Note

‘Niigata S3’ is a new strawberry cultivar suitable for forcing culture under low temperature and insolation conditions

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‘Niigata S3’ is a new strawberry (*Fragaria* × *ananassa* Duch.) cultivar that is early flowering and possesses high soluble solid content and good coloration. It was selected from a cross between Kei812 (seed parent) and ‘Asuka-Ruby’ (pollen parent). The first harvest date of ‘Niigata S3’ was December 27, 34 days earlier than ‘Echigohime’ and 9 days earlier than ‘Asuka-Ruby’ (means of 2007 and 2008). The marketable yield of ‘Niigata S3’ was 85% of ‘Echigohime’, 107% of ‘Asuka-Ruby’, while the early yield was 145% of ‘Echigohime’, 85% of ‘Asuka-Ruby’ (based on 2007 and 2008 means). The shape of the fruit is long conical, and its skin color medium-red. The fruit skin hardness of ‘Niigata S3’ was 31.5 g/mm², which was harder than ‘Echigohime’, and its average soluble solid content was 11.4%, which was higher than the values for ‘Echigohime’ and ‘Asuka-Ruby’ (2008). Furthermore, ‘Niigata S3’ did not bear apical overripe fruit. This new cultivar is adaptable to the climatic conditions of Niigata, as well as other regions that experience low winter temperatures and insolation.

Key Words: breeding, forcing culture, early flowering, fruit quality.

Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is a popular fruit vegetable and widely cultivated worldwide. In Japan, the strawberry is one of the most important fruit crops and its planting area was 6,020 ha in 2011 (Ministry of Agriculture, Forestry, and Fisheries of Japan (MAFF) 2013). In Japan, strawberries are mostly cultivated under forcing culture conditions (Mochizuki *et al.* 2009) using Junebearing cultivars (Durner *et al.* 1984). In the 1980s, two major cultivars, ‘Nyoho’ (Akagi *et al.* 1985) and ‘Toyonoka’ (Honda *et al.* 1985) were cultivated widely in Japan (Minegishi 1989). Since then, many other cultivars such as ‘Akihime’ (Hagiwara 1992), ‘Tochiotome’ (currently the most widely planted in Japan; Ishihara *et al.* 1996), ‘Sachinoka’ (Morishita *et al.* 1997), ‘Asuka-Ruby’ (Nobuoka and Taimatsu 1997, Taimatsu *et al.* 2000), ‘Sagahonoka’ (Mori *et al.* 1998, Tanaka *et al.* 2001), and ‘Fukuoka S6’ (Mitsui *et al.* 2003) have been released and their production has

gradually increased (Mochizuki *et al.* 2007). Many prefectures have developed their own strawberry cultivars, and the breeding of new cultivars is ongoing. Most breeding programs are based on crossbreeding (Faedi *et al.* 2002, Mochizuki 2000).

In forcing cultivation of strawberry, nursery plants are planted in autumn, and fruits are harvested from winter to spring. Winter temperatures and insolation in Niigata are typically low (Fig. 1). These winter conditions give rise to physiological disorders and/or declines in fruit quality (Anttonen *et al.* 2006, Watson *et al.* 2002), and the major strawberry cultivars bred in other regions show low adaptability in Niigata. For these reasons, the Niigata prefectural government initiated a breeding program of new cultivars adapted to local environmental conditions, resulting in the release of ‘Echigohime’ in 1995 (Kurashima *et al.* 1997). The advantages of ‘Echigohime’ are its superior-tasting fruit, high yield, and strong vigorous growth during the winter season. The cultivated area of ‘Echigohime’ has continuously increased, making up more than 32 ha in 2012, and accounting for more than 90% of the total strawberry cultivation area in Niigata prefecture. However, the disadvantages of ‘Echigohime’ in the winter season are the

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Fig. 1. Climatic conditions of major strawberry producing cities during the strawberry production period (means of 2007–2009). Weather data were excerpts from observation data of the Japan Meteorological Agency. (A) Niigata (Niigata pref.); (B) Moka (Tochigi pref.); (C) Tamana (Kumamoto pref.); (D) Kurume (Fukuoka pref.). Sunshine, monthly total duration of sunshine; Avg, monthly average air temperature; Max, monthly average maximum air temperature; Min, monthly average minimum air temperature.

occurrence of late flowering, the relatively pale red fruits, and apical overripe fruits. Apical overripe fruits have reduced marketability due to their low sugar concentration, low firmness, dull skin color and fermented flavor. In ‘Nyoho’, apical overripe fruit formation is accelerated by high humidity, low temperature and low insolation during fruit maturation (Akagi 1989, Fushihara 1988). In ‘Toyonoka’, a similar fruit disorder, termed Hakkoka, is accelerated by similar causes. At high temperatures (20°C in the daytime, >6°C at night) and low humidity, these fruit disorders diminish (Fushihara 1988). However, winter climate conditions, including low insolation and temperature and snow-fall (Fig. 1), make the implementation of measures to promote favorable conditions difficult or too expensive for farmers. Thus, it is difficult to harvest high-quality fruit from ‘Echigohime’ during early winter in Niigata, particularly in the mountainous region.

Hence, we sought to breed a new cultivar, with the following attributes compared to ‘Echigohime’: earlier fruit bearing, stronger plant vigor during winter, more vivid fruit color, firmer fruit, similar soluble solid content (SSC) and fruit size, greater tolerance to powdery mildew, and fewer apical overripe fruits. In this report, we describe the breeding process and main agronomic characteristics of this new strawberry cultivar, ‘Niigata S3’.

Breeding process

The pedigree of ‘Niigata S3’ is shown in Fig. 2. The total breeding population for each year was 10–60 cross combinations and 3,000–5,000 nursery plants at the Niigata Agricultural Research Institute Horticultural Research Center, Seiro, Japan. Nursery plants were assessed and selected based on tolerance to powdery mildew disease under natural conditions, and ~1,200 plants were selected and transplanted to a greenhouse. Individual plants were then assessed and selected for plant vigor and fruit quality under forcing culture conditions. To breed a cultivar adapted to winter climate conditions in Niigata, we repeated crossing and selection. The parent plants selected for the breeding program

Fig. 2. Pedigree of ‘Niigata S3’. Each pairs mean seed parent (upper) and pollen parent (lower). Dotted lines indicate self pollination.

Table 1. Breeding procedure of 'Niigata S3'

Year	Generation	Breeding experiments		Name of selected plant ^b
		Cross combination or selection ^a	Transplanted/ nursery ^c	
1996	(Crossing)	Kitanokagayaki (LF, FF, PT)/Kei203 (LF)		
	F ₁	Individual selection ^d	7/68	Kei311 (LF, FF, PT)
1997	(Crossing)	Kei311/Kei301 (EF, LaF, PT)		
	F ₁	Individual selection	13/55	Kei404 (MF, FF, PT)
1998	(Crossing)	Kurume No. 54 (SV, LaF)/Kei404		
	F ₁	Individual selection	15/26	Kei516 (SV, LF, LaF, PT)
1999	F ₂	Individual selection	64/110	Kei609 (SV, MF, FF, PT)
2001	(Crossing)	Kei713 (EF, HS)/Kei609		
	F ₁	Individual selection	47/75	Kei812 (SV, EF, FF, HS, PT)
2003	(Crossing)	Kei812/Asuka-Ruby (EF, FF, PT)		
	F ₁	Individual selection	45/105	Kei914, Kei915 (SV, EF, FF, HS, PT)
2003–05		↓ Line selection based on early yield and fruit quality	1 line/2 lines	Kei915
2006–08		↓ Performance test		
2007–08		↓ Local adaptability test		
2012		↓ Registration by MAFF		Niigata S3

^a Abbreviations in parentheses are the main characters of parents. SV, strong vigor; LF, late flowering; MF, medium flowering; EF, early flowering; LaF, large fruit; FF, firm fruit; HS, high soluble solid content; PT, powdery mildew tolerance.

^b Abbreviations in parentheses are the main characters of selected plants.

^c Number of transplanted plants for selection/number of nursery plants raised from each generation.

^d Individual selection based on fruit taste and plant vigor were performed in a greenhouse under forcing culture conditions after nursery selection based on powdery mildew tolerance.

possessed the following favorable traits: 'Kitanokagayaki' (Okimura and Igarashi. 1997), firm fruit and tolerance to powdery mildew; Kurume No. 54 (former experimental line name of 'Strawberry parental line Nou-1'; Mochizuki *et al.* 2004), strong vigor and large fruit; 'Tochiotome', early flowering, good fruit flavor, firm fruit, and vivid fruit color; 'Asuka-Ruby', early flowering, firm fruit, and tolerance to powdery mildew. By repeated cross-pollination and selection, we gradually improved the performance of the breeding stock (Table 1). For example, the tolerance to powdery mildew of Kei311 and its progeny were greater than that of 'Echigohime'. The winter vigor of selected lines gradually became stronger than that of 'Echigohime' (in December 2001, the plant heights of 'Echigohime', Kei 516 and Kei609 were 14.6, 17.7 and 20.8 cm, respectively, and in December 2004, 'Echigohime' and Kei812 were 17.4 and 28.7 cm, respectively). The first harvesting dates of the selected lines were also earlier than for 'Echigohime' (February 5, January 19 and January 11, 2004, for 'Echigohime', Kei609 and Kei812, respectively). Kei516 is the progeny of Kurume No. 54 and is characterized by strong plant vigor, large fruit, and tolerance to powdery mildew, but the progeny of Kei516 did not inherit all of these favorable traits. The progeny had strong vigor, firm fruit, and powdery mildew tolerance, but did not have large fruit.

'Niigata S3' was initially named Kei915 and was selected from the progeny of a cross between Kei812, as the seed parent and 'Asuka-Ruby', as the pollen parent. Kei812 dis-

plays strong vigor under low temperatures and insolation, and its fruit possesses a firm skin and flesh and high SSC. 'Asuka-Ruby' is a high-yielding cultivar, released from the Nara prefecture, and its fruit skin color is bright red.

In 2003, the Kei812 × 'Asuka-Ruby' cross was performed in February, and the seeds were sown on a vermiculite bed in April. These seedlings were planted in a greenhouse in October. Line selection based on early yield and fruit flavor was conducted three times in the greenhouse from 2003 to 2005 under forcing culture conditions. The selected clonal line was named Kei915.

Agronomic characteristic tests of Kei915 were conducted over a period of three years (2006–2008), and the local adaptability of Kei915 was evaluated in Shibata and Gosen in Niigata prefecture over a period of two years (2007 and 2008). Kei915 was eventually recommended to the Niigata prefecture as a suitable strawberry cultivar, and in 2012, officially registered as 'Niigata S3' by the MAFF.

Plant characteristics

To evaluate their agronomic characteristics, in 2008, 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' were cultivated using an elevated bench culture system under forcing culture conditions in a greenhouse at the Niigata Agricultural Research Institute Horticultural Research Center. At September 30, young plants were transplanted 25 cm apart in rows with 10 cm inter-row spacing. The planting density was 666.7 plants per are. The strawberry plants were

fertigated with 0.067% Drip Fertigation No. 6 Solution (Otsuka Agri Techno Co. Ltd., Tokyo, Japan) at a drain rate of ~30%. Preparation of nursery plants, culture practices, and fungicide and insecticide treatments were similar to those used in commercial strawberry production using the forced elevated bench culture system in Niigata. The assessment method followed the 2008 MAFF testing guidelines. In this study, we re-describe the characteristics that suit the amended guidelines published in 2011 (Plant variety protection office at MAFF 2011). All plant characteristics, except stolon number, flowering date, first harvest date, and effective cumulative air temperature, were evaluated in mid-January 2009, whereas stolon number was evaluated in mid-June 2009. The effective cumulative air temperature for maturation was calculated as the sum of the equivalents of air temperature, as described by Morishita and Honda (1985), during the first fruit maturation period. The equivalent of air temperature depends on cultivar; however, we used the equivalent for 'Harunoka' in our calculations. The air tem-

perature in the greenhouse was logged with a thermo-recorder (TR-71U, T & D Corp., Matsumoto, Japan).

Plant characteristics of 'Niigata S3' are presented in Table 2, and Tukey-Kramer tests were used to compare means and variances of 'Echigohime' and 'Asuka-Ruby'. The flowering habit and plant vigor of all three cultivars were classified as June-bearing and strong. The plant growth habit of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' were classified as upright, semi-upright and spreading, respectively (Fig. 3). The plant height of 'Niigata S3' was 20.4 cm, which was 2.2 cm taller than 'Echigohime' and 3.8 cm taller than 'Asuka-Ruby'. The number of axillary buds of 'Niigata S3' was 3.0, which was 0.8 buds more than 'Echigohime' and 1.3 buds more than 'Asuka-Ruby'. The number of stolons showed no significant difference among the three cultivars. The terminal leaflet size of 'Niigata S3' was 58.3 cm², which was 19.6 cm² larger than that of 'Echigohime' and almost equal to that of 'Asuka-Ruby'. The peduncle length of 'Niigata S3' was 12.9 cm, which was longer than

Table 2. Plant characteristics of 'Niigata S3' and control cultivars grown by forcing culture in 2008^a

Cultivar	Niigata S3	Echigohime	Asuka-Ruby
Flowering habit	Junebearing	Junebearing	Junebearing
Plant growth habit	upright	semi-upright	spreading
Plant vigor	strong	strong	strong
Plant height (cm)	20.4 a ^b	18.2 ab	16.6 b
Number of axillary buds	3.0 a	2.2 b	1.7 b
Stolon number	19.0 a	18.7 a	16.7 a
Terminal leaflet size (cm ²)	58.3 a	38.7 b	55.9 ab
Length in relation to width of terminal leaflet	1.46 a	1.44 a	1.36 a
Peduncle length (cm)	12.9 a	11.7 a	9.7 b
Flower number ^c	14.6 a	14.2 a	11.0 b
Flowering date ^d	Nov. 02 a	Nov. 24 c	Nov. 10 b
First harvesting date ^d	Dec. 18 a	Jan. 30 c	Jan. 06 b
Effective cumulative air temperature (°C·day)	460.5 b	504.0 a	473.9 b

^a Ten plants were used for the assesment.

^b Values within a row followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

^c The number of the flowers of the first flower cluster.

^d The date when half of the plant flowered or were harvested.

Fig. 3. Plants and fruit of the second cluster of 'Niigata S3' (A), 'Echigohime' (B) and 'Asuka-Ruby' (C) in the middle of March (2009). Plants were cultivated under forcing culture conditions in a greenhouse at the Niigata Agricultural Research Institute Horticultural Research Center.

Table 3. Fruit characteristics of 'Niigata S3' and control cultivars grown by forcing culture in 2008

Character ^a	Cultivar		
	Niigata S3	Echigohime	Asuka-Ruby
Shape	conical	conical	conical
Ratio of vertical to horizontal length	1.34 a ^b	1.08 b	1.05 b
Difference in shapes of terminal and other fruits	slight	slight	very slight
Evenness of surface	even	slightly uneven	even
Position of achenes	deep below surface	very deep below surface	below surface
Skin hardness ^c (g/mm ²)	31.5 a	26.4 b	29.2 ab
Flesh firmness ^c (g/mm ²)	32.3 a	32.0 a	26.9 b
Skin color	medium red	medium red	orange red
Flesh color	light red	orange red	light red

^a Five uniform fruit were measured per each cultivar. Fruit characteristics were evaluated at the middle of January, 2009, except skin hardness and flesh firmness.

^b Values within a row followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

^c Measured with universal hardness meter at the middle of March, 2009. 5 mm diameter cylinder shaped plunger was used.

'Echigohime' and 'Asuka-Ruby'. The flower numbers of the first flower cluster of 'Echigohime' and 'Niigata S3' were 14.2–14.6, which was 3.2–3.6 more than 'Asuka-Ruby', respectively. The flowering date of 'Niigata S3' was November 2, 2008, which was 22 days earlier than 'Echigohime' and 8 days earlier than 'Asuka-Ruby'. The first harvesting date of 'Niigata S3' was December 18, 2009, which was 43 days earlier than 'Echigohime' and 19 days earlier than 'Asuka-Ruby'. The effective cumulative air temperature during the first fruit maturation period of 'Niigata S3' was 460.5°C·day which was the lowest of the three cultivars.

Fruit characteristics

Fruit characteristics of 'Niigata S3', including fruit shape, vertical-horizontal length ratio of fruit, difference in shapes of terminal and other fruit, fruit skin color, evenness of surface, position of achenes and fruit flesh color were assessed at the time of first-cluster harvest. Fruit skin hardness and fruit flesh firmness were assessed at the time of second-cluster harvest to ensure evaluation of fruit of about the same size and at the same time (Table 3). The evaluated fruit was harvested from the same plants as described in *Plant characteristics*. Fruit skin hardness and fruit flesh firmness were measured with a universal hardness meter with a cylindrical plunger 5 mm in diameter (KIYA Co. Ltd., Tokyo, Japan). Skin hardness was measured by inserting the plunger into the skin, and flesh firmness was measured by inserting the plunger into a vertical section of the fruit (Monma *et al.* 1977). Fruit skin color was measured in terms of L^* , a^* and b^* value with a chroma meter (CR-300, Minolta Co. Ltd., Tokyo, Japan). These values were converted to hue angle ($h^\circ = \arctangent [b^*/a^*]$) where 0° = red-purple, 90° = yellow, 180° = bluish-green and 270° = blue; and chroma ($C^* = [(a^*)^2 + (b^*)^2]^{1/2}$), which indicates the color intensity or saturation (McGuire 1992, Yoshida *et al.* 2002). SSC was measured with a refractometer (AT-20, Atago Co. Ltd., Tokyo, Japan). Fruit acidity was measured with an automatic potentiometric titrator (CAM-500, Kyoto Electronics Manufacturing Co. Ltd., Kyoto, Japan) as the citric acid conversion value. Five fruits weighting between

10 and 25 g were used for the assessment, and SSC and acidity were measured once a month from December, 2008 to May, 2009. Tukey-Kramer tests were used to compare 'Niigata S3' means and variances with 'Echigohime' and 'Asuka-Ruby'.

The fruit characteristics of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' are presented in Table 3. Fruit shape of all three cultivars was classified as conical (Fig. 3). The vertical–horizontal length ratio of 'Niigata S3' fruit was 1.34, and was 0.26 higher than 'Echigohime' fruit and 0.29 higher than 'Asuka-Ruby' fruit (Figs. 3, 4). The difference in shape of terminal and other fruit of 'Niigata S3' was classified as slightly, which was marginally greater than the classification of 'Asuka-Ruby'. Evenness of the fruit surface of 'Niigata S3' and 'Asuka-Ruby' were classified as even, while 'Echigohime' was classified as slightly uneven. The position of achenes of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' were classified as deep below the surface, very deep below the surface and below the surface, respectively. The fruit skin hardness of 'Niigata S3' was 31.5 g/mm², which was 5.1 g/mm² harder than 'Echigohime'. The fruit flesh firmness values of 'Niigata S3' and 'Echigohime' were

Fig. 4. Longitudinal section of fruit of the first cluster of 'Niigata S3'.

Table 4. Fruit skin color evaluation of 'Niigata S3' and control cultivars grown by forcing culture in 2008^a

Cultivar	L*	a*	b*	h°	C*
Niigata S3	38.2 c ^b	37.9 a	27.1 b	35.4 c	46.7 b
Echigohime	41.4 b	38.5 a	33.0 a	40.6 b	50.8 a
Asuka-Ruby	45.3 a	34.4 b	33.3 a	44.1 a	47.9 b

^a Ten uniform fruit were measured per each cultivar.

^b Values within a column followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

Table 5. Changes in soluble solid content in fruit of 'Niigata S3' and control cultivars grown by forcing culture in 2008

Cultivar	Dec. ^a (%)	Jan. (%)	Feb. (%)	Mar. (%)	Apr. (%)	May (%)	Avg. (%)
Niigata S3	11.0	11.8 a ^b	10.7 a	10.1 a	11.1 a	13.3 a	11.3
Echigohime	—	8.5 b	8.8 b	9.2 ab	9.4 b	11.8 ab	9.5
Asuka-Ruby	—	8.2 b	7.4 c	8.5 b	8.3 b	9.0 b	8.3

^a Five uniform fruit were measured per each cultivar once in the middle of each month.

^b Values within a column followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

Table 6. Changes in acidity as the citric acid conversion value in fruit of 'Niigata S3' and control cultivars grown by forcing culture in 2008

Cultivar	Dec. ^a (%)	Jan. (%)	Feb. (%)	Mar. (%)	Apr. (%)	May ^b (%)	Avg. (%)
Niigata S3	0.52	0.43 b ^c	0.44 ab	0.61 a	0.57 a	0.60 b	0.53
Echigohime	—	0.38 c	0.36 b	0.38 b	0.48 b	0.60 b	0.44
Asuka-Ruby	—	0.54 a	0.52 a	0.55 a	0.63 a	0.84 a	0.62

^a Five uniform fruit were measured per each cultivar once in the middle of each month (December–April).

^b Four or five uniform fruit were measured per each cultivar in the middle of May.

^c Values within a column followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

32.0–32.3 g/mm², these were 5.1–5.4 g/mm² firmer than 'Asuka-Ruby', respectively. The fruit skin colors of 'Niigata S3' and 'Echigohime' were classified as medium red, while 'Asuka-Ruby' was classified as orange red. Similarly, the fruit flesh colors of 'Niigata S3' and 'Asuka-Ruby' were classified as light red, while 'Echigohime' was classified as orange red. The fruit skin color evaluation is presented in Table 4. The L* value, which denotes the lightness of fruit skin, was 38.2 for 'Niigata S3', which was 3.2 lower than 'Echigohime' and 7.1 lower than 'Asuka-Ruby'. The hue angle (H°) of 'Niigata S3' was 35.4, which was 5.2 lower than 'Echigohime' and 8.7 lower than 'Asuka-Ruby'. The chroma (C*) was 46.7, which was 4.1 lower than 'Echigohime' and almost equal to 'Asuka-Ruby'. These data demonstrate that the fruit skin color of 'Niigata S3' is redder than 'Echigohime' and 'Asuka-Ruby'.

The changes in fruit SSC of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' from December to May are presented in Table 5. The fruit SSC of 'Niigata S3' exceeded 10.0% throughout the harvest period, and was consistently higher

than 'Echigohime' and 'Asuka-Ruby'. The changes in fruit acidity of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' from December to May are shown in Table 6. The average fruit acidity of 'Niigata S3' was 0.53% (citric acid conversion value), which was intermediate between 'Echigohime' and 'Asuka-Ruby'.

Yield evaluation

To assess yields, nursery plants of 'Niigata S3', 'Echigohime' and 'Asuka-Ruby' were transplanted onto a forced elevated bench culture system in a plastic greenhouse at the Niigata Agricultural Research Institute Horticultural Research Center, Seiro, Japan. Plants were cultivated as described in the *Plant characteristics* section of this paper. The transplanting dates were October 2, 2007 and September 30, 2008, and 10 plants with three replicates per cultivar were examined. The fruit harvests were finished on March 30, 2008 and March 29, 2009.

To evaluate the yield of 'Niigata S3', first harvesting date, marketable yield, early yield (from December to February), average marketable fruit weight, non-marketable yield (including malformed fruit, apical overripe fruit and fruit below 6 g), marketable fruit ratio and tolerance to powdery mildew were assessed (Table 7). Tukey-Kramer tests were used to compare means and variance with 'Echigohime' and 'Asuka-Ruby'.

The first harvesting date of 'Niigata S3' was December 27, which was 34 days earlier than 'Echigohime', 9 days earlier than 'Asuka-Ruby'. The yield from December to February of 'Niigata S3' was 92.7 kg/a, which was 145% of 'Echigohime' and 85% of 'Asuka-Ruby'. The total marketable yield of 'Niigata S3' was 277.4 kg/a, which was 85% of 'Echigohime' and 107% of 'Asuka-Ruby'. The average weight of marketable fruit was 12.4 g, which was slightly lower than 'Echigohime' and 1.0 g lower than 'Asuka-Ruby'. 'Niigata S3' produced more fruit below 6 g than 'Echigohime' and 'Asuka-Ruby', but also produced the fewest malformed and apical overripe fruit of the three cultivars. Thus, 'Niigata S3' possessed the highest marketable fruit ratio of the three cultivars. The tolerance of 'Niigata S3' to powdery mildew was also stronger than 'Echigohime' and equal to 'Asuka-Ruby', but tolerance to other diseases was not assessed.

Discussion

Breeding strategy

Many breeding objectives of strawberry are for quantitatively inherited traits, so most breeding programs are based on crossbreeding (Faedi *et al.* 2002, Hortyński 1989, Mochizuki 2000). Morishita (1994) suggested that the strategy for optimal strawberry breeding should be to select for fruit quality in individuals or line first, and selection for other characteristics, including yield, should be practiced in preliminary performance and performance tests. In addition, Ohtsuka *et al.* (2004) suggested that the optimum breeding

Table 7. Yield evaluation of 'Niigata S3' and control cultivars grown by forcing culture (means of 2007 and 2008)^a

Cultivar	First harvesting date (month.day)	Marketable yield ^b			Average fruit weight (g)	Percentage of Marketable/Total yield (%)
		Dec. ^c (kg/a)	Early ^d (kg/a)	Total (kg/a)		
Niigata S3	12.27 a ^f	7.4 a	92.7 a	277.4 ab	12.4 a	83.5 a
Echigohime	1.30 b	0.0 b	63.9 b	327.9 a	13.2 a	77.6 a
Asuka-Ruby	1.05 a	0.7 b	109.0 a	260.2 b	13.4 a	77.6 a

Cultivar	Non-marketable yield			Total yield (kg/a)	Powdery ^e mildew diseased fruits (%)
	Malformed (kg/a)	Apical overripe (kg/a)	Below 6 g (kg/a)		
Niigata S3	8.9 b	0.0 b	46.1 a	55.0 c	6.6 b
Echigohime	47.8 a	16.5 a	30.4 b	94.7 a	12.8 a
Asuka-Ruby	45.1 a	1.8 b	28.2 b	75.1 b	6.8 b

^a Plants were transplanted at 25 cm apart in rows and 10 cm inter-row spaces. Planting density was 666.7 plants·are⁻¹. Yield data recorded from 10 plants and 3 replications.

^b Marketable yield includes fruits above 6 g except malformed or apical overripe fruit.

^c Marketable yield in December.

^d Marketable yield from December to February.

^e Percentage of powdery mildew diseased fruit of the total yield.

^f Values within a column followed by different letters are significantly different ($P < 0.05$) among cultivars by Tukey-Kramer test.

method for strawberry cultivars containing large amounts of sugar and hexose may use of parental lines with high total sugar and hexose contents and select F₁ individuals with high sugar content. Referencing these studies, we selected lines for fruit quality and plant vigor for the initial selection. However, the maturation time of strawberry fruit is affected by the cumulative temperature (Morishita and Honda 1985), and in Niigata, temperature and insolation are low during winter. These winter climatic conditions significantly delay the maturation of strawberry fruit in the region, although the extent depends on specific annual conditions. These conditions also make it difficult for plants to maintain vigor during the winter. Therefore, cultivation of vigorous cultivars, which require low effective cumulative air temperature during the fruit maturation period in Niigata, is necessary to reduce the negative effects of suboptimal winter climatic conditions. We selected lines based on early flowering, but the effective cumulative air temperature of 'Niigata S3' was also reduced as a result. Further studies are needed to reveal their relationships.

Many cultivars are not adapted to Niigata due to the difficult conditions during winter, thus, we attempted to improve these characteristics in the total population. This initial step may be important for breeding cultivars that have further adaptability to specific growth conditions. In the end, we established 'Niigata S3', a cultivar that adapts to the winter climatic conditions of Niigata by flowering early and producing high-quality fruit.

Agronomic characteristics

The outstanding features of 'Niigata S3' are early flowering, high soluble solid content, and good coloration under winter conditions. In addition, the upright plant growth and long peduncle of 'Niigata S3' facilitate defoliation of old

leaves and fruit harvesting by farmers. Strong vigor during winter also allows farmers to produce high-quality fruit during low-temperature and insolation conditions. While the 'Echigohime' cultivar can also adapt to low-temperature and insolation conditions, commercial production is hindered by its pale red fruit color in the winter and low shipping quality due to low fruit firmness. Conversely, 'Niigata S3' produces vivid red fruit under low insolation conditions that are of high shipping quality. The fruit quality of 'Niigata S3' was also higher than those of other early ripening cultivars. Early yield (yield during the most economically beneficial period) of 'Niigata S3' was higher than that of 'Echigohime', and incidences of apical overripe and mildew-ridden fruit were lower than those of 'Echigohime'. However, several defects were encountered. The trait of many axillary buds may be troublesome to farmers. Another defect is the lower total yield than 'Echigohime'. While further studies on cultural practices (for example, root zone heating) are required to increase total yields, 'Niigata S3' currently has sufficient commercial productivity and marketability.

Overall, 'Niigata S3' is a useful cultivar that adapts to the winter climate conditions of the Niigata prefecture. Trial production of 'Niigata S3' has started in the intermediate and mountainous areas of the region. This cultivar also has the potential to be widely cultivated in other areas with a low winter temperature and insolation conditions, such as mountainous regions and near the Sea of Japan.

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