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Improving Skin Color of 'Fuji' Apple in Japan

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Abstract

Poor red coloration is often a serious problem in the culture of 'Fuji' apple. To overcome this situation, introduction of red sports and the practice of fruit bagging are widely carried out in Japan. This paper describes the selection procedures of red sport strains of 'Fuji' and the current tendencies of popular selections of them. Details of bagging are described along with information on some physiological characteristics of 'Fuji' fruit as related to its poor coloration behavior and responses to bagging.

'Fuji' is the predominant apple cultivar in Japan, accounting for about 50 percent of the total annual production (5). The high popularity of 'Fuji' is due to its good taste and excellent keeping quality. Unfortunately, however, 'Fuji' does not color well, which can be a serious problem, particularly in regions where weather conditions are not favorable for skin color development.

Increased red color can be accomplished by: (1) selection of naturally occurring, spontaneous sports or radiation-induced mutations; (2) a practice known as "paper bagging," which inhibits chlorophyll development in the skin and allows for anthocyanin development once the bag is removed several weeks before harvest; and (3), as with most other cultivars, management practices, e.g., irrigation, fertilization, pruning, thinning, etc. This paper will address the first two of these aspects — color sports or mutations and paper bagging practice and also the physiological bases for red color development in 'Fuji' apple.

Selection of Color Sports

'Fuji' was bred in 1939 from a crossing between 'Ralls Janet' and 'Delicious' at the Morioka Branch of the Fruit Tree Research Station in Aomori Prefecture. It was not until 1958 that the selection was made available for trial planting by growers. In 1962, it was registered and given the name 'Fuji' (10).

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From about 1965, when 'Fuji' was widely grown in commercial orchards, spontaneous red sports were found in almost every apple-producing area. Code numbers were given to such red sports by horticultural research stations of the individual prefectures (6). The code number includes an identification number in combination with one of the Chinese characters to represent the name of the individual prefecture where the sport occurred and "fu" for 'Fuji' (Table 1). Hokkaido and Aomori prefectures were divided into two districts each, and different series of numbers were assigned to each of them, starting from 1 and 101, respectively. Radiation-induced color sports from the Morioka Branch of the Fruit Tree Research Station were given identification numbers in combination with Mori-ho-fu (6).

During the 10-year period from 1971 to 1980, research stations in apple-growing prefectures made observations on the behavior of color sports, including those originating in other prefectures. Most of the studies were conducted in commercial orchards. The Morioka Branch of the Fruit Tree Research Station organized meetings almost every year during this period, to compare each others observations and to select promising sports. Ninety-nine color sports were studied. Characteristics evaluated were: fruit weight, skin color (type and intensity), general appearance, soluble solids content, acidity, flesh firmness, flesh texture, flavor, and aroma.

Some results of the comparative studies were as follows (6):

1. Coloring pattern of sports often is very unstable. Some stains first described as of solid coloring type later turned out to be of a stripe type (e.g. Iwa-fu 1, Naga-fu 6, Mori-ho-fu 1, 6). On the other hand, Naga-fu 2 which was classified as stripe coloring type was often found to produce solid coloring type apples mixed with stripe-colored ones.

2. The striped-type sports showed more tendency to develop red color in sectors than did the solid-type sports. The development of sectors suggests that the mutation took place as sectorial chimera. The sports which have colored sectors are considered unstable, and it will be a problem with these sports as to how to fix the good coloring tendency.

Table 1. Original system for naming of color sports of 'Fuji.'

Prefecture of origin	Code name
Hokkaido (central)	Kita[z]-fu 1~
Hokkaido (southern)	Kita[z]-fu 1~
Aomori (western)	Ao-fu 1~
Aomori (eastern)	Ao-fu 101~
Iwate	Iwa-fu 1~
Akita	Aki-fu 1~
Yamagata	Yama-fu 1
Fukushima	Fuku-fu 1~
Nagano	Naga-fu 1~
Gunma	Gun-fu 1~
Morioka Branch, Tree Fruit Research Station	Mori-ho-fu 1~

[z]Kita is another sound of the Chinese character for Hok(u).

3. Poor eating quality was detected in some red sports, more often in solid-type sports than in striped ones. There are some promising striped-type sports whose eating quality is comparable with standard 'Fuji.'

4. Evaluation of color sports often varies, depending on the location and site where they are grown and the year when they are observed. The major reason is the influence of climatic conditions, as well as cultural conditions. Fertilization, for instance, can mask delicate genetic differences.

The interprefectural project was discontinued in 1980 without achieving the selection of promising strains, because of difficulties involved in the screening process, leaving the individual prefectures to take action. Some prefectures tentatively recommended some strains; others left the choice of strains to growers. Strains recommended by major apple producing prefectures were as follows. Nagano: Naga-fu 2, 6, 12, Akita: Aki-fu 1, Iwate: Iwa-fu 10, Yamagata: Yama-fu 1, Naga-fu 2, Aki-fu 1. Aomori did not recommend particular strains (6).

Since that time, a great number of color sports has been found in many prefectures. Research stations have given up evaluating new strains, which occur one after another. Today most growers prefer color sports when they plant new 'Fuji' trees. They usually buy nursery trees of color sports from nurserymen who sell strains they consider best, often choosing from strains, which some prefectures recommend or once recommended. Current tendencies in the choice of color sports is summarized below. This summary is based on informal reports from research stations and growers' organizations and also catalogs of major nurserymen.

Only a few prefectures have their favorite strains. Nagano Fruit Tree Experiment Station has been recommending Naga-fu 6 for a long time, and this strain is sold by many nurserymen not only in Nagano Prefecture but also in other prefectures. Another strain gaining nationwide popularity is Mishima Fuji, which was found in Akita Prefecture in 1978 and tentatively named Aki-fu 47. Akita Fruit Tree Experiment Station now recommends this strain in place of Aki-fu 1. Naga-fu 2 and Naga-fu 12 are popular to some extent among Nagano growers. Gunma Horticultural Research Station favors Gun-fu 1 and Gun-fu 3 (Gunma is not a major apple growing prefecture but it is active in breeding apple cultivars for warm districts).

Increasingly nurserymen give their own trade names to new strains they picked up from growers. Some of these strains (e.g. 2001-nen Fuji, Royal Fuji, Rakuraku Fuji) are considered to be identical with Mishima Fuji. Thus, strains are being planted in increasing number which have not undergone any objective evaluation.

The solid-coloring strains no longer are popular among growers, because it is feared that this type of apple cannot easily be recognized by shoppers as 'Fuji.' Therefore, the color sports of 'Fuji' sold by nurseries today are exclusively of striped-coloring type.

Factors Affecting Color Development in 'Fuji' Apple

Some of the physiological characteristics of 'Fuji' apple responsible for its poor coloration have been described by a series of studies by Arakawa (1, 2, 3). Several practical suggestions are summarized as follows:

'Fuji' apple produces little anthocyanin (red color pigment) when only visible light is given (1). Ultraviolet irradiation (280-320 nm) is imperative for better coloration of this cultivar. This contrasts with other cultivars, such as 'Starking Delicious' and 'Jonathan,' which color fairly well under visible light, particularly when the fruit is approaching full maturity. 'Fuji' apples require a higher intensity of light than do other cultivars to produce the same quantity of anthocyanin (2).

The intensity of ultraviolet rays diminishes sharply on an overcast day or even on a sunny day, within the tree canopy (9). Therefore, sunny weather in the coloration period and good within-canopy light conditions are particularly important for culture of highly colored fruit.

'Fuji' apples develop red color best at 15 to 20 degrees C (measured at the surface of the fruit), which is lower than the temperature range for 'Jonathan' (20-25 degrees C) (3). Coloration declines sharply in 'Fuji' as temperature goes up or down from the optimum range. This also is different from that for 'Jonathan' apple, which colors over a broader temperature range.

As typically demonstrated with 'Jonathan' fruit, red color of apples usually develops rapidly with the advance of fruit ripening due to an increase in anthocyanin producing ability of the fruit. This ability reaches a maximum level at the full-ripening stage of the fruit, and then declines sharply. 'Fuji' fruit is somewhat specific in its coloring behavior: red color development is slow and lacks a distinct anthocyanin production peak (2). The practice of bagging brings about the same pattern of physiological change that is critical to color

development in 'Fuji' and other cultivars: the peak anthocyanin production comes immediately before the onset of the ripening process, followed by a rapid decline of this ability to develop color. Thus a delay in removing bags before harvest may result in a loss of good red color development.

Poor color development of 'Fuji' apple emphasizes the importance of careful selection of the orchard site. The important things to consider include prevailing weather conditions, particularly temperatures, during the coloration period.

The characteristics of color development of 'Fuji' red sports are not well known. The fruit of red sports produces larger amount of anthocyanin than original 'Fuji' under the same light conditions, especially under visible light (Arakawa, O., unpublished data).

Bagging Practice in 'Fuji' Culture in Japan

In Japan, bagging is practical on five cultivars; 'Tsugaru,' Sekai-icht, 'Jonagold,' 'Mutsu,' and 'Fuji' (Fig. 1). The practice of bagging in Japan is decreasing because of high production cost, particularly labor cost, while it has been adopted commercially in North America within the past several years (7, 8). Bagging slightly reduced soluble solids concentration in all cultivars examined, while effects on fruit weight, firmness, and acid concentration were different with each cultivar (4).

Many kinds of paper bags are used in Japan, depending on cultivar, grower preference, and manufacturer suggestions. Bags used for 'Fuji' usually have double layers. Inner bags without bottoms are made of red or blue waxed paper. Outer bags are usually made of light colored or white paper, and colored black on the inner side, so they are nearly impervious to light. There is no scientific basis to use specific colors for inner bags.

Bags are placed onto fruitlets 4 to 6 weeks after petal fall, targetting individual fruits, usually king fruit, of selected terminal fruit clusters. Fruit thinning

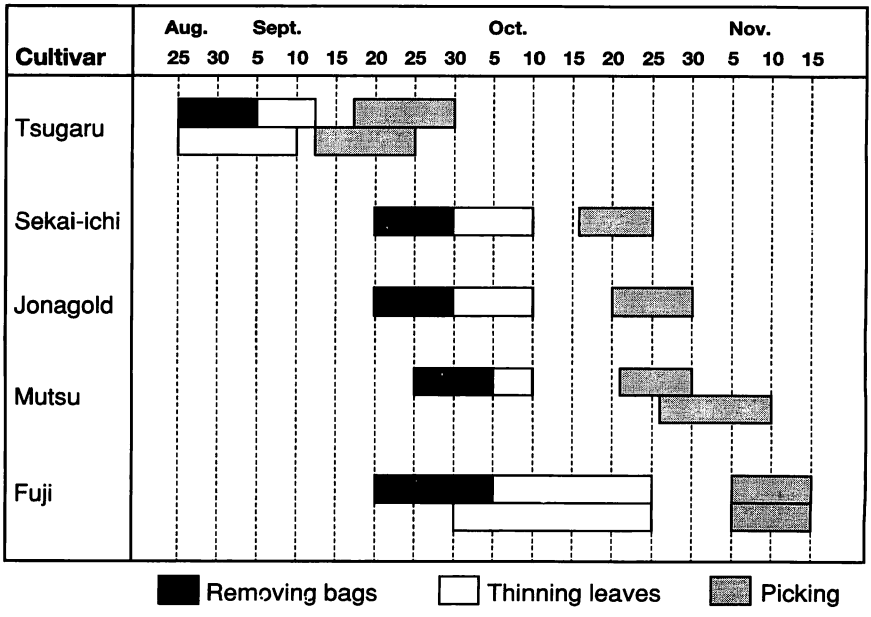

Fig. 1. The dates of removing paper bags, thinning leaves, and picking in Aomori Prefecture (Aomori Prefectural Government). The lower bars given for 'Tsugaru,' 'Mutsu,' and 'Fugi' represent the practices in the non-bagging culture.

must be finished by the time bagging is started. Whether thinning is by hand or with chemicals, the finishing touch is given by hand, so that excessive fruit load is avoided. While corrective thinning later in the season is a common and useful practice in non-bag culture, it would not be useful in bag culture.

In Aomori Prefecture, bags are removed 4 to 6 weeks before harvest to expose individual fruits to sunlight, allowing them to develop red color. 'Fuji' apples require a longer exposure period than other cultivars possibly because the weather conditions are not favorable for red color development at this time in Aomori Prefecture; temperature often goes down below the optimum range and sunshine hours are short. Bags are removed in two steps. First, only the outer bags are removed, to allow acclimation of the fruit to the sunlight; the inner bags are removed 4 to 6 days later. Outer bags have perforation lines to facilitate removal.

When bags are taken off, the fruit skin is pale, because double-layer bags shut off sunlight to inhibit chlorophyll production on the skin. In a couple of weeks' exposure, the fruit develops red color quickly. The red color is bright and attractive, because of the lack of chlorophyll which otherwise would have given a dull shade to the red over-color.

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Apple Training System on Yield

Two apple cultivars at similar spacings and on Mark rootstock were trained as slender spindles, vertical axis, Y-trellis and 6 wire palmette trellis. In years 3–6 there was a clear effect of tree density on yield within each system, however no influence of training system. In the 4th and 5th years the Y-trellis had slightly higher yields than other systems and by year 6 it had the greatest accumulated yield with no difference among the other systems. It was striking that the training systems were very similar in their performance. All systems had minimal pruning in the early years in common. These results indicate training system has a minor effect on tree performance as long as excessive pruning is not done. From Robinson et al. 1994. ISHS Hort Congress Abstracts O-345 p.75