. Indo caused by *Alternaria mali*: (A) Leaf spotting and (B) fruit spotting and scabbing.

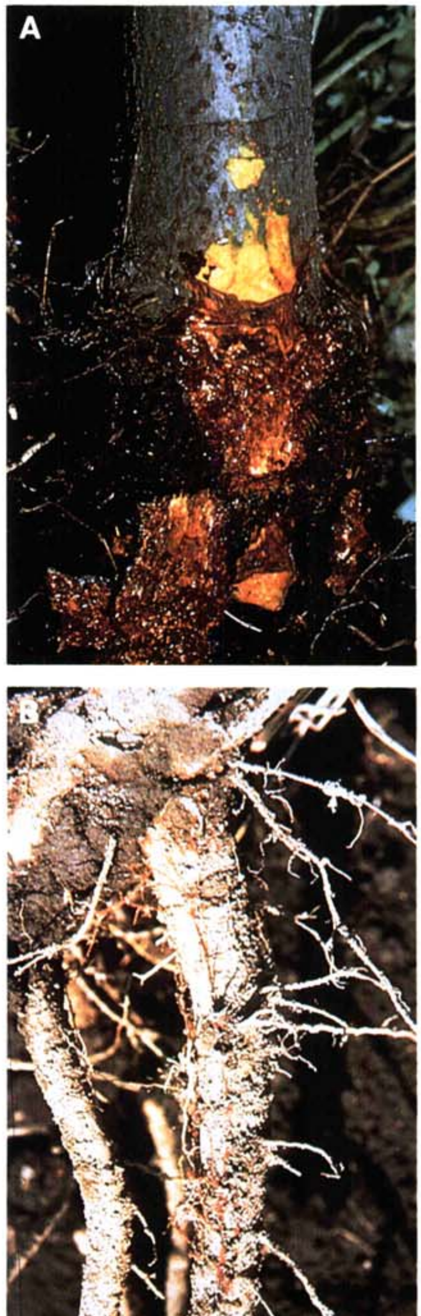

Fig. 8. Apple trees with (A) white root rot caused by *Rosellinia necatrix* and (B) violet root rot caused by *Helicobasidium mompa*, with strands of mycelium on the root surface.

in 1905, especially in orchards adjacent to residential districts. In 1910, a leading grower proposed the mandatory removal of *Juniperus* trees, and the prefectural government published such a decree in 1918. But as expected, the order was not well observed. In an attempt to develop a more acceptable control method, K. Sawamura (*unpublished*) restricted formation of aecia on the abaxial surface by spraying the adaxial surface with a spore suspension of nonpathogenic *Alternaria* sp. isolated from the diseased lesion or *Fusarium* sp. isolated from soil.

Powdery mildew. Although the cultivar Jonathan meets the market demand for fruit with a deep red color, those involved with apple diseases understand well that powdery mildew, caused by *Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon, is a serious problem with Jonathan (7). Control with chemicals involves spraying every 10 days to protect leaves and developing fruit. Mildew has not been a major disease problem, however, since the introduction of new, more effective organic fungicides, such as fenarimol (Rubigan) and the blend of mancozeb and dinocap (Dikar), and the replacement of Jonathan and Ralls with more mildew-resistant cultivars.

Apple topworking disease (*ringo taka tsugi byo*). Multiple topworking done to replace old cultivars with more popular selections presented a mysterious new condition that was named *taka tsugi byo*. This disease affects all apple cultivars, is characterized by general tree decline, and was first observed 1–2 years after regrafting trees with scions of new cultivars introduced from the United States. The problem was recognized in all major apple-growing areas of Japan as early as 1938 (33). In cooperative efforts, Japanese and United States researchers found that one or more viral agents were being imported into Japan in some of the promising new American apple cultivars (14,15). They showed the extreme sensitivity of the two main Japanese rootstock cultivars, *M. p. ringo (marubakaido)* and *M. sieboldii* (Regel) Rehd. (*mitsubakaido*), to one or more of the so-called latent apple viruses. The type strains of apple chlorotic leaf spot virus (ACLV) were found to cause decline of trees grown on rootstocks of *M. p. ringo*. Inoculations with single viruses and with ACLV combined with apple stem pitting virus and apple stem grooving virus caused decline of trees grown on rootstocks of *M. sieboldii* and *M. s. arborescens* Rehd. (*kobanozumi*). As the virus infects the rootstock, wood pitting and bark necrosis develop on the understock, and the trees decline and become nonproductive (39). Since the establishment of the certification program against fruit tree viruses in Japan, the incidence of this disorder has greatly decreased (12,17). Other apple-producing countries have not experienced this disorder because most apple seedlings and nearly all dwarfing and semidwarfing clonal rootstocks are tolerant of the three viruses.

Alternaria blotch. In 1956, an unknown disease characterized by severe defoliation of spotted leaves in midsummer was detected in southern Iwate Prefecture on Indo. Indo is an unimportant cultivar, but the high susceptibility of Delicious strains, mainly Starking Delicious, was of concern (28). Fortunately, Jonathan, the main cultivar in this prefecture, was highly resistant to the disease. The disease quickly spread throughout the apple-producing area of Honshu and later into Hokkaido. It was caused by a pathogenic strain of *Alternaria mali* Roberts (*A. alternata* (Fr.:Fr.) Keissl., apple pathotype) (9) and was named Alternaria blotch (*hantenrakuyo-byo*) to distinguish it from Alternaria leaf spot and storage rot of apple in the United States, which apparently is caused by a biotype of *A. alternata*. The disease resembled the black spot disease of Nijisseiki pears (*Pyrus serotina* Rehd. var. *culta* Rehd.) caused by *A. kikuchiana* Tanaka (*A. alternata*, Japanese pear pathotype), a pathogen that produces a host-specific toxin (AK-toxin).

Alternaria blotch varies markedly in severity on different cultivars, has a short incubation period, and can be controlled with fungicidal sprays, beginning in late spring (23,24). Without this protection, the leaves develop small, round, blackish lesions that later turn yellowish brown, then grayish with purplish margins (Fig. 7A). The lesions gradually enlarge to 2–5 mm in diameter, resulting in serious defoliation. Fruit infection does not cause decay, but fruit lose marketability because of lenticel discoloration and black spots and scabs (Fig. 7B). The bagging process reduces this secondary fruit infection, which begins during the rainy season (mid-June to late July) when the fruit is covered. The optimum temperature for disease development is 25–30 C, the most favorable temperature for growth of mycelium, sporulation, and spore germination. Rains during the summer can result in leaf infections within 24–48 hours (23).

Unfortunately, many of the cultivars planted in Japan were derived from the highly susceptible Indo and Delicious. The decreasing order of field susceptibility of the important cultivars in Japan to Alternaria blotch is Indo, Redgold, Raritan, Starking Delicious, Orin, Fuji, Golden Delicious, Ralls, Toko, Tsugaru, Mutsu, Jonagold, and Jonathan. In fruit breeding programs, susceptibility to this disease can be evaluated within 3 hours after fungal penetration on the basis of discoloration of the leaf epidermal and palisade parenchyma cells. The culture filtrate from *A. mali* grown on Richards's solution contains the host-specific toxin alternariolide (18,19), only the fifth host-specific toxin known. The toxin induces necrosis in susceptible leaves at a minimum concentration of 1 μg/ml. Two additional host-specific toxins, AM-Toxin II and III, also have been reported by other authors (18,19) for this fungus. The use of these fungal toxins as a tool for testing disease resistance could be considered a milestone in the identification of resistant and susceptible cultivars (20). Knowledge of relative susceptibility of a cultivar could be used as a guide for determining the minimal number of fungicide applications required for effective disease control. Polyoxin AL (an antibiotic) and iprodione are considered superior to copper 8-quinolinol, captan, and the dithiocarbamates.

Scab. *Kurohoshi-byo*, caused by *Venturia inaequalis* (Cooke) G. Wint., was not a problem on commercial imported apple cultivars for more than half of this century until its official recognition in 1955 in orchards in Hokkaido, near the city of Sapporo (25). Before then, Sawamura (22) had noticed scab on the Asian crabapple cultivar Waringo at the Tohoku Agricultural Experiment Station research orchard in Aomori; the imported western cultivars growing nearby were free from the disease. Sawamura showed that all isolates (Asian strain) obtained from Waringo were nonpathogenic to commercial apple cultivars, such as McIntosh and Golden Delicious, but some isolates (western strain) from commercial apple cultivars varied from weakly to highly pathogenic to Waringo (26). Within 10 years, scab had spread throughout the apple orchards in Hokkaido.

In 1968, scab invaded the main apple-growing regions in the northern part of the main island (Honshu) and caused a grower panic that will be long remembered, as the government's plant protection authorities imposed an eradication program requiring removal of all scab-infected trees. Conidial pustules rarely survived on 1-year-old shoots and bud scales, although Kudo et al (11) reported this source of inoculum in some localities. Growers refused to comply with the mandate. Scientists already knew that the scab pathogen overwinters in dead leaves on the ground and supplies the primary inoculum in the spring. Young leaves of Waringo trees are severely infected, but pseudothecial formation has not yet been detected. In laboratory experiments, however, mature pseudothecia have been obtained by artificial mating of monoconidial isolates of the western strain with the Asian strain. Natural crosses would be possible, because pseudothecia of the western strain are common and some biotypes of this strain attack Asian crabapple.

For scab control, 12 spray applications of such fungicides as sterol biosynthesis inhibitors, captan, mancozeb, thiram, and ziram are recommended during the period from April through late August but not after the bags are removed. Thus, the bagging system can reduce exposure of the fruit to direct application of fungicides during the major portion of fruit development.

White and violet root rots. Two root rot pathogens, *Rosellinia necatrix* Prill. (cause of white root rot, *shiro mompabyo*) and *Helicobasidium mompa* Tanaka (cause of violet root rot, *murasaki mompa byo*), were reported on apples as early as 1904 and 1915, respectively (36). The root rot complex ranks second in importance to Valsa canker, because effective control measures are not available and the diseases continue to spread. With Rosellinia root rot (Fig. 8A), apparently healthy trees with a full load of fruit may die suddenly in late summer just before harvest. Trees affected with violet root rot (Fig. 8B), on the other hand, begin to decline a few years before they die. Elimination of diseased trees and soil treatment with chloropicrin could possibly reduce spread of these diseases through root contact to adjacent trees, but growers are not inclined to remove apparently healthy large trees. Elimination of these diseases is unlikely because the pathogens are endemic in Japan on many crops. Biological suppressants are being investigated for prevention of new infections as well as for possible eradication of these root rot pathogens.

Bacterial diseases. Bacterial diseases that are of concern in other apple-producing regions but that have not been detected in Japan (9) are fire blight (caused by *Erwinia amylovora* (Burrill) Winslow et al), bacterial blast (caused by *Pseudomonas syringae* pv. *syringae* van Hall), and blister spot of Mutsu (caused by *P. s. papulans* (Rose) Dhanvantari). Growers use Bordeaux mixture, a combination of copper and lime, to control diseases and to produce firm fruit; other calcium formulations (e.g., calcium carbonate) are also used to accomplish the latter. Copper residues on trees could be inhibiting the establishment of bacterial diseases. The bactericides oxine-copper and polyoxin AL are currently used to control other diseases and could have an effect on bacterial populations.

Postharvest diseases. Postharvest diseases of fresh-market apples cause losses (32) but appear to be of little concern, and no type of treatment is used for their control. Pathogens such as *Phytophthora, Penicillium, Alternaria, Monilinia, Gloeosporium, Phomopsis,* and *Botrytis* have been identified on decaying fruit in cold storage (34). Unique to apple harvesting is the marketability of fallen fruit for the manufacture of processed items such as juice, pie, and jam. These apples are picked up almost as quickly as they fall, a practice that decreases the number of

K. Sawamura

Dr. Sawamura is a professor emeritus at Hirosaki University, Hirosaki, Japan. He received a degree in agriculture in 1950 and his doctor's degree in 1967 from Hokkaido University, Sapporo. He worked as a plant pathologist at the Fruit Tree Research Station, Ministry of Agriculture and Forestry, from 1950 to 1971, at which time he joined Hirosaki University as a professor in plant pathology. He is known for his work on the epidemiology and etiology of apple diseases, including scab, Alternaria blotch, Valsa canker, and virus and viruslike diseases. He is also interested in chemical and biological control of fungal diseases of apple.

Y. Harada

Dr. Harada is a professor in the Faculty of Agriculture at Hirosaki University. He graduated from Hokkaido University in 1962 and earned his doctor's degree in plant pathology from the same university in 1976. Since 1962, he has been associated with Hirosaki University, where he teaches master degree and doctor degree courses on fungal diseases of deciduous fruit trees. His research specialty includes apple tree diseases, biology of fungi, and rust taxonomy.

T. Kikuchi

Dr. Kikuchi is a professor of pomology in the Faculty of Agriculture at Hirosaki University. He earned his master's degree and also his doctor's degree in pomology at Kyoto University. His research specialty includes training, pruning, and orchard systems of apple trees, with special reference to dry matter production of trees and within-canopy environment.

J. M. Ogawa

Dr. Ogawa is professor emeritus of plant pathology in the Department of Plant Pathology at the University of California at Davis. He earned both his B.S. degree in pomology and his Ph.D. degree in plant pathology at the same institution. Research responsibilities were on etiology, epidemiology, and control of fungal diseases of deciduous fruit trees and nut crops. His current research efforts are on postharvest diseases of stone and pome fruit crops, fresh market tomatoes, and sweet potatoes; nonfungicidal control methods using nutrients; and application of control measures using forecasting systems. His most recent text is on *Diseases of Temperate Zone Tree Fruit and Nut Crops*, with H. English and published in 1991 by the University of California. In fall of 1990, he spent 3 months as a Japanese Society for Promotion of Science fellow with K. Sawamura at Hirosaki University, Hirosaki, Aomori Prefecture, to study apple diseases, with emphasis on postharvest diseases. Dr. Ogawa retired on 30 June 1991 but continues to take an active role in cooperative research programs.

propagules of decay organisms in the orchard. Another potential benefit from quick removal of the fallen fruit is reduction in the number of possible insect vectors, such as members of the Nitidulidae. Insects feeding on decaying fruit become contaminated with microorganisms and are attracted to freshly injured fruit. Populations of these insects remain low because fallen fruit are not left to decay in the orchard. Furthermore, in orchards with bagged fruit, the reflector sheet placed underneath each tree during the last month before harvest provides a buffer against contamination from soilborne fruit-decaying pathogens as well as from injuries that provide entry sites for the pathogens.

The important factors for preventing postharvest decay are careful hand-harvesting, placement of the fruit in small baskets, and carrying the baskets to the grading site either by hand or in a small vehicle with pneumatic tires. Bagging reduces fruit russeting and cracking of the skin around the stem, a possible site for infection by pathogens that cause decay. These practices result in minimal decay problems in fresh-market apples, so postharvest treatments to control decay are not used. However, fruit for processing that have been picked up from the orchard floor may decay unless they are immediately processed or are held in cold storage.

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