FRUITS OF THE *ACTINIDIA* GENUS

ICHIRO NISHIYAMA

Department of Food and Nutrition, Komazawa Women's Junior College
Inagi, Tokyo 206-8511, Japan

Kiwifruit is the most well-known crop in the genus *Actinidia*. Although *Actinidia* fruit sales in the international market are dominated by a single kiwifruit cultivar *Actinidia deliciosa* ''Hayward,'' there are a considerable number of cultivars and selections in the genus that have widely diverse shape, size, and hairiness. They also offer a wide variation in sensory attributes such as flesh color, flavor, and taste, and in nutritional attributes such as the vitamin C level and carotenoid content. The level of actinidin, which is a cysteine protease in kiwifruit, also varies greatly among cultivars. This chapter reviews available information related to several important components, allergenic properties, and health benefits of *Actinidia* fruits.

ADVANCES IN FOOD AND NUTRITION RESEARCH VOL 52 ISSN: 1043-4526

DOI: 10.1016/S1043-4526(06)52006-6

I. INTRODUCTION

Among the fruits of the *Actinidia* genus, kiwifruit is the most well-known, and is one of the few crops marketed worldwide. At the beginning of the nineteenth century, kiwifruit merely grew wild in China. In 1904, kiwifruit seeds were brought to New Zealand for the first time (Ferguson, 2004). Subsequently, it was domesticated in New Zealand and launched onto world markets in the 1960s. The kiwifruit industry has made rapid progress since then and kiwifruit are now common and easily obtainable throughout the year. Kiwifruit is one of only four new fruit crops introduced to international trade in the twentieth century. They are now grown in many countries, notably Italy, China, New Zealand, Chile, France, Greece, Japan, and the United States. The industry's remarkable progress might be attributed to the success of a single cultivar, "Hayward" (Ferguson, 1999). "Hayward" fruit have an attractive emerald green flesh and fine flavor, which is sometimes described as a mix of strawberry, banana, and pineapple. Until recently, the cultivar name "Hayward" was often taken as synonymous with kiwifruit as most consumers are not aware of other varieties. However, not all of the attributes of "Hayward" are perfect. Fruits of some *Actinidia* cultivars are much sweeter than those of "Hayward," have much higher vitamin C content, or have much higher contents of carotenoids such as β-carotene and lutein.

In 2000, the yellow-fleshed fruit of a novel cultivar "Hort16A" were released as "ZESPRI™ GOLD Kiwifruit" from New Zealand into the world market. They shattered the common perception that the flesh of kiwifruit is absolutely green. Since then, the production of "Hort16A" has grown dramatically and is likely to account for 17–18% of New Zealand kiwifruit exports (Belrose, Inc., 2006).

Quite recently, fruits of *Actinidia arguta*, which is closely related to kiwifruit, have become commercially available (Williams *et al.*, 2003). These fruits are sold under commercial names, such as "Baby kiwi," "Kiwi berry," or "Grape kiwi," because they are grape-sized fruits with a completely hairless skin.

In addition to the cultivars described above, several *Actinidia* cultivars have already been launched onto markets on a small scale. Moreover, development of new *Actinidia* cultivars of commercial potential is now in progress in several countries including New Zealand, Italy, China, Korea, and Japan. New and quite different *Actinidia* fruit, with widely diverse size, shape, hairiness, flesh color, nutritional value, and flavor, are anticipated for introduction to future international trade. The kiwifruit industry is now in a transition period from domination by only one variety, “Hayward,” into increasing varietal diversity, which offers greater choice to the consumers.

These novel and/or minor cultivars, however, are probably unfamiliar to most people, even to those interested in food science; most readily available information on kiwifruit or on *Actinidia* fruits refers to “Hayward.” In this chapter, several cultivars representative of *Actinidia* species are presented. The available information concerning several important components, allergenic properties, and health benefits of *Actinidia* fruits are also reviewed.

II. *ACTINIDIA* SPECIES AND CULTIVARS

The genus *Actinidia* is composed of 76 species and about 120 taxa in all (Ferguson and Huang, 2007). In international trade today, the term kiwifruit is taken as including two distinct *Actinidia* species: *A. deliciosa* and *A. chinensis*. Recently, fruit of *A. arguta* have made an entry into international trade. Other *Actinidia* species have commercial potential, or are important as useful genetic resources for cultivar development by interspecific hybridization techniques.

A. *A. DELICIOSA*

The most common type of kiwifruit is *A. deliciosa*. Fruit of this species has a dull-brown skin with dense hair. Its flesh is translucent and bright green, which contrasts against its white core and black seeds.

“Hayward” (Figure 1) is the most commercially available cultivar. Therefore, it is the standard cultivar against which the quality of a new cultivar is evaluated. The mature fruit have a moderate sugar–acid balance and their flavor is considered by many to be superior. The most important advantage of this cultivar is the remarkably long storage life of the fruit, which enables exports by ship to distant markets (Ferguson, 1999).

“Koryoku” (Figure 1) is a seedling produced by open pollination of “Hayward.” The fruit are long and cylindrical; they have dense, easily shed hair. Total soluble sugar in its mature fruit is higher than that in “Hayward.” “Ryoku” in the cultivar name means “green” in Japanese. Consistent with that name, the green flesh color is deeper than that of “Hayward.” The carotenoid content of “Koryoku” fruit is much higher than that of “Hayward.”

“Sanryoku” (Figure 1) is an interspecific hybrid of *A. deliciosa* “Koryoku” × *A. chinensis*. The fruit has a distinctive bulletlike shape: a long cylindrical shape with a pointed end. The flesh is lime-green. Density of the hair on

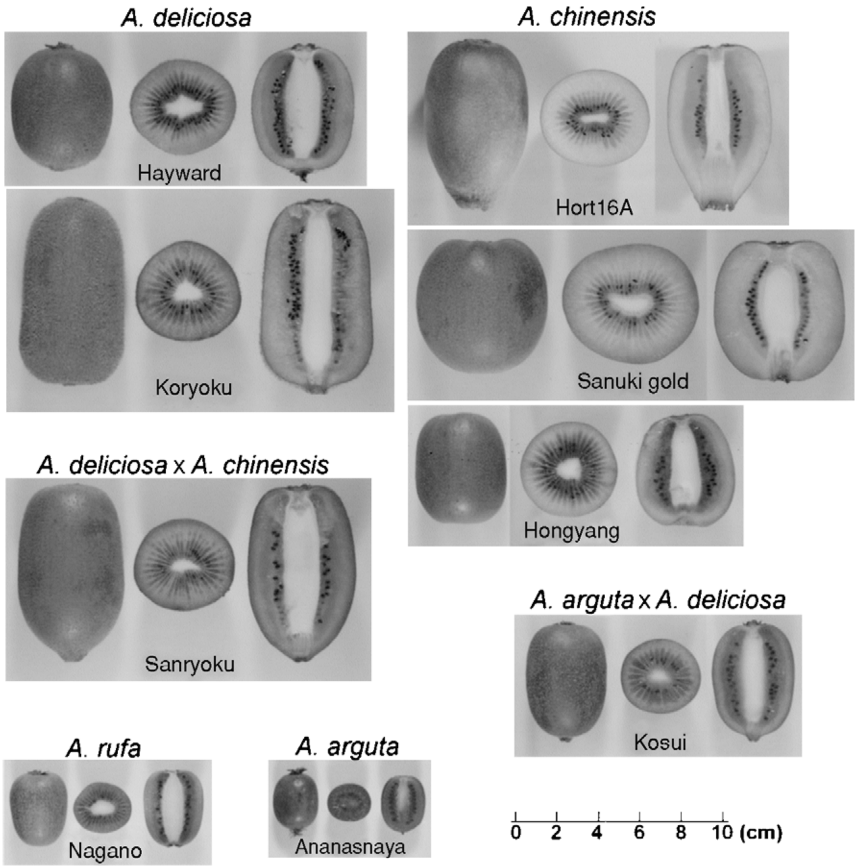

FIG. 1 Fruits of *Actinidia* species.

the surface is sparse, like *A. chinensis* fruit described below. Soluble solid contents of ripe fruit are 16–19%.

B. *A. CHINENSIS*

A. deliciosa and *A. chinensis* are very similar species. They had been classified as the same species until 1984, when they were determined to be two distinct species by Liang and Ferguson (1984). The variant with smooth-skinned, almost hairless fruit retained the original name *A. chinensis*, and the hairy-fruited variant took the name *A. deliciosa* (Ferguson, 2004). The *A. chinensis* fruit are usually, although not always, yellow-fleshed, whereas those of *A. deliciosa* have green flesh without exception.

"Hort16A" (Figure 1) is a cultivar developed by HortResearch in New Zealand. The fruit have a characteristic shape with a protrusion of the stylar end, which is a so-called "beak." The fruit have a bright-yellow flesh, and are marketed under the commercial name "ZESPRI^{TM} GOLD Kiwifruit." "Hort16A" fruit are currently grown under license to ZESPRI International in countries of the Northern hemisphere such as Italy, Japan, Korea, France, and the United States.

"Sanuki gold" (Figure 1), which is a hybrid of *A. chinensis* "Kuimi" and a male line of the same species, was produced recently by Kagawa Agricultural Experiment Station in Japan. It produces applelike globose fruit with a deep yellow flesh. The fruit are remarkably large. The most prominent property of "Sanuki gold" is its exceptionally high vitamin C content (Table II).

"Jintao" is a yellow-fleshed kiwifruit developed by the Wuhan Institute of Botany in China (Huang *et al.*, 2002). The name "Jintao" means "golden peach" in China. The fruit are long and cylindrical. "Jintao" is being commercialized under the name "Kiwigold" by the Kiwigold Consortium in Italy.

"Hongyang" (Figure 1) is a selected clone from a red-fleshed *A. chinensis* resource collected from Henan Province in China. The fruit of "Hongyang" have a deep red color around the core. The red and yellowish-green appearance of the transverse section of the fruit is particularly striking and decorative. The fruit have a sweet taste with a mean soluble solids concentration of 19.6% when ripe (Wang *et al.*, 2003). "Hongyang" fruit are now marketed under the name "Red sun."

"Chuhong" is a novel red-fleshed cultivar that was released officially in 2005 from China. The average soluble solid content of ripe fruit is 16.5%, with a maximum of 21%. The fruit are long or flat, and elliptical (Zhong *et al.*, 2007).

C. *A. ARGUTA*

A. arguta is a species with high cold hardiness: it is sometimes called "hardy kiwi." It can grow well in places where *A. deliciosa* or *A. chinensis* vines cannot survive. *A. arguta* produces smooth and hairless grape-sized fruit, weighing 5–15 g. The skin is edible, so these fruit are consumed whole. A disadvantage of the fruit of this species is that the storage life and shelf life of the fruit are more limited than those of either *A. deliciosa* or *A. chinensis* (Fisk *et al.*, 2006).

"Ananasnaya" (Figure 1), which is sometimes called "Anna" in abbreviation, is the most widely grown *A. arguta* cultivar in United States and Chile. The fruit are sweeter than "Hayward" fruit. They are bite-sized and completely fuzzless, thus they are marketed under the name "Baby kiwi" or

"Kiwi berry." Although the cultivar name "Ananasnaya" has come into wide use, it has engendered some confusion. The true "Ananasnaya" is possibly a hybrid of *A. arguta* and *A. kolomikta* selected many years ago by Michurin

TABLE I

VARIOUS *ACTINIDIA* GENOTYPES

Species genotype	Color of flesh	Density of hairs	Average fruit weight (g)
A. deliciosa			
Hayward	Green	Dense	99.0
Bruno	Green	Dense	101.8
Abbott	Green	Dense	79.8
Elmwood	Green	Dense	116.0
Koryoku	Deep green	Dense	98.7
A. deliciosa × *A. chinensis*			
Sanryoku	Lime green	Sparse or absent	107.0
A. chinensis			
Jiangxi 79–1[a]	Yellow	Sparse or absent	97.8
Golden king	Yellow	Sparse or absent	136.6
Kuimi[b]	Yellow	Sparse or absent	102.5
Sanuki gold	Deep yellow	Sparse or absent	166.1
Kobayashi39	Yellow	Sparse or absent	106.9
Hongyang[c]	Yellow, partly red	Absent	77.6
Hort16A[d]	Yellow	Sparse or absent	104.4
A. rufa			
Awaji	Deep green	Absent	9.4
Nagano	Deep green	Absent	16.4
A. arguta			
Hirano	Green	Absent	6.5
Gassan	Green	Absent	11.3
Issai	Green	Absent	7.8
Mitsuko	Green	Absent	10.1
Ananasnaya[e]	Green	Absent	6.5
A. arguta × *A. deliciosa*			
Kosui[f]	Deep green	Absent	37.8
Shinzan	Deep green	Absent	20.6

[a]Synonymous with "Koshin" or "Red princess."
[b]Synonymous with "Applekiwi" or "Kaimitsu."
[c]Synonymous with "Rainbow red."
[d]Known commercially as ZESPRI^{TM} GOLD Kiwifruit.
[e]Known commercially as "Baby kiwi."
[f]Recent study using RAPD analysis suggested *A. rufa*, not *A. arguta*, is involved in the parentage.
Values are means ± SD ($n = 24$).

(Ferguson, 1999). In this chapter, however, the name "Ananasnaya" is used for this *A. arguta* cultivar.

"Kosui" (Figure 1) is a cultivar released from Kagawa Agricultural Experiment Station in Japan. The fruit have an intermediate size between that of kiwifruit and *A. arguta* fruit (Table I). The average soluble solid content of the ripe fruit is 17%, with a maximum of 21%. "Kosui" is reported to be an interspecific hybrid between *A. arguta* "Issai" and *A. deliciosa* "Matua." However, a study using random amplified polymorphic DNA (RAPD) analysis suggested the possibility that *A. rufa* is involved in the parentage of this cultivar (Kokudo *et al.*, 2003).

Recently, several novel *A. arguta* cultivars have been developed. They include "Hortgem Tahi," "Hortgem Toru," "Hortgem Wha," and "Hortgem Rua" which were developed in New Zealand (Williams *et al.*, 2003), and "Chiak" in Korea (Jo *et al.*, 2007b). These fruit might enter the international trade arena in the near future.

D. *A. RUFA*

In Japan and Korea, *A. rufa* is distributed wild (Ferguson, 1991). Mature fruit have hairless brown skin and weight of 8–20 g. *A. rufa* fruit have several unique characteristics, such as high quinic acid and low protease contents (Kim *et al.*, 2007; Nishiyama *et al.*, 2007a). These characteristics make *A. rufa* valuable genetic resources for crossbreeding of *Actinidia* plants.

E. OTHER *ACTINIDIA* SPECIES

The *A. eriantha* fruit are long and cylindrical. The fruit surface is densely covered with white villose. They have easily peeled skin, and the flesh is jade green. Although *A. eriantha* fruit are typically tart and not so palatable, a new cultivar, "Bidan," which was developed quite recently in Korea, is reportedly sweet (Jo *et al.*, 2007a).

Several desirable attributes of another species, *A. kolomikta*, are its cold-hardiness, precocity, and extraordinary high vitamin C content. For those reasons, it might be a useful genetic resource for cultivar development in *Actinidia* species.

Other *Actinidia* species are presently underutilized, but they remain potentially useful genetic resources. Characteristics of other species are detailed elsewhere by Huang *et al.* (2003) and Ferguson and Huang (2007).

III. FRUIT COMPONENTS

A. SUGAR AND SUGAR ALCOHOL

Sugar content is a basic parameter in evaluating fruit market quality attributes. For rough estimation of total soluble sugar content, total soluble solids are measured using refractometry as a convenient method. The total soluble solid content of mature "Hayward" fruit juice is 13–15%. The levels of soluble solids in eating-ripe fruit are generally higher in "Koryoku," "Sanryoku," "Hongyang," and "Kosui," compared with "Hayward," although it might be affected by several environmental factors.

Compositions of soluble sugars and sugar alcohols in kiwifruit have been determined using HPLC (Pérez *et al.*, 1997), gas chromatography (Sanz *et al.*, 2004), and electrochemical biosensors (Esti *et al.*, 1998). The main soluble sugars in "Hayward" fruit are glucose and fructose, whereas sucrose is present in smaller amounts. Glucose and fructose are present in almost equal amounts. The concentrations of glucose and fructose are approximately 3–5 g/100 g fresh weight (FW); that of sucrose is 0.7–1.5 g/100 g FW (Pérez *et al.*, 1997; Sanz *et al.*, 2004).

"Hayward" fruit also contain *myo*-inositol, a hexahydric sugar alcohol. The *myo*-inositol level in the "Hayward" fruit, which was reported to be 153 mg/100 g FW, is higher than commonly consumed fruits, including orange, grapefruit, and mandarin orange (Sanz *et al.*, 2004).

The sugar composition in *A. chinensis* fruit resembles that of "Hayward." Glucose and fructose are the predominant soluble sugars in fruits of most *A. chinensis* genotypes (Esti *et al.*, 1998).

The composition of soluble sugars in *A. arguta* fruit differs greatly from those in *A. deliciosa* and *A. chinensis* fruit. *A. arguta* fruit contain 5.0–9.5 g/100 g FW sucrose as a predominant soluble sugar, and glucose and fructose at concentrations of 0.8–2.0 g/100 g FW (Nishiyama *et al.*, in preparation). The difference in soluble sugar composition between *A. arguta* fruit and kiwifruit might cause a difference in the sweetness of these fruit even if they have the same soluble sugar content.

In addition, *A. arguta* fruit contain *myo*-inositol at high concentrations of 0.65–1.05 g/100 g FW (Nishiyama *et al.*, in preparation). Klages *et al.* (1997) suggested that part of the *myo*-inositol in the fruit might be synthesized in the fruit, whereas some of *myo*-inositol might be translocated from the phloem as a minor component. These fruit are considered to be the richest dietary source of *myo*-inositol among commonly consumed foods including fruits, vegetables, beans, grains, nuts, fish, and meats (Clements and Darnell, 1980). Although the nutritional significance of *myo*-inositol has not been established, it is classified as a member of vitamin B complex and the high content of *myo*-inositol might be a strength of *A. arguta* fruit.

B. ORGANIC ACIDS

Acidity of fruits is an important factor that affects the sensory characteristics because the taste of fruits is determined primarily by the sugar–acid balance. Importance of some organic acids, such as citric and malic acids, to the production of energy in the body is well established. In addition, high fruit acidity might play a preventive role against proliferation of microorganisms and might contribute toward their long storage life. Ascorbic acid is an important component of the fruit both as vitamin C and as an antioxidant factor. For that reason, it will be addressed separately in the next section.

The major organic acids in "Hayward" fruit are citric, quinic, malic, and ascorbic acids. Among them, citric and quinic acid concentrations are higher than those of malic and ascorbic acids. The respective concentrations of citric, quinic, and malic acids in eating-ripe "Hayward" fruit are 0.99–1.29, 0.74–1.18, and 0.08–0.19 g/100 g FW (Marsh *et al.*, 2003, 2004). According to MacRae *et al.* (1989), these organic acids are not distributed uniformly among "Hayward" fruit. Citric acid is highest in the inner cortex and quinic acid is highest in the outer cortex. The core has the lowest total acid content in the fruit.

These organic acids cause different perceptions of acidity. At equivalent molar concentrations, quinic acid has a greater impact on the perception of acidity than malic or citric acids (Marsh *et al.*, 2003). The proportion of these organic acids appreciably changes during fruit ripening depending on the storage temperature (Marsh *et al.*, 2004). Therefore, the fruit taste might be influenced by storage conditions.

In other *A. deliciosa, A. chinensis*, and *A. rufa* fruits, the compositions of organic acids are fundamentally equivalent to those in "Hayward." In *A. arguta* fruit, the concentrations of quinic acid are 0.60–0.71 g/100 g FW: somewhat lower than that in "Hayward" (Nishiyama *et al.*, in preparation).

The predominant organic acids in commonly consumed fruit are citric and/or malic acids. *Actinidia* fruits are unusual in that quinic acid levels are similar to that of citric acid as the predominant organic acid. Although the nutritional importance of quinic acid has not been established, it is an intensely interesting compound because it is a key intermediate for aromatic compound biosynthesis via the shikimic acid pathway. Moreover, quinic acid is a component of several potent free radical scavengers, including chlorogenic acid.

C. VITAMIN C

Humans, in common with other primates, are incapable of vitamin C biosynthesis. For that reason, this nutrient must be obtained from dietary sources. Vitamin C is well known to be essential for capillary and blood vessel integrity and cartilage and bone development because it is required for collagen biosynthesis (Ball, 2005).

Aside from its role as a vitamin, vitamin C has various physiological and pharmacological effects. Vitamin C improves the bioavailability of iron by facilitating its absorption in the intestine. It also prevents formation of carcinogenic nitrosamines in the stomach (Bender, 2003). Vitamin C acts as a radical trapping antioxidant and plays an important role in the defense against cellular damage by oxidants (Ball, 2005). Therefore, increased intake of vitamin C is associated with reduced risks of certain diseases, including cancer and cardiovascular diseases.

The most active form of vitamin C, L-ascorbic acid (AA), is a labile substance that is readily oxidized to L-dehydroascorbic acid (DHAA), mainly through activity of L-ascorbate oxidase and reaction with oxygen in the presence of heavy metal ions and light (Gregory, 1996). Although DHAA itself does not exhibit vitamin C activity, its biological activity has been considered to be equivalent to AA because it can be converted readily in the human body into AA by either NADPH or glutathione-dependent reductases (Bender, 2003). Vitamin C activity is lost when DHAA is further oxidized to 2,3-diketo-L-gulonic acid because of the irreversibility of this reaction (Gregory, 1996). Therefore, vitamin C content in food is usually expressed as the sum of AA and its partially oxidized form, DHAA.

Table II shows the contents of vitamin C, which is designated as the sum of AA and DHAA, in the fruits of several *Actinidia* cultivars (Nishiyama *et al.*, 2004b). "Hayward" fruit contain 65.5 mg/100 g FW vitamin C. The 2000 Dietary Intake values for vitamin C are 75 mg/day for women and 90 mg/day for men. Therefore, intake of one average-sized "Hayward" fruit a day supplies about 70–90% of the required vitamin C. Among cultivars of *A. deliciosa*, "Abbott" fruit show the lowest vitamin C concentration; fruit of "Bruno" show the highest.

Actinidia fruits are an excellent dietary source of vitamin C. Vitamin C contents in *Actinidia* fruits vary from less than 10 mg/100 g FW to more than 2000 mg/100 g FW (Huang *et al.*, 2003). Among the species, the highest vitamin C content is observed in *A. latifolia* fruit (671–2140 mg/100 g FW), followed by *A. eriantha* fruit (500–1379 mg/100 g FW), although they are not commercial crops (Huang *et al.*, 2003). The vitamin C contents of *A. deliciosa, A. chinensis*, and *A. arguta* fruits are distributed respectively in the ranges of 50–250, 50–420, and 81–430 mg/100 g FW (Ferguson, 1991; Ferguson and MacRae, 1991; Huang *et al.*, 2003; Nishiyama *et al.*, 2004b; Rassam and Laing, 2005).

In most cultivars of *A. chinensis*, vitamin C contents tend to be higher than *A. deliciosa*. For example, the vitamin C content of "Hort16A" fruit is about 1.6 times that in "Hayward" fruit. Among the *A. chinensis* fruits,

TABLE II

CONCENTRATION OF VITAMIN C IN FRUIT OF *ACTINIDIA* GENOTYPES

Species genotype	Concentration (mg/100 g fresh weight)[a]	Ratio to Hayward
A. deliciosa		
Hayward	65.5 ± 14.2	1.00
Bruno	80.0 ± 16.8**	1.22
Abbott	29.2 ± 5.5**	0.45
Elmwood	47.0 ± 4.4**	0.72
Koryoku	39.9 ± 4.0**	0.61
A. deliciosa × *A. chinensis*		
Sanryoku	75.0 ± 9.0	1.15
A. chinensis		
Jiangxi 79-1	73.7 ± 19.9	1.13
Golden king	144.2 ± 16.5**	2.20
Kuimi	157.1 ± 36.4**	2.40
Sanuki gold	205.8 ± 19.8**	3.14
Kobayashi 39	129.1 ± 16.2**	1.97
Hongyang	64.4 ± 10.0	0.98
Hort16A	103.7 ± 13.1**	1.58
A. rufa		
Awaji	25.5 ± 3.3**	0.39
Nagano	47.1 ± 6.4**	0.72
A. arguta		
Hirano	37.3 ± 10.9**	0.57
Gassan	141.0 ± 24.2**	2.15
Issai	184.6 ± 23.4**	2.82
Mitsuko	150.6 ± 33.0**	2.30
A. arguta × *A. deliciosa*		
Kosui	40.9 ± 9.4**	0.62
Shinzan	99.8 ± 32.1**	1.52

[a]Values are means ± SD of 12 experiments.

**: Significantly different vs "Hayward" at $p < 0.01$.

Reprinted with modification from Nishiyama *et al.* (2004b, Table III) with permission.

"Sanuki gold" fruit contain an exceptionally large amount of vitamin C. The concentration is more than three times that in "Hayward." Average-sized "Sanuki gold" fruit are 1.7 times larger than that of "Hayward." Therefore, they contain about five times more vitamin C than "Hayward."

In *A. rufa* fruit, vitamin C contents are low among the *Actinidia* fruits. However, they are excellent sources of vitamin C among commercially available fruit. The vitamin C contents in fruit of *A. arguta* and its interspecific hybrids show wide variation within species. Vitamin C contents are extremely high in "Gassan," "Issai," "Mitsuko," and "Shinzan" fruit. In contrast, "Hirano" and "Kosui" fruits contain low levels of vitamin C.

Because *Actinidia* fruits contain high levels of vitamin C, they are attractive materials for nutritional juice production. However, high vitamin C can cause nonenzymic browning in juice products during storage (Wong and Stanton, 1989).

D. CALCIUM OXALATE

Kiwifruits of all varieties contain appreciable amounts of oxalate, which causes unpleasant oral irritation when ingested. They contain insoluble calcium oxalate as raphide crystals in idioblast cells. The fine, double-pointed needlelike crystals are the main cause of mechanical irritation of mucous membranes in the mouth (Perera *et al.*, 1990). The raphide crystals are usually embedded in mucilage within the idioblast cells in intact tissue, but they are released after the cells are broken off from tissue damage by chewing. When the kiwifruit flesh is processed into puree or nectars, more idioblast cells are broken and needlelike crystals are dispersed throughout the product, engendering more intense irritation than that by nonprocessed flesh. Dried or lyophilized fruit also cause unpleasant irritation because the mucilage in the idioblast cells shrinks during drying and some of the sharp crystals protrude from the dried mucilage matrix (Perera *et al.*, 1990).

Microscopic observation revealed that most raphide-containing idioblast cells are located in the locular region adjacent to the seed in *A. deliciosa* (Perera *et al.*, 1990), *A. chinensis, A. rufa*, and *A. arguta* fruits (Watanabe and Takahashi, 1998). Concurrent with those observations, quantitative analyses by Rassam and Laing (2005) showed that the inner pericarp contains the highest concentrations of oxalate, and the core and outer pericarp contain much lower levels among the edible parts of *A. chinensis* fruit. Oxalate is also observed at high concentrations in kiwifruit skin. The presence of high concentrations of oxalate in locules and skin support the idea that the component serves as a defensive factor to protect seeds and the fruit itself (Rassam and Laing, 2005; Rassam *et al.*, 2007).

The extent of the irritation caused by kiwifruit might be affected by several factors, including oxalate concentration, the shape of the raphides, the presence of cysteine protease "actinidin" (Boyes *et al.*, 1997), and the fruit acidity. Considerable variation exists among species in oxalate content and in the raphide shape. Total oxalate concentrations in fruits are estimated to be 37–65 mg/100 g FW in *A. deliciosa* (Perera *et al.*, 1990), 18–45 mg/100 g FW in *A. chinensis* (Rassam and Laing, 2005), and 5.0–8.5 mg/100 g FW in *A. arguta* (Watanabe and Takahashi, 1998). The length of raphides in *A. deliciosa* fruit is

0.4–0.5 mm, and 0.2–0.3 mm in *A. chinensis, A. arguta*, and *A. rufa* (Watanabe and Takahashi, 1998). However, the difference in the irritant sensation caused by the fruits of these species has not been quantified. Synergic effects of actinidin and acidity on calcium oxalate-induced irritation remain to be evaluated.

Aside from the unpleasant sensation, oxalic acid might cause adverse nutritional and pathological effects. Ingested oxalic acid binds calcium, and reduces its absorption in the intestine, resulting in a reduced bioavailability of calcium (Noonan and Savage, 1999). It is also considered that ingestion of a high oxalic acid diet can be a risk factor for kidney stone formation. However, oxalate concentrations in the *Actinidia* fruits described above correspond to only 1–10% of that in spinach on a weight-for-weight basis. Therefore, antinutritional properties of oxalate in *Actinidia* fruits seem to be negligible. Nevertheless, development of new *Actinidia* cultivars with lower oxalate content is expected, both for sensory and in nutritional aspects.

E. PIGMENTS

Actinidia fruits contain several types of pigment, including chlorophylls and carotenoids. The pigments in the fruits were initially studied using spectrophotometric methods or thin-layer chromatography (Fuke *et al.*, 1985; Possingham *et al.*, 1980). Recently, however, analyses of the pigments are performed exclusively by HPLC using a reversed-phase column. Thus far, chlorophylls and their degradative products, lutein, β-carotene, and some other carotenoids in the fruits, have been determined in several *Actinidia* species (Cano, 1991; Fuke *et al.*, 1985; McGhie and Ainge, 2002; Montefiori *et al.*, 2005; Nishiyama *et al.*, 2005). The pigment profiles in fruit of *A. deliciosa* closely resemble those in green leaves, but at much lower pigment concentration. Anthocyanins have also been determined in fruits of some *Actinidia* genotypes (Montefiori *et al.*, 2005; Seager, 1997).

1. Chlorophyll

Many fruits including tomato, orange, citrus, banana, and paprika are known to change color from green to yellow, orange, or red during ripening. This phenomenon is usually attributed to chlorophyll degradation and carotenoid synthesis, which are induced by ethylene (Schoefs, 2005). Therefore, chlorophyll is generally scarce in ripe fruit. Instead, yellow or red colors predominate due to the presence of carotenoids and anthocyanins. In contrast, chlorophylls in *A. deliciosa* fruit must be retained during ripening, giving them a rare deep green flesh even when ripe. Moreover, the low concentrations of chlorophyll pigments in their pericarp persist for several months during storage of the fruit.

Wide variation exists in chlorophyll contents between and within species (Nishiyama *et al.*, 2005, 2007). The chlorophyll content in *A. deliciosa* fruit

TABLE III

CONCENTRATION OF CHLOROPHYLLS IN FRUIT OF *ACTINIDIA* GENOTYPES

Species genotype	Concentration (mg/100 g fresh weight)[a]			Chlorophylls a + b
	Chlorophyll a	Chlorophyll b	Chlorophylls a + b	Ratio to Hayward
A. deliciosa				
Hayward	1.12 ± 0.20	0.53 ± 0.11	1.65 ± 0.31	1.00
Bruno	1.02 ± 0.18	0.44 ± 0.07	1.46 ± 0.25	0.88
Abbott	0.92 ± 0.15	0.41 ± 0.10	1.33 ± 0.24	0.81
Elmwood	1.28 ± 0.15	0.59 ± 0.08	1.87 ± 0.22	1.13
Koryoku	1.84 ± 0.57*	0.90 ± 0.23**	2.74 ± 0.80*	1.66
A. deliciosa × *A. chinensis*				
Sanryoku	1.59 ± 0.19	0.74 ± 0.06	2.33 ± 0.25	1.41
A. chinensis				
Jiangxi 79-1	Traces[b]	Traces	–	–
Golden king	0.10 ± 0.03**	Traces	–	–
Kuimi	0.20 ± 0.10**	0.07 ± 0.04**	0.27 ± 0.14**	0.16
Sanuki gold	0.07 ± 0.02**	Traces	–	–
Kobayashi39	0.26 ± 0.09**	0.08 ± 0.05**	0.34 ± 0.14**	0.21
Hongyang	0.53 ± 0.17*	0.20 ± 0.07**	0.73 ± 0.24*	0.44
Hort16A	0.07 ± 0.05**	Traces	–	–
A. rufa				
Awaji	2.83 ± 0.20**	1.37 ± 0.08**	4.20 ± 0.28**	2.55
Nagano	2.41 ± 0.18**	1.18 ± 0.09**	3.59 ± 0.28**	2.18
A. arguta				
Hirano	2.55 ± 0.89**	1.07 ± 0.28**	3.62 ± 1.17**	2.19
Gassan	2.41 ± 0.65**	0.98 ± 0.19**	3.39 ± 0.83**	2.05
Issai	2.32 ± 0.78**	0.99 ± 0.29**	3.31 ± 1.06**	2.01
Mitsuko	3.00 ± 0.90**	1.21 ± 0.29**	4.21 ± 1.19**	2.55
Ananasnaya	2.68 ± 0.67**	1.20 ± 0.16**	3.88 ± 0.80**	2.35
A. arguta × *A. deliciosa*				
Kosui	1.99 ± 0.22**	0.92 ± 0.19**	2.91 ± 0.40**	1.76
Shinzan	3.15 ± 0.55**	1.24 ± 0.23**	4.39 ± 0.79**	2.66

[a]Values are means ± SD of eight experiments.
[b]Concentration below the limit of detection (<0.05).
*, **: Significantly different vs "Hayward" at $p < 0.05$ and $p < 0.01$, respectively.
Reprinted with permission from Nishiyama *et al.* (2005, Table III).

ranges from 1.33 to 2.74 mg/100 g FW (Table III). The concentrations of chlorophyll in *A. deliciosa* fruit are about 2% or less than those of spinach, which contains 80–110 mg/100 g FW chlorophyll (Nishiyama, unpublished data). Of the *A. deliciosa* cultivars, "Koryoku" is the only one that showed a significantly higher chlorophyll concentration than "Hayward." The high chlorophyll concentration in "Koryoku" fruit is considered to be the main reason for its deep green flesh color.

In contrast to *A. deliciosa*, fruit of *A. chinensis* are usually, although not always, yellow-fleshed. As implied by their flesh color, the chlorophyll content in *A. chinensis* fruit is much lower than those in *A. deliciosa* fruit (Table III): chlorophyll concentrations in those fruits range from less than 0.05 to 0.73 mg/100 g FW. The low chlorophyll concentration in *A. chinensis* fruit is considered to be associated with the transition of chloroplast to chromoplast during fruit ripening (McGhie and Ainge, 2002). Fluorescence microscopic observation indicates that the remaining chloroplasts in *A. chinensis* fruit are localized mainly in the outermost region of the outer pericarp (Nishiyama *et al.*, unpublished data).

The chlorophyll concentrations in *A. rufa, A. arguta*, and their interspecific hybrid fruits are much higher than that in "Hayward." The chlorophyll contents of the fruits are 1.76–2.66 times that of "Hayward" on a weight-for-weight basis (Table III).

It is well established that chlorophyll molecules are converted easily into olive-brown pheophytins in acidic conditions. Degradation of the pigments in the acidic environment is markedly accelerated by heating (von Elbe and Schwartz, 1996). Kiwifruits contain high levels of organic acids. Thus, the chlorophyll in the fruits is readily degraded by intrinsic acidity when the fruits are macerated. Consequently, kiwifruit puree spontaneously loses its green color. Processing of kiwifruit through thermal treatment thoroughly degrades chlorophyll (Cano and Marín, 1992). Freezing and thawing processes also induce serious degradation of chlorophyll molecules in the kiwifruits (Cano and Marín, 1992; Venning *et al.*, 1989). Therefore, kiwifruit lose their green color, which is the most prominent feature of the fruit, when they are canned or processed into juice, jam, or sauce (Robertson and Swinburne, 1981). Although freeze-drying is a good option to stabilize the green color of the fruit, the application of the method is limited. The degradation of chlorophyll during kiwifruit processing is a serious issue to be solved.

2. *Carotenoids*

Actinidia fruits contain several types of carotenoids, including violaxanthin, neoxanthin, lutein, and β-carotene, which are identical components to those generally found in green leaves (Cano, 1991; McGhie and Ainge, 2002; Montefiori *et al.*, 2005; Nishiyama *et al.*, 2005, 2007). These carotenoids are important both as colorants and as health-promoting constituents. After ingestion, β-carotene is converted *in vivo* into vitamin A, which is necessary for normal retinal function. Carotenoids have potent antioxidant activity

(Young *et al.*, 2004), and a higher dietary intake of carotenoids is associated with a lower risk of cardiovascular disease, cataract, age-related macular degeneration, and certain types of cancer (Block *et al.*, 1992; Giovannucci, 1999; Granado *et al.*, 2003; Kritchevsky, 1999; Rock, 2004; Seddon *et al.*, 1994; Sesso and Gaziano, 2004; van Poppel, 1996).

A considerable variation exists in carotenoid contents among species. The concentrations of lutein and β-carotene in "Hayward" fruit are 0.418 and 0.088 mg/100 g FW, respectively. Among *A. deliciosa* fruit, the fruits of "Koryoku" and "Sanryoku" have markedly higher lutein concentrations than "Hayward" (Table IV). Lutein concentrations of commonly consumed fruits are estimated to be less than 0.15 mg/100 g FW (Hart and Scott, 1995; Tee and Lim, 1991). Therefore, *A. deliciosa* fruits are the richest dietary source of lutein among commonly consumed fruits. The high lutein contents of *A. deliciosa* fruit are probably attributable to the remaining chloroplasts in the fruit. This idea is strongly supported by the fact that a significant positive correlation exists between the concentration of lutein or β-carotene and that of total chlorophyll (Nishiyama *et al.*, 2005).

In most *A. chinensis* genotypes, the lutein contents are much lower than that in "Hayward" and other green-fleshed cultivars, whereas the β-carotene contents are almost of the same or of a slightly higher level than that in "Hayward" (Table IV). These data suggest that the yellow flesh color of *A. chinensis* is mainly attributable to the absence of chlorophyll from the fruit instead of an abundance of these carotenoids.

As implied by the higher chlorophyll content, both lutein and β-carotene contents in *A. rufa, A. arguta*, and their interspecific hybrids are much higher than those in "Hayward." The respective concentrations of lutein and β-carotene in these fruits are 0.736–1.082 mg/100 g FW and 0.143–0.285 mg/100 g FW (Table IV). The data indicate that these fruits are outstanding dietary sources of lutein among fruits. Particularly, *A. arguta* fruit are an extremely convenient lutein source because they have a soft and edible skin, which has a higher lutein concentration than the pulp. Therefore, whole *A. arguta* fruit contain about 1.4 times more lutein than those without skin on a weight-for-weight basis (Nishiyama *et al.*, 2007).

Additional information about the contents of other carotenoids including violaxanthin, neoxanthin, zeaxanthin, and β-cryptoxanthin in *Actinidia* fruits are available elsewhere (Cano, 1991; McGhie and Ainge, 2002; Montefiori *et al.*, 2005).

Carotenoids are chemically more stable than chlorophyll. Freezing and thawing of the food causes little change in the carotenoid content. Thermal processing has minimal effect on the carotenoid content (Boileau and Erdman, 2004; Updike and Schwartz, 2003). However, thermal treatments of food induce isomerization of carotenoids from *trans* to *cis* isomers, thereby decreas-

TABLE IV

CONCENTRATION OF LUTEIN AND β-CAROTENE IN FRUIT OF *ACTINIDIA* GENOTYPES

	Lutein		β-Carotene	
Species genotype	(mg/100 g fresh weight)[a]	Ratio to Hayward	(mg/100 g fresh weight)[a]	Ratio to Hayward
A. deliciosa				
Hayward	0.418 ± 0.082	1.00	0.088 ± 0.013	1.00
Bruno	0.434 ± 0.063	1.04	0.094 ± 0.014	1.07
Abbott	0.398 ± 0.101	0.95	0.085 ± 0.009	0.97
Elmwood	0.569 ± 0.104	1.36	0.093 ± 0.017	1.06
Koryoku	0.897 ± 0.138**	2.15	0.150 ± 0.036**	1.70
A. deliciosa × *A. chinensis*				
Sanryoku	0.691 ± 0.056**	1.65	0.110 ± 0.015	1.25
A. chinensis				
Jiangxi 79-1	0.107 ± 0.026**	0.26	0.115 ± 0.015	1.31
Golden king	0.087 ± 0.015**	0.21	0.121 ± 0.017	1.38
Kuimi	0.152 ± 0.032**	0.36	0.097 ± 0.019	1.10
Sanuki gold	0.117 ± 0.012**	0.28	0.150 ± 0.037**	1.70
Kobayashi39	0.144 ± 0.025**	0.34	0.081 ± 0.007	0.92
Hongyang	0.404 ± 0.072	0.97	0.123 ± 0.016	1.39
Hort16A	0.155 ± 0.030**	0.37	0.066 ± 0.008	0.75
A. rufa				
Awaji	0.926 ± 0.050**	2.22	0.177 ± 0.012**	2.01
Nagano	0.876 ± 0.061**	2.10	0.145 ± 0.017**	1.65
A. arguta				
Hirano	0.786 ± 0.209**	1.88	0.224 ± 0.049**	2.54
Gassan	0.746 ± 0.140**	1.78	0.227 ± 0.048**	2.58
Issai	0.799 ± 0.178**	1.91	0.247 ± 0.019**	2.80
Mitsuko	0.933 ± 0.214**	2.23	0.245 ± 0.033**	2.78
Ananasnaya	0.762 ± 0.132**	1.82	0.285 ± 0.041**	3.23
A. arguta × *A. deliciosa*				
Kosui	0.736 ± 0.074**	1.76	0.143 ± 0.007**	1.62
Shinzan	1.082 ± 0.172**	2.59	0.269 ± 0.022**	3.05

[a]Values are means ± SD of eight experiments.

**: Significantly different vs "Hayward" at $p < 0.01$.

Reprinted with permission from Nishiyama *et al.* (2005, Table IV).

ing provitamin A activity (von Elbe and Schwartz, 1996). Regardless of isomerization, processed products such as jams and juices made from *Actinidia* fruits are promising dietary sources of these carotenoids.

3. *Anthocyanins*

Most people recognize that the kiwifruit flesh color is green or yellow, thus the presence of red pigments in kiwifruits is surprising. Although red pigments occur in the inner pericarp of fruits of several genotypes in *A. deliciosa* and *A. chinensis* (Montefiori *et al.*, 2005), "Hongyang" (Wang *et al.*, 2003) is the only commercially grown cultivar. Recently, a novel red-fleshed cultivar "Chuhong" was released from China (Zhong *et al.*, 2007). Development of new cultivars of red-fleshed *A. chinensis* and *A. deliciosa* has now progressed mainly in China and New Zealand.

The red pigment is water-soluble, and turns pale blue under alkaline conditions. Consequently, the red pigment in the *Actinidia* fruits has been believed to be anthocyanins. Liquid chromatography-mass spectrometry analyses revealed that the major anthocyanins are cyanidin 3-*O*-xylo-(1-2)-galactoside in *A. chinensis* fruit and cyanidin 3-*O*-galactoside and cyanidin 3-*O*-glucoside in *A. deliciosa* fruit (Montefiori *et al.*, 2005).

Anthocyanin compounds have been reported to exhibit antioxidative (Pool-Zobel *et al.*, 1999; Tsuda *et al.*, 1996), antimutagenic (Yoshimoto *et al.*, 1999, 2001), antidiabetic (Jayaprakasam *et al.*, 2005; Matsui *et al.*, 2002), and anticarcinogenic (Hou *et al.*, 2004; Kamei *et al.*, 1995) activities. Although anthocyanins in red-fleshed kiwifruit offer potential health benefits, those benefits should not be overestimated because anthocyanin concentrations in kiwifruit are only 10% or less than those in whole blueberry fruits (Montefiori *et al.*, 2005). Instead, the principal benefit of these pigments in red-fleshed kiwifruit is aesthetic, to foster commercial appeal. Attractiveness of "Hongyang" fruit was actually evidenced by an experimental market method (Jaeger and Harker, 2005), which showed that consumers were willing to pay a considerable price premium for the fruit.

F. ACTINIDIN

It is a well-established household fact that raw kiwifruit prevent setting of gelatin-based food such as table jelly and bavarois. This phenomenon is attributable to large amounts of protease in the fruit. The protease was first characterized by Arcus (1959) and named "Actinidin" after the generic name "*Actinidia*." Later, biochemical and enzymological properties of actinidin (EC 3.4.22.14) were studied extensively by several investigators.

Actinidin is a cysteine protease that requires a free sulfhydryl group for activity (Arcus, 1959; McDowall, 1970). This protease is composed of 220 amino acid residues with molecular mass of 23,500 (Carne and Moore, 1978). The amino acid sequence of the enzyme shows considerable homology with papain, a well-known cysteine protease in immature papaya fruit (Carne and

Moore, 1978). The conformation of the polypeptide chain is also remarkably similar to that of papain (Baker, 1977). Actinidin is thus classified in a member of the papain superfamily, which includes papain and bromelain, and the mammalian cathepsins B, K, and L. The optimal pH of actinidin is about 4 when using food proteins such as gelatin (Arcus, 1959) or myofibrillar proteins (Nishiyama, 2001) as the substrate. The optimal pH is around 6 when the enzyme activity is measured with synthetic peptides as the model substrates (Boland and Hardman, 1972; Boyes *et al.*, 1997; McDowall, 1970; Sugiyama *et al.*, 1997). Regardless of this accumulated knowledge, nothing is known as yet about the physiological function of actinidin in fruits.

In the biochemical field, "actinidin" is officially designated as "actinidain" because it is recommended by the International Union of Biochemistry and Molecular Biology (IUBMB) Enzyme Nomenclature List. However, the name "actinidin" is used widely all over the world in other fields including food science, horticulture, and medicine. It might become a cause of some confusion.

1. *Spatial distribution in the fruit*

Distribution of actinidin within kiwifruits has been reported in some *Actinidia* fruits (Boyes *et al*., 1997; Lewis and Luh, 1988a; Préstamo, 1995). The actinidin activity is observed mainly in outer and inner pericarp regions; very little activity is detected in the skin and the core. Longitudinal distribution of the enzyme has not been reported.

2. *Changes during fruit growth and ripening*

Concentrations of actinidin in kiwifruits were reported to increase rapidly during their growth. Therefore, immature thinned fruit contain only a small amount of actinidin, and are not utilizable as raw materials for producing actinidin products. The protease activity in the fruits doubles or triples during postharvest ripening (Lewis and Luh, 1988a). This phenomenon contrasts against the fact that papain in immature papaya fruit decreases to trace amounts during their maturation.

3. *Effects on food proteins*

Kiwifruit generally contain a large amount of actinidin. For that reason, they cannot be used satisfactorily as a food ingredient for protein-based foods. Particularly, gelatin is susceptible to actinidin (Arcus, 1959). Therefore, thermal treatment of kiwifruit flesh or juice is required to inactivate the protease prior to addition to gelatin jelly or bavarois. Heat treatment of kiwifruit, however, inevitably degrades its fresh flavor, bright green color, and nutrients such as vitamin C.

To solve that problem, Funaki *et al.* (1996) adopted oryzacystatin, an edible inhibitor for cysteine protease occurring in rice seed, for preventing hydrolysis of gelatin by actinidin. This method is of potential usefulness, but it has not become widespread. Perhaps it is simpler and easier to replace gelatin with some polysaccharide gelling agent such as agar or carageenan.

The proteolytic enzymes of plant origin, including papain, bromelain, and ginger proteases, have proteolytic effects on myofibrillar proteins and/or collagen. Therefore, these enzymes are used for meat tenderization (Lawrie, 1998). Among these enzymes, papain is the most widely used as a meat tenderizer. However, the enzyme treatment of meat tends to overtenderize the surface, producing a mushy texture, while leaving the interior unaffected (Lawrie, 1998).

Actinidin also possesses proteolytic activity on muscular proteins. It is useful as an effective meat tenderizer (Lewis and Luh, 1988b). Although the commercial utilization of actinidin as a meat tenderizer remains quite limited, it offers potential advantages. According to Nishiyama (2001), actinidin shows unique pH-dependence on hydrolysis of myofibrillar proteins (Figure 2). For pH of 3–4.5, actinidin thoroughly hydrolyzes all myofibrillar proteins, including myosin heavy chain and actin, in a nonspecific manner. In contrast, for pH of 5.5–8, actinidin hydrolyzes myosin heavy chain into fragments, whereas it showed little or no proteolytic effect on actin (Nishiyama, 2001). In contrast,

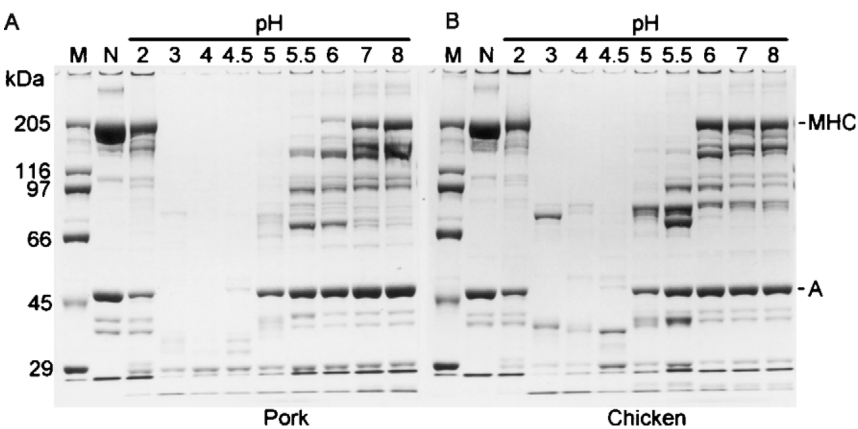

FIG. 2 Sodium dodecyl sulfate-polyacrylamide gel electrophoresis analysis of pork and chicken myofibrillar proteins treated with purified actinidin at various pH values. MHC, myosin heavy chain; A, actin. Reprinted with permission from Nishiyama (2001, Figs. 2 and 5A).

papain or bromelain nonselectively hydrolyzes all myofibrillary proteins in a wide pH range (Nishiyama, 2001). These results suggest that overtenderization of the meat surface can be controlled, to some extent, by regulating the pH condition in which the meat is treated with actinidin. Further experiments are necessary to elucidate the advantages of actinidin as a meat tenderizer.

Although actinidin has no collagenase activity, it cleaves the aterocollagen molecule of yellowfin tuna at specific sites inside the interstrand cross-linking peptide (Morimoto *et al.*, 2004). Sugiyama *et al.* (2005) also reported that kiwifruit juice degrades nonhelical domains of beef collagen. These effects of actinidin on collagen probably aid meat tenderization. Effects of kiwifruit juice on the organization of collagen fiber in muscular tissue was also confirmed by immunohistochemical studies using anticollagen antiserum (Nishiyama, 2000).

Actinidin also hydrolyzes α-casein and β-casein in milk (Nishiyama and Oota, 2002; Yamaguchi *et al.*, 1982). Bachmann and Farah (1982) demonstrated the occurrence of a bitter taste in mixtures of milk proteins and raw kiwifruit, which was attributed to a caseinolytic protease in kiwifruit splitting casein into bitter peptides.

4. Utilization for enzyme supplement

Actinidin vigorously hydrolyzes food proteins including myofibrillar proteins, gelatin, and milk proteins. Therefore, kiwifruit are expected to have a digestion-promoting effect. Actually, in New Zealand, currently marketed kiwifruit-derived dietary supplements such as "Zylax" and "Kiwi Crush" were developed as digestive enhancers. At pH 2 or below, however, actinidin exhibits low proteolytic activity and is rapidly inactivated (Nishiyama, 2001). Therefore, the digestion-promoting effect of kiwifruit must be highly dependent on the gastric pH.

5. Differences among cultivars

Varietal differences in actinidin contents were first reported by Préstamo (1995), and slight differences were observed among four *Actinidia* cultivars. Although Boyes *et al.* (1997) observed considerable variation in actinidin levels among *Actinidia* genotypes, most plant materials were not commercially grown cultivars but conserved strains. The first striking discovery about a commercially grown cultivar was that "Hort16A" fruit contain only a trace amount of actinidin (Nishiyama, 2000). Subsequently, wide variation in actinidin levels was found to exist among *Actinidia* genotypes (Nishiyama and Oota, 2002).

TABLE V

ACTINIDIN CONCENTRATION AND PROTEASE ACTIVITY IN FRUIT JUICE FROM *ACTINIDIA* GENOTYPES

Species genotype	Actinidin concentration (mg/ml)	Protease activity (nmol *p*NA released/min)
A. deliciosa		
Hayward	2.91 ± 0.18	6.34 ± 0.78
Bruno	3.13 ± 0.12	5.59 ± 0.23
Abbott	3.89 ± 0.14**	10.2 ± 0.99*
Elmwood	3.05 ± 0.14	5.75 ± 0.18
Koryoku	4.35 ± 0.11**	11.9 ± 0.53**
A. deliciosa × *A. chinensis*		
Sanryoku	3.16 ± 0.24	7.66 ± 0.29
A. chinensis		
Jiangxi 79-1	2.80 ± 0.13	5.47 ± 0.17
Golden king	2.55 ± 0.06	5.92 ± 0.21
Kuimi	5.74 ± 0.28**	13.3 ± 1.56*
Sanuki gold	6.10 ± 0.53**	15.1 ± 0.77**
Kobayashi39	2.60 ± 0.20	6.73 ± 0.92
Hongyang	ND	0.44 ± 0.02**
Hort16A	ND	0.42 ± 0.02**
A. rufa		
Awaji	ND	0.84 ± 0.15**
Nagano	ND	0.82 ± 0.12**
A. arguta		
Hirano	10.7 ± 1.36**	166 ± 7.38**
Gassan	10.6 ± 1.61**	115 ± 25.4**
Issai	1.64 ± 0.55**	25.7 ± 7.63**
Mitsuko	9.27 ± 2.55**	114 ± 29.6**
Ananasnaya	5.35 ± 1.02**	113 ± 1.8**
A. arguta × *A. deliciosa*		
Kosui	ND	0.38 ± 0.04**
Shinzan	4.95 ± 0.18**	208 ± 4.38**

*$p < 0.01$; **$p < 0.001$ vs the corresponding value of Hayward; ND, not detected.
Each value represents mean ± SE of at least six experiments.
Reprinted with modification from Nishiyama and Oota (2002, Table II), Nishiyama *et al.* (2004a, Table II), and Yamanaka *et al.* (2004, Table II) with permission.

In *A. deliciosa, A. chinensis*, and their interspecific hybrid, actinidin concentrations in the fruit juice range from trace amounts to 6.1 mg/ml (Table V and Figure 3). "Abbott," "Koryoku," "Kuimi," and "Sanuki gold" exhibit considerably higher actinidin concentration compared to "Hayward." In contrast, "Hongyang" and "Hort16A" fruit contain very little actinidin. In *A. rufa* fruit, the actinidin content is below the detection limit. In *A. arguta*

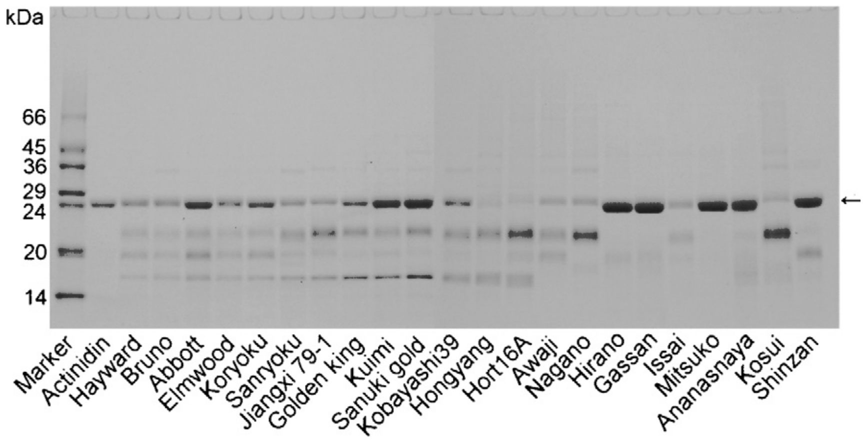

FIG. 3 Sodium dodecyl sulfate-polyacrylamide gel electrophoresis analysis of actinidin in fruit juice of *Actinidia* genotypes. The arrow indicates actinidin.

and its interspecific hybrids, actinidin concentrations in fruit juice are markedly higher in "Hirano," "Gassan," "Mitsuko," "Ananasnaya," and "Shinzan" than that in "Hayward." In contrast, "Kosui" fruit contain only trace amounts of actinidin. However, the low content of actinidin in "Kosui" fruit might be an inherited trait from some *A. rufa* genotype because a study using RAPD analysis suggested that *A. rufa*, not *A. arguta*, is involved in the parentage of this cultivar (Kokudo *et al.*, 2003).

Because the amount of actinidin in the fruits might affect the taste (Boyes *et al.*, 1997), digestion-promoting effect, allergenic properties (Pastorello *et al.*, 1998), and characteristics for processing the fruit, it is probably an important index of fruit quality. Fruits of cultivars with higher actinidin content are expected to have higher digestion-promoting effects. In addition, they are promising as raw materials for industrial manufacture of actinidin products such as a meat tenderizer and a digestive enhancer. On the other hand, fruits of cultivars with trace amounts of actinidin are suitable as ingredients of protein-based foods.

Although the effects of actinidin on the taste of kiwifruit have not been well established, it is speculated that the enzyme causes a tingling sensation in the lips, mouth, tongue, and throat. Therefore, the higher actinidin content might, to some extent, adversely affect the fruit taste. However, fruits with high actinidin levels, such as those of "Sanuki gold" and *A. arguta*, apparently do not cause a more irritating sensation than "Hayward" fruit. Further experiments are necessary to clarify the relationship between actinidin concentration and taste of the fruit.

Whereas actinidin in "Hayward" fruit has been studied intensively, the analogous protease in *A. arguta* fruit has rarely been studied biochemically. The protein with an apparent molecular mass of 24,500 in *A. arguta* fruit (Figure 3) is detectable using immunoblot analysis using antiactinidin antiserum, which does not bind to the analogous proteases such as papain and bromelain (Nishiyama and Oota, 2002). Therefore, it is tentatively regarded as actinidin at the present time.

However, a distinct difference exists in enzymological properties of these two proteases. The protease activity in the juice of *A. arguta* and its interspecific hybrid fruits is 18–33 times that of "Hayward," even though actinidin concentration is merely 1.7–3.7 times greater (Nishiyama *et al.*, 2004a; Table V). Moreover, a purified protease in "Shinzan" fruit exhibits decidedly different specificities toward synthetic peptide substrates compared to actinidin purified from "Hayward" fruit (Nishiyama *et al.*, 2004a; Table VI).

Actinidin reportedly consists of two (McDowall, 1973) or six (Sugiyama *et al.*, 1996) closely related components. Therefore, both the "purified" actinidin from "Hayward" and that from "Shinzan" might consist of several isozymes. If it was the case, the difference in the substrate specificity between actinidin and the protease from "Shinzan" might be explained using the difference in the proportion of each isozyme. Otherwise, the protease in *A. arguta* fruit must be regarded as a distinct protease that is related closely to actinidin; the enzyme should perhaps be given a different name such as "argutain."

G. OTHER COMPONENTS

Among fresh fruits, "Hayward" fruit are considered to have large amounts of vitamin E (1–2 mg/100 g FW). Although vitamin E possesses health benefits such as antioxidant activity, kiwifruit do not seem to be a good

TABLE VI

COMPARISON OF SUBSTRATE SPECIFICITY BETWEEN ACTINIDIN AND A PROTEASE PURIFIED FROM "SHINZAN"

	Specific activity of protease (nmol *p*NA released/min/mg protein)	
Substrate	Actinidin	Protease from Shinzan
Bz-Arg *p*NA	1.22	14.8
Pyr-Phe-Leu *p*NA	35.5	367
Bz-Phe-Val-Arg *p*NA	1460	420

Reprinted with modification from Nishiyama *et al.* (2004a, Table III) with permission.

dietary source of the vitamin because it is probably localized in the seeds (Ferguson and Ferguson, 2003).

Kiwifruit are a rich source of dietary fiber among fresh fruits and vegetables. ‘‘Hayward’’ fruit contain about 2–3 g/100 g FW dietary fiber, which is probably responsible for the mild laxative properties of the fruit (Rush *et al.*, 2002).

Kiwifruit are also a rich dietary source of potassium. Dietary potassium has been associated with prevention of hypertension, apoplexy, and osteoporosis. An average-sized ‘‘Hayward’’ fruit contains 200–300 mg potassium, which supplies about 10–15% of the daily requirement.

Varietal differences in the contents of these health-associated components have thus far not been fully investigated.

IV. ALLERGENIC PROPERTIES

Acute allergy to kiwifruit was first described by Fine (1981), and kiwifruit have now become a major elicitor of plant food allergies (Lucas *et al.*, 2003; Mills *et al.*, 2004). It is also reported that kiwifruit allergies are often cross-reactive with other allergies such as those to pollens, rye, hazelnut, chestnut, banana, and avocado (Lucas *et al.*, 2003). Pastorello *et al.* (1998) revealed that the major allergen of *A. deliciosa* ‘‘Hayward’’ is actinidin, which is designated Act c 1 according to the allergen nomenclature. This finding engendered the speculation that fruit of ‘‘Hort16A,’’ which contain extremely low levels of actinidin, are much less allergenic than those of ‘‘Hayward.’’

However, it is not as simple as that. A study (Bublin *et al.*, 2004) revealed that ‘‘Hort16A’’ fruit contain chitinase-related protein as a novel allergen in addition to allergens that are commonly found in ‘‘Hayward’’ fruit: phytocystatin and thaumatin-like protein (Act c 2). It has also been demonstrated that patients who are allergic to ‘‘Hayward’’ fruit face a high risk of allergy to ‘‘Hort16A’’ (Lucas *et al.*, 2005). A recent *in vitro* study has suggested that some kiwifruit-allergic individuals might suffer allergic cross-reactions if they consume raw *A. arguta* fruit (Chen *et al.*, 2006). These results give rise to the speculation that ‘‘Hongyang’’ and ‘‘Kosui’’ fruits might not be free from allergenic risk even though they contain very low concentrations of actinidin. Allergenic properties of each *Actinidia* cultivar should be examined carefully in future studies.

Although *Actinidia* fruits are consumed principally as a fresh fruit, they are also used as a component in some processed foods including beverages and jam. Fiocchi *et al.* (2004) demonstrated that heat-treatment and homogenization of ‘‘Hayward’’ fruit extremely, but not completely, reduces their allergenicity. Reduced allergenicity of *A. arguta* pulp by heat-treatment has also been suggested in results of an *in vitro* IgE binding study (Chen *et al.*, 2006). In contrast, lyophilization does not seem to be able to reduce kiwifruit allergenicity (Mempel *et al.*, 2003).

V. HEALTH BENEFITS

Kiwifruit contain several health-beneficial constituents. Among the components, antioxidants such as vitamin C, vitamin E, carotenoids, and polyphenolics are considered to be the main factors responsible for health-promoting properties of kiwifruit. Although antioxidant activities of these components have been well established through *in vitro* studies, direct effects of kiwifruit consumption on oxidative stress in human cells has been scarcely studied. Collins *et al.* (2001, 2003) have shown that kiwifruit supplementation provides dual protection against oxidative DNA damage, enhancing antioxidant levels and stimulating cellular DNA repair. A similar effect of kiwifruit consumption on cellular protection against DNA damage has been shown by Rush *et al.* (2006). These results suggest that consumption of kiwifruit protects against a kind of DNA damage that has been shown to cause mutations through miscoding (Shibutani and Grollman, 1994) and that therefore might be responsible for initiating carcinogenesis (Collins *et al.*, 2003).

Kiwifruit might also provide protective effects against cardiovascular diseases. According to Duttaroy and Jørgensen (2004), consuming two or three kiwifruits per day for 28 days significantly reduces platelet aggregation response and plasma triacylglycerol levels in human volunteers. The antiplatelet potential of the kiwifruit is probably unrelated to its antioxidant activity, and the antiplatelet factor(s) in the kiwifruit remain to be elucidated.

Kiwifruit apparently have laxative effects and relieve constipation. However, reliable scientific data on the laxative effect of kiwifruit remain limited. Rush *et al.* (2002) showed that, for elderly persons, ingestion of an adequate amount of kiwifruit enhances various parameters of laxation, including frequency and ease of defecation, stool bulk and softness. This laxative effect of kiwifruit is probably caused mainly by dietary fiber in the fruit (Rush *et al.*, 2002).

VI. PERSPECTIVES

As a consequence of active development of new *Actinidia* cultivars in several countries, some novel fruits are anticipated soon in international markets.

These fruits, in combination with the preexisting varieties, show a wide diversity of sensory and nutritional attributes such as taste, shape, hairiness, flesh color, vitamin C level, and carotenoid content. This will provide greater choice for the consumers. They will also vary in storageability and transportability, which are of particular concern to producers and retailers. In addition, we have to pay attention to the differences in allergenic properties of these fruits. The extensive genetic diversity within the genus *Actinidia* ensures cultivar development by conventional selection and breeding methods without using genetic modification technology, which would be likely to engender consumer anxiety.

Among the *Actinidia* fruit, *A. arguta* seems to be a highly promising crop. They are small and smooth-skinned. Therefore, they are edible whole. They are ultimately an easy-to-eat fruit that promises consumers' convenience. Moreover, they are a rich dietary source of β-carotene, lutein, and *myo*-inositol in addition to vitamin C. For the expansion of production and marketing of the *A. arguta* fruit, however, their short storage life will have to be overcome through future development. Their storage life might be improved by treatment with 1-methyl cyclopropene, which retards fruit ripening by blocking ethylene action.

Although kiwifruit are marketed mostly as fresh fruit at present, an increased utilization of processed fruits is expected. Among the processed products, kiwifruit juice seems to be the most promising because consumers can conveniently enjoy health-promoting benefits of the fruit. Kiwifruit are difficult to process, but progress in processing technologies including membrane separation and osmotic distillation will make it possible to manufacture safe and stable beverage products that retain the nutrients and flavor of kiwifruit. Of course other *Actinidia* fruits such as those of *A. arguta* can be good raw materials for highly nutritious juice products.

ACKNOWLEDGMENTS

I am grateful to Dr. Ferguson in HortResearch in New Zealand for providing valuable literatures.

REFERENCES

Arcus, A.C. 1959. Proteolytic enzyme of *Actinidia chinensis*. *Biochim. Biophys. Acta* **33**, 242–244.

Bachmann, M.R. and Farah, Z. 1982. Occurrence of bitter taste in mixtures of milk proteins and kiwi fruit (*Actinidia chinensis*). *Lebensm. Wiss. Technol.* **15**, 157–158.

Baker, E.N. 1977. Structure of actinidin: Details of the polypeptide chain conformation and active site from an electron density map at 2.8 Å resolution. *J. Mol. Biol.* **115**, 263–277.

Ball, G.F.M. 2005. Vitamin C. *In* "Vitamins in Foods" (G.F.M. Ball, ed.), pp. 289–308. CRC Press, Taylor & Francis Group, New York.

Belrose, Inc. 2006. "World Kiwifruit Review", 2006 Ed. Belrose, Inc., Washington.

Bender, D.A. 2003. Vitamin C (Ascorbic acid). *In* "Nutritional Biochemistry of the Vitamins" (D.A. Bender, ed.), pp. 357–384. Cambridge University Press, Cambridge.

Block, G., Patterson, B., and Subar, A. 1992. Fruit, vegetables, and cancer prevention: A review of the epidemiological evidence. *Nutr. Cancer* **18**, 1–29.

Boileau, A.C. and Erdman, J.W., Jr. 2004. Impact of food processing on content and bioavailability of carotenoids. *In* "Carotenoids in Health and Disease" (N.I. Krinsky, S.T. Mayne, and H. Sies, eds), pp. 209–228. Marcel Dekker, Inc., New York.

Boland, M.J. and Hardman, M.J. 1972. Kinetic studies on the thiol protease from *Actinidia chinensis*. *FEBS Lett.* **27**, 282–284.

Boyes, S., Strübi, P., and Marsh, H. 1997. Actinidin levels in fruit of *Actinidia* species and some *Actinidia arguta* rootstock-scion combinations. *Lebensm. Wiss. Technol.* **30**, 379–389.

Bublin, M., Mari, A., Ebner, C., Knulst, A., Scheiner, O., Hoffmann-Sommergruber, K., Breiteneder, H., and Radauer, C. 2004. IgE sensitization profiles toward green and gold kiwifruits differ among patients allergic to kiwifruit from 3 European countries. *J. Allergy Clin. Immunol.* **114**, 1169–1175.

Cano, M.P. 1991. HPLC separation of chlorophyll and carotenoid pigments of four kiwi fruit cultivars. *J. Agric. Food Chem.* **39**, 1786–1791.

Cano, M.P. and Marín, M.A. 1992. Pigment composition and color of frozen and canned kiwi fruit slices. *J. Agric. Food Chem.* **40**, 2141–2146.

Carne, A. and Moore, C.H. 1978. The amino acid sequence of the tryptic peptides from actinidin, a proteolytic enzyme from the fruit of *Actinidia chinensis*. *Biochem. J.* **173**, 73–83.

Chen, L., Lucas, J.S., Hourihane, J.O., Lindemann, J., Taylor, S.L., and Goodman, R.E. 2006. Evaluation of IgE binding to proteins of hardy (*Actinidia arguta*), gold (*Actinidia chinensis*) and green (*Actinidia deliciosa*) kiwifruits and processed hardy kiwifruit concentrate, using sera of individuals with food allergies to green kiwifruit. *Food Chem. Toxicol.* **44**, 1100–1107.

Clements, R.S. and Darnell, B. 1980. *Myo*-inositol content of common foods: Development of a high-*myo*-inositol diet. *Am. J. Clin. Nutr.* **33**, 1954–1967.

Collins, A.R., Harrington, V., Drew, J., and Melvin, R. 2003. Nutritional modulation of DNA repair in a human intervention study. *Carcinogenesis* **24**, 511–515.

Collins, B.H., Horská, A., Hotten, P.M., Riddoch, C., and Collins, A.R. 2001. Kiwifruit protects against oxidative DNA damage in human cells and *in vitro*. *Nutr. Cancer* **39**, 148–153.

Duttaroy, A.K. and Jørgensen, A. 2004. Effects of kiwi fruit consumption on platelet aggregation and plasma lipids in healthy human volunteers. *Platelets* **15**, 287–292.

Esti, M., Messia, M.C., Bertocchi, P., Sinesio, F., Moneta, E., Nicotra, A., Fantechi, P., and Palleschi, G. 1998. Chemical compounds and sensory assessment of kiwifruit (*Actinidia chinensis* (Planch.) var. *chinensis*): Electrochemical and multivariate analyses. *Food Chem.* **61**, 293–300.

Ferguson, A.R. 1991. Kiwifruit (*Actinidia*). *Acta Hortic.* **290**, 603–653.

Ferguson, A.R. 1999. Kiwifruit cultivars: Breeding and selection. *Acta Hortic.* **498**, 43–51.

Ferguson, A.R. 2004. 1904-the year that kiwifruit (*Actinidia deliciosa*) came to New Zealand. *NZ J. Crop Hortic. Sci.* **32**, 3–27.

Ferguson, A.R. and Ferguson, L.R. 2003. Are kiwifruit really good for you? *Acta Hortic.* **610**, 131–138.

Ferguson, A.R. and Huang, H. 2007. Genetic resources of kiwifruit: Domestication and breeding. *Hortic. Rev.* **33**, 1–121.

Ferguson, A.R. and MacRae, E.A. 1991. Vitamin C in *Actinidia*. *Acta Hortic.* **297**, 481–487.

Fine, A.J. 1981. Hypersensitivity reaction to kiwi fruit (Chinese gooseberry, *Actinidia chinensis*). *J. Allergy Clin. Immunol.* **68**, 235–237.

Fiocchi, A., Restani, P., Bernardo, L., Martelli, A., Ballabio, C., D'Auria, E., and Riva, E. 2004. Tolerance of heat-treated kiwi by children with kiwifruit allergy. *Pediatr. Allergy Immunol.* **15**, 454–458.

Fisk, C.L., McDaniel, M.R., Strik, B.C., and Zhau, Y. 2006. Physicochemical, sensory, and nutritive qualities of hardy kiwifruit (*Actinidia arguta* 'Ananasnaya') as affected by harvest maturity and storage. *J. Food Sci.* **71**, S204–S210.

Fuke, Y., Sasago, K., and Matsuoka, H. 1985. Determination of chlorophylls in kiwi fruit and their changes during ripening. *J. Food Sci.* **50**, 1220–1223.

Funaki, J., Yano, M., Abe, K., and Arai, S. 1996. Inhibiting the activity of actinidin by oryzacystatin for the application of fresh kiwifruit to gelatin-based foods. *J. Food Biochem.* **19**, 355–365.

Giovannucci, E. 1999. Tomatoes, tomato-based products, lycopene, and cancer: Review of the epidemiologic literature. *J. Natl. Cancer Inst.* **91**, 317–331.

Granado, F., Olmedilla, B., and Blanco, I. 2003. Nutritional and clinical relevance of lutein in human health. *Br. J. Nutr.* **90**, 487–502.

Gregory, J.F., III 1996. Vitamins. *In* "Food Chemistry Third Edition" (O.R. Fennema, ed.), pp. 531–616. Marcel Dekker, Inc., New York.

Hart, D.J. and Scott, K.J. 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chem.* **54**, 101–111.

Hou, D.-X., Kai, K., Li, J.-J., Lin, S., Terahara, N., Wakamatsu, M., Fujii, M., Young, M.R., and Colburn, N. 2004. Anthocyanidins inhibit activator protein 1 activity and cell transformation: Structure-activity relationship and molecular mechanisms. *Carcinogenesis* **25**, 29–36.

Huang, H., Wang, S., Huang, R., Jiang, Z., and Zhang, Z. 2002. 'Jintao', a novel, hairless, yellow-fleshed kiwifruit. *J. Am. Soc. Hortic. Sci.* **37**, 1135–1136.

Huang, H., Wang, S., Jiang, Z., Zhang, Z., and Gong, J. 2003. Exploration of *Actinidia* genetic resources and development of kiwifruit industry in China. *Acta Hortic.* **610**, 29–44.

Jaeger, S.R. and Harker, F.R. 2005. Consumer evaluation of novel kiwifruit: Willingness-to-pay. *J. Sci. Food Agric.* **85**, 2519–2526.

Jayaprakasam, B., Vareed, S.K., Olson, L.K., and Nair, M.G. 2005. Insulin secretion by bioactive anthocyanins and anthocyanidins present in fruits. *J. Agric. Food Chem.* **53**, 28–31.

Jo, Y.S., Cho, H.S., Park, M.Y., and Bang, G.P. 2007a. Selection of a sweet *Actinidia eriantha*, 'Bidan'. *Acta Hortic.* (in press).

Jo, Y.S., Ma, K.C., Cho, H.S., Park, J.O., Kim, S.C., and Kim, W.S. 2007b. 'Chiak', a new selection of *Actinidia arguta*. *Acta Hortic.* (in press).

Kamei, H., Kojima, T., Hasegawa, M., Koide, T., Umeda, T., Yukawa, T., and Terabe, K. 1995. Suppression of tumor cell growth by anthocyanins *in vitro*. *Cancer Invest.* **13**, 590–594.

Kim, J.G., Mizugami, T., Beppu, K., Fukuda, T., and Kataoka, I. 2007. Fruit characteristics of "Shima sarunashi" (*Actinidia rufa* (Sieb. et Zucc.) Planch. ex Miq.), a unique resources of *Actinidia* native to Japan. *Acta Hortic.* (in press).

Klages, K., Smith, G., and Bieleski, R. 1997. *Myo*-inositol is a major carbohydrate in species of *Actinidia*. *Acta Hortic.* **444**, 361–368.

Kokudo, K., Beppu, K., Kataoka, I., Fukuda, T., Mabuchi, S., and Suezawa, K. 2003. Phylogenetic classification of introduced and indigenous *Actinidia* in Japan and identification of interspecific hybrids using RAPD analysis. *Acta Hortic.* **610**, 351–356.

Kritchevsky, S.B. 1999. β-Carotene, carotenoids and the prevention of coronary heart disease. *J. Nutr.* **129**, 5–8.

Lawrie, R.A. 1998. The eating quality of meat. *In* "Lawrie's Meat Science" (R.A. Lawrie, ed.), Sixth Edition, pp. 212–257. Woodhead Publishing, Ltd., Cambridge.

Lewis, D.A. and Luh, B.S. 1988a. Development and distribution of actinidin in kiwifruit (*Actinidia chinensis*) and its partial characterization. *J. Food Biochem.* **12**, 109–116.

Lewis, D.A. and Luh, B.S. 1988b. Application of actinidin from kiwifruit to meat tenderization and characterization of beef muscle protein hydrolysis. *J. Food Biochem.* **12**, 147–158.

Liang, C.-F. and Ferguson, A.R. 1984. Emendation of the Latin name of *Actinidia chinensis* Pl. var. *hispida* C.F. Liang. *Guihaia* **4**, 181–182.

Lucas, J.S.A., Lewis, S.A., and Hourihane, J.O'B. 2003. Kiwi fruit allergy: A review. *Pediatr. Allergy Immunol.* **14**, 420–428.

Lucas, J.S.A., Lewis, S.A., Trewin, J.B., Grimshaw, K.E.C., Warner, J.O., and Hourihane, J.O'B. 2005. Comparison of the allergenicity of *Actinidia deliciosa* (kiwi fruit) and *Actinidia chinensis* (gold kiwi). *Pediatr. Allergy Immunol.* **16**, 647–654.

MacRae, E.A., Bowen, J.H., and Stec, M.G.H. 1989. Maturation of kiwifruit (*Actinidia deliciosa* cv. 'Hayward') from two orchards: Differences in composition of the tissue zones. *J. Sci. Food Agric.* **47**, 401–416.

Marsh, K., Rossiter, K., Lau, K., Walker, S., Gunson, A., and MacRae, E.A. 2003. The use of fruit pulps to explore flavour in kiwifruit. *Acta Hortic.* **610**, 229–237.

Marsh, K., Attanayake, S., Walker, S., Gunson, A., Boldingh, H., and MacRae, E. 2004. Acidity and taste in kiwifruit. *Postharvest Biol. Technol.* **32**, 159–168.

Matsui, T., Ebuchi, S., Kobayashi, M., Fukui, K., Sugita, K., Terahara, N., and Matsumoto, K. 2002. Anti-hyperglycemic effect of diacylated anthocyanin derived from *Ipomoea batatas* cultivar Ayamurasaki can be achieved through the α-glucosidase inhibitory action. *J. Agric. Food Chem.* **50**, 7244–7248.

McDowall, M.A. 1970. Anionic proteinase from *Actinidia chinensis*. Preparation and properties of the crystalline enzyme. *Eur. J. Biochem.* **14**, 214–221.

McDowall, M.A. 1973. The action of proteinase A_2 of *Actinidia chinensis* on the B-chain of oxidized insulin. *Biochim. Biophys. Acta* **293**, 226–231.

McGhie, T.K. and Ainge, G.D. 2002. Color in fruit of the genus *Actinidia*: Carotenoid and chlorophyll compositions. *J. Agric. Food Chem.* **50**, 117–121.

Mempel, M., Rakoski, J., Ring, J., and Ollert, M. 2003. Severe anaphylaxis to kiwi fruit: Immunologic changes related to successful sublingual allergen immunotherapy. *J. Allergy Clin. Immunol.* **111**, 1406–1409.

Mills, E.N.C., Jenkins, J.A., Alcocer, M.J.C., and Shewry, P.R. 2004. Structural, biological, and evolutionary relationships of plant food allergens sensitizing via the gastrointestinal tract. *Crit. Rev. Food Sci. Nutr.* **44**, 379–407.

Montefiori, M., McGhie, T.K., Costa, G., and Ferguson, A.R. 2005. Pigments in the fruit of red-fleshed kiwifruit (*Actinidia chinensis* and *Actinidia deliciosa*). *J. Agric. Food Chem.* **53**, 9526–9530.

Morimoto, K., Kunii, S., Hamano, K., and Tonomura, B. 2004. Preparation and structural analysis of actinidain-processed atelocollagen of yellowfin tuna (*Thunnus albacares*). *Biosci. Biotechnol. Biochem.* **68**, 861–867.

Nishiyama, I. 2000. Comparison of the proteolytic effects of Hayward and Hort16A kiwifruit juice. *J. Home Econ. Jpn.* **51**, 621–626 (in Japanese).

Nishiyama, I. 2001. pH-dependent proteolytic effects of actinidin on myofibrillar proteins. *J. Home Econ. Jpn.* **52**, 1083–1089 (in Japanese).

Nishiyama, I. and Oota, T. 2002. Varietal difference in actinidin concentration and protease activity in the kiwi fruit juice. *J. Jpn. Soc. Food Sci. Technol.* **49**, 401–408 (in Japanese).

Nishiyama, I., Fukuda, T., and Oota, T. 2004a. Varietal differences in actinidin concentration and protease activity in the fruit juice of *Actinidia arguta* and *Actinidia rufa*. *J. Jpn. Soc. Hortic. Sci.* **73**, 157–162 (in Japanese).

Nishiyama, I., Yamashita, Y., Yamanaka, M., Shimohashi, A., Fukuda, T., and Oota, T. 2004b. Varietal difference in vitamin C content in the fruit of kiwifruit and other *Actinidia* species. *J. Agric. Food Chem.* **52**, 5472–5475.

Nishiyama, I., Fukuda, T., and Oota, T. 2005. Genotypic difference in chlorophyll, lutein, and β-carotene contents in the fruits of *Actinidia* species. *J. Agric. Food Chem.* **53**, 6403–6407.

Nishiyama, I., Fukuda, T., and Oota, T. 2007. Cultivar difference in chlorophyll, lutein, and β-carotene content in the fruit of kiwifruit and other *Actinidia* species. *Acta Hortic.* (in press).

Noonan, S.C. and Savage, G.P. 1999. Oxalate content of foods and its effect on humans. *Asia Pac. J. Clin. Nutr.* **8**, 64–74.

Pastorello, E.A., Conti, A., Pravettoni, V., Farioli, L., Rivolta, F., Ansaloni, R., Ispano, M., Incorvaia, C., Giuffrida, M.G., and Ortolani, C. 1998. Identification of actinidin as the major allergen of kiwi fruit. *J. Allergy Clin. Immunol.* **101**, 531–537.

Perera, C.O., Hallett, I.C., Nguyen, T.T., and Charles, J.C. 1990. Calcium oxalate crystals: The irritant factor in kiwifruit. *J. Food Sci.* **55**, 1066–1069, 1080.

Pérez, A.G., Olías, R., Espada, J., Olías, J.M., and Sanz, C. 1997. Rapid determination of sugars, non-volatile acids, and ascorbic acid in strawberry and other fruits. *J. Agric. Food Chem.* **45**, 3545–3549.

Pool-Zobel, B.L., Bub, A., Schröder, N., and Rechemmer, G. 1999. Anthocyanins are potent anti-oxidants in model systems but do not reduce endogenous oxidative DNA damage in human colon cells. *Eur. J. Nutr.* **38**, 227–234.

Possingham, J.V., Coote, M., and Hawker, J.S. 1980. The plastids and pigments of fresh and dried Chinese gooseberries (*Actinidia chinensis*). *Ann. Bot.* **45**, 529–533.

Préstamo, G. 1995. Actinidin in kiwifruit cultivars. *Z. Lebensm. Unters. Forsch.* **200**, 64–66.

Rassam, M. and Laing, W. 2005. Variation in ascorbic acid and oxalate levels in the fruit of *Actinidia chinensis* tissues and genotypes. *J. Agric. Food Chem.* **53**, 2322–2326.

Rassam, M., Bulley, S., and Laing, W. 2007. Oxalate and ascorbic acid in *Actinidia* fruit. *Acta Hortic.* (in press).

Robertson, G.L. and Swinburne, D. 1981. Changes in chlorophyll and pectin after storage and canning of kiwifruit. *J. Food Sci.* **46**, 1557–1559.

Rock, C.L. 2004. Relationship of carotenoids to cancer. *In* "Carotenoids in Health and Disease" (N.I. Krinsky, S.T. Mayne, and H. Sies, eds), pp. 373–407. Marcel Dekker Inc., New York.

Rush, E., Ferguson, L.R., Cumin, M., Thakur, V., Karunasinghe, N., and Plank, L. 2006. Kiwifruit consumption reduces DNA fragility: A randomized controlled pilot study in volunteers. *Nutr. Res.* **26**, 197–201.

Rush, E.C., Patel, M., Plank, L.D., and Ferguson, L.R. 2002. Kiwifruit promotes laxation in the elderly. *Asia Pac. J. Clin. Nutr.* **11**, 164–168.

Sanz, M.L., Villamiel, M., and Martínez-Castro, I. 2004. Inositols and carbohydrates in different fresh fruit juices. *Food Chem.* **87**, 325–328.

Schoefs, B. 2005. Plant pigments: Properties, analysis, degradation. *Adv. Food Nutr. Res.* **49**, 41–91.

Seager, N. 1997. Synthesis and degradation of anthocyanin in *Actinidia arguta* × *melanandra*. *Acta Hortic.* **444**, 523–528.

Seddon, J.M., Ajani, U.A., Sperduto, R.D., Hiller, R., Blair, N., Burton, T.C., Farber, M.D., Gragoudas, E.S., Haller, J., Miller, D.T., Yannuzzi, L.A., and Willett, W. 1994. Dietary carotenoids, vitamins A, C, and E, and advanced age-related macular degeneration. Eye disease case-control study group. *J. Am. Med. Assoc.* **272**, 1413–1420.

Sesso, H.D. and Gaziano, J.M. 2004. Heart and vascular diseases. *In* "Carotenoids in Health and Disease" (N.I. Krinsky, S.T. Mayne, and H. Sies, eds), pp. 473–490. Marcel Dekker, Inc., New York.

Shibutani, S. and Grollman, A.P. 1994. Miscoding during DNA synthesis on damaged DNA templates catalysed by mammalian cell extract. *Cancer Lett.* **83**, 315–322.

Sugiyama, S., Ohtsuki, K., Sato, K., and Kawabata, M. 1996. Purification and characterization of six kiwifruit proteases isolated with two ion-exchange resins, Toyopearl-SuperQ and Bakerbond WP-PEI. *Biosci. Biotechnol. Biochem.* **60**, 1994–2000.

Sugiyama, S., Ohtsuki, K., Sato, K., and Kawabata, M. 1997. Enzymatic properties, substrate specificities and pH-activity profiles of two kiwifruit proteases. *J. Nutr. Sci. Vitaminol.* **43**, 581–589.

Sugiyama, S., Hirota, A., Okada, C., Yorita, T., Sato, K., and Ohtsuki, K. 2005. Effect of kiwifruit juice on beef collagen. *J. Nutr. Sci. Vitaminol.* **51**, 27–33.

Tee, E.-S. and Lim, C.-L. 1991. Carotenoid composition and content of Malaysian vegetables and fruits by the AOAC and HPLC methods. *Food Chem.* **41**, 309–339.

Tsuda, T., Ohshima, K., Kawakishi, S., and Osawa, T. 1996. Oxidation products of cyanidin 3-O-β-D-glucoside with a free radical initiator. *Lipids* **31**, 1259–1263.

Updike, A.A. and Schwartz, S.J. 2003. Thermal processing of vegetables increases cis isomers of lutein and zeaxanthin. *J. Agric. Food Chem.* **51**, 6184–6190.

Venning, J.A., Burns, D.J.W., Hoskin, K.M., Nguyen, T., and Stec, M.G.H. 1989. Factors influencing the stability of frozen kiwifruit pulp. *J. Food Sci.* **54**, 396–400, 404.

van Poppel, G. 1996. Epidemiological evidence for beta-carotene in prevention of cancer and cardiovascular disease. *Eur. J. Clin. Nutr.* **50**(Suppl.), S57–S61.

von Elbe, J.H. and Schwartz, S.J. 1996. Colorants. *In* "Food Chemistry Third Edition" (O.R. Fennema, ed.), pp. 651–696. Marcel Dekker, Inc., New York.

Wang, M., Li, M., and Meng, A. 2003. Selection of a new red-fleshed kiwifruit cultivar 'Hongyang'. *Acta Hortic.* **610**, 115–117.

Watanabe, K. and Takahashi, B. 1998. Determination of soluble and insoluble oxalate contents in kiwifruit (*Actinidia deliciosa*) and related species. *J. Jpn. Soc. Hortic. Sci.* **67**, 299–305.

Williams, M.H., Boyd, L.M., McNeilage, M.A., MacRae, E.A., Ferguson, A.R., Beatson, R.A., and Martin, P.J. 2003. Development and commercialization of 'Baby Kiwi' (*Actinidia arguta* Planch.). *Acta Hortic.* **610**, 81–86.

Wong, M. and Stanton, D.W. 1989. Nonenzymic browning in kiwifruit juice concentrate systems during storage. *J. Food Sci.* **54**, 669–673.

Yamaguchi, T., Yamashita, Y., Takeda, I., and Kiso, H. 1982. Proteolytic enzymes in green asparagus, kiwi fruit and miut: Occurrence and partial characterization. *Agric. Biol. Chem.* **46**, 1983–1986.

Yamanaka, M., Oota, T., Fukuda, T., and Nishiyama, I. 2004. Varietal difference in actinidin concentration and protease activity in fruit juice of *Actinidia* species. *J. Jpn. Soc. Food Sci. Technol.* **51**, 491–494. (in Japanese).

Yoshimoto, M., Okuno, S., Yoshinaga, M., Yamakawa, O., Yamaguchi, M., and Yamada, J. 1999. Antimutagenicity of sweetpotato (*Ipomoea batatas*) roots. *Biosci. Biotechnol. Biochem.* **63**, 537–541.

Yoshimoto, M., Okuno, S., Yamaguchi, M., and Yamakawa, O. 2001. Antimutagenicity of deacylated anthocyanins in purple-fleshed sweetpotato. *Biosci. Biotechnol. Biochem.* **65**, 1652–1655.

Young, A.J., Phillip, D.M., and Lowe, G.M. 2004. Carotenoid antioxidant activity. *In* "Carotenoids in Health and Disease" (N.I. Krinsky, S.T. Mayne, and H. Sies, eds), pp. 105–126. Marcel Dekker, Inc., New York.

Zhong, C.H., Wang, Z.Y., Bu, F.W., and Peng, D.F. 2007. Selection of a new red-fleshed kiwifruit cultivar 'Chuhong'. *Acta Hortic.* (in press).