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# Cold Hardiness and Foliar Disease Resistance of Northern American and Asian *Fragaria*

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**Abstract**

Thirty-two wild strawberry genotypes and two commercial cultivars were obtained from the US Department of Agriculture (USDA), Agricultural Research Service (ARS), National Clonal Germplasm Repository-Corvallis (NCGR) and planted in the field to test cold hardiness and foliar disease resistance at the University of Minnesota North Central Research and Outreach Center at Grand Rapids, MN. This station is located in USDA plant hardiness zone 3b. Among the 34 genotypes tested, *Fragaria iinumae* was sensitive to powdery mildew, leaf scorch, frost and mid-winter injury while *F. nipponica* was resistant to powdery mildew and leaf scorch. *Fragaria iinumae* suffered severe injury after winter 2009-10, while *F. nipponica* and *F. orientalis* survived that winter well, producing dense and vigorous plants in 2010. These species could be potentially useful diploid or tetraploid parents in breeding programs developing strawberries for the mid-western United States. *Fragaria chiloensis* PI 637983, was similar to the standard cultivars for winter hardiness and disease resistance. Wild strawberries bloomed earlier and had softer, smaller fruit than did the commercial *F. ×ananassa* 'Jewel' and 'Mesabi'. *Fragaria nipponica* had the softest fruit. *Fragaria orientalis* PI 637933 and PI 637939 were notable for their pleasing taste and aroma, while most *Fragaria nipponica, F. iturupensis,* and *F. virginiana* were very sour. The feral *F. ×ananassa* PI 641087 and PI 641088 may have the greatest immediate utility, with a combination of winter hardiness and excellent disease resistance, for octoploid breeding programs.

In the northeastern and mid-western United States and eastern Canada, including northern Minnesota, cold winter weather is a critical limiting factor for strawberry production. Some cultivars released from warmer climates have unknown cold-hardiness levels, which could pose a risk for cold-climate growers. Several breeding programs (US Department of Agriculture (USDA) Agriculture Research Service (ARS) Fruit Laboratory at Beltsville, Cornell University, University of Minnesota, University of Wisconsin-River Falls, University of Guelph, and Agriculture and Agri-Food Canada at Quebec and Nova Scotia) are actively developing new octoploid strawberry (*F. ×ananassa*) cultivars for this region. Diploid cultivars are also grown in this region, primarily in home landscapes, and several cultivars of the species *F. vesca* are available through North American nurseries (2). Wild strawberry species represent potential sources for cold hardiness (5, 10) but this trait is not easily tested by breeders.

Foliar diseases like leaf spot, leaf scorch and powdery mildew are important foliar diseases and could be destructive in strawberry production (7). Disease resistance is one of the important objectives for strawberry breeding programs (6, 7, 13). Strawberry cultivars and wild strawberry species have a varied degree of resistance to leaf diseases and could be utilized in future breeding (4, 12).

Breeders would like to expand the gene pool for commercial strawberries (3, 14). The NCGR in Corvallis, OR acquired wild strawberries that have potential utility in breeding for cold climates. These include: 1) several species from Japan and Russia Federation (4), including the diploids, *F. nipponica* Makino and *F. iinumae* Makino, the tetraploid, *F. orientalis* Losinsk, and the decaploid, *F. iturupensis* Staudt; 2) recent acquisitions of North and South American octoploid *F. chiloensis* (L.) Mill.; and 3) *F. virginiana* Mill. collected

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from high elevations in the southernmost parts of its range in western North America. The objectives of this study were to evaluate these strawberry genotypes for cold-hardiness, frost tolerance, and foliar disease resistance and to document other key plant and fruit traits. In addition, the results were to be documented for the germplasm user community on the Germplasm Resources Information Network (GRIN).

## Material and methods

The evaluation was conducted at the University of Minnesota North Central Research and Outreach Center (NCROC) at Grand Rapids, MN, in USDA plant hardiness zone 3b (1). Field trials at this location have been useful in evaluating strawberry winter injury over the past three decades (8, 16) and selecting cultivars for northern climates based on winter hardiness and other important traits in a collaborative breeding program between the USDA Agriculture Research Service (ARS) and the University of Minnesota (9, 11).

The evaluation included 34 genotypes of *Fragaria iinumae, F. orientalis, F. nipponica, F. iturupensis, F. vesca, F. chiloensis, F. virginiana,* and wild accessions and standard cultivars ('Jewel' and 'Mesabi') of *F. ×ananassa* Duchesne ex Rozier (Table 1). 'Mesabi' was selected at Grand Rapids, MN, and is well adapted there for winter survival and fruiting (11). 'Jewel,' selected in New York (15), is widely grown in the eastern and mid-western US but is not reliably winter hardy for commercial production at Grand Rapids (16).

Wild strawberries were shipped as runners from NCGR-Corvallis and propagated in the greenhouse and in the field at NCROC in 2008. In mid Oct. 2008, plants were dug and potted to 10 cm pots and grown in a heated greenhouse until January 2009, when they were moved to a cellar to spend their dormancy. Potted plants were moved out of the cellar on May 10, 2009, and stayed outdoors until planting.

On 28 May 2009, two, two-plant plots of each genotype were established in each of four blocks in a split block design. In each block, there were two sub-blocks with identical planting plans. One was overwintered with straw mulch, and the adjacent sub-block was overwintered without mulch. In addition to the 34 replicated entries, two other wild genotypes, PI 637954 and PI 641089, with insufficient plants for complete replication, were planted in a border row for observation (Table 1). Starter fertilizer (11-52-0, monoammonium phosphate at rate of 80 g·114 $L^{-1}$ rate and 500 ml solution per plant) was used at planting and no additional fertilizer was applied after planting. Drip irrigation was installed as one T-tape per row (emitters spaced at 305 mm, 1.7 $L \cdot min^{-1}$, 102 $L \cdot h^{-1}$ for 30 m at 55.6 kPa, John Deere Water, San Marcos, CA) and the field was irrigated once or twice per week as a supplement to precipitation. Weeds were manually removed and the space between rows was tilled as necessary to control weeds and runners. Straw mulch of 10-15 cm was applied on mulched plots in early Nov. 2009, and removed to between rows in early Apr. 2010. Straw was also added between the rows of the non-mulched plots in April so that all plots had surrounding straw during the 2010 growing season.

### *2009 Evaluations*

Plants in each plot were initially spaced 0.6 m apart in rows 1.3 m apart. Plants were allowed to runner in 2010 to form short matted row plots. Some genotypes with excessive runners were trimmed manually to maintain them within their plot. Runners per plot were rated on 6 Aug. 2010 from 1 = 1-5 runners per plot; 2 = 6-10; 3 = 11-20; 4 = 21-30; and 5 = >30. Powdery mildew *(Podosphaera aphanis* (Wallr.) U. Braun & S. Takamatsu) and fungal leaf spot (*Mycosphaerella fragariae* (Tul.) Lindau) and leaf scorch (*Diplocarpon earliana* Ell. et Ev. (Wolf)) infections were rated on 6 Aug. and 25 Sept. 2009, from 1 = no disease to 9 = severe infection. Frost resistance was evaluated on 13 Oct. 2009, after several hard frosts from 9 Oct. to 13 Oct. 2009, on a scale from 1 = no damage to 9 = all leaves fully desiccated.

**Table 1.** Wild strawberry (*Fragaria*) genotypes tested.

| Ploidy | Plant introduction | Corvallis | Species | Source |
|---|---|---|---|---|
| Diploid | PI 637963 | 1849.001 | *F. iinumae* HD-2004-15 | Hokkaido, Japan |
| | PI 637964 | 1850.001 | *F. iinumae* HD-2004-23 | Hokkaido, Japan |
| | PI 637965 | 1851.001 | *F. iinumae* HD-2004-25 | Hokkaido, Japan |
| | PI 637966 | 1852.002 | *F. iinumae* HS-2004-32 | Hokkaido, Japan |
| | PI 637967 | 1853.001 | *F. iinumae* HD-2004-38 | Hokkaido, Japan |
| | PI 637968 | 1854.001 | *F. iinumae* HD-2004-40 | Hokkaido, Japan |
| | PI 637969 | 1855.001 | *F. iinumae* HD-2004-42 | Hokkaido, Japan |
| | PI 637970 | 1856.001 | *F. iinumae* HD-2004-48 | Hokkaido, Japan |
| | PI 637971 | 1857.001 | *F. iinumae* HD-2004-50 | Hokkaido, Japan |
| | PI 637972 | 1858.001 | *F. iinumae* HD-2004-53 | Hokkaido, Japan |
| | PI 637973 | 1859.001 | *F. iinumae* HD-2004-63 | Hokkaido, Japan |
| | PI 637982 | 1870.001 | *F. iinumae* HD-2004-89 | Hokkaido, Japan |
| | PI 637974 | 1861.001 | *F.* hybrid (*iinumae* x *nipponica*) HD-2004-67 | Hokkaido, Japan |
| | PI 637980 | 1868.001 | *F.* hybrid (*iinumae* x *nipponica*) HD-2004-78 | Hokkaido, Japan |
| | PI 637975(001) | 1862.001 | *F. nipponica* HD-2004-71 | Hokkaido, Japan |
| | PI 637975(002) | 1862.002 | *F. nipponica* HD-2004-71 | Hokkaido, Japan |
| | PI 637976 | 1863.001 | *F. nipponica* HD-2004-72 | Hokkaido, Japan |
| | PI 637977 | 1864.001 | *F. nipponica* HD-2004-73 | Hokkaido, Japan |
| | PI 637979 | 1866.001 | *F. nipponica* HD-2004-76 | Hokkaido, Japan |
| | PI 637952 | 1827.001 | *F. vesca* f. *bracteata* OJ-2003-11 | Cochise Co., AZ |
| Tetraploid | PI 602942 | 1612.001 | *F. orientalis* 96058 | Jilin, China |
| | PI 637933 | 1801.001 | *F. orientalis* HVSC-001 | Primorye, Russian Federation |
| | PI 637934 | 1803.001 | *F. orientalis* HCSC-035 | Primorye, Russian Federation |
| | PI 637939 | 1808.001 | *F. orientalis* HVSC-120 | Primorye, Russian Federation |
| | PI 637940 | 1809.001 | *F. orientalis* HVSC-121 | Primorye, Russian Federation |
| Octoploid | PI 637983 | 1871.001 | *F. chiloensis* subsp. *pacifica* KH-2004-01 | Gig Harbor, WA |
| | PI 641086 | 1872.001 | *F. chiloensis* subsp. *pacifica* KH-2004-04 | Coos Bay, OR |
| | PI 637951 | 1826.001 | *F. virginiana* subsp. *glauca* OJ-2003-09 | Cochise Co., AZ |
| | PI 637953 | 1828.001 | *F. virginiana* subsp. *glauca* OJ-2003-14 | Lincoln Co., NM |
| | PI 637954 | 1829.001 | *F. virginiana* subsp. *glauca* OJ-2003-20 | Conoino Co., AZ |
| | PI 641087 | 1837.001 | F. ×*ananassa* AS-03-036 | Sakhalin, Russian Federation |
| | PI 641088 | 1838.001 | *F.* ×*ananassa* AS-03-038 | Sakhalin, Russian Federation |
| | PI 641089 | 1839.001 | *F.* ×*ananassa* AS-03-039 | Sakhalin, Russian Federation |
| | PI 551927 | 636.001 | *F.* ×*ananassa* 'Jewel' | cultivar from New York |
| | PI 616936 | 1687.001 | *F.* ×*ananassa* 'Mesabi' | cultivar from Minnesota |
| Decaploid | PI 641091 | 1841.001 | *F. iturupensis* AS-03-042 SG#19 | Iturup Island, Sakhalin, Russian Fed. |

*2010 Evaluations*

In 2010, genotypes were evaluated for several plant and fruit traits. The stand (% coverage of the plot) was estimated on 15 May during flowering and again at the early stage fruiting on 18 June. Winter injury was rated on 4 June from 1 (= all plants surviving and vigorously growing) to 9 (= all plants dead) based on visual estimation of survival of the plants and the health and regrowth of the surviving plants. Plant vigor was rated on 18 June from 0 (= dead) to 9 (= highly vigorous) based primarily on the number and size of leaves produced. Growth habit was rated on 28 June from 1 (= prostrate) to 5 (= erect). Productivity was rated from 0 (no fruit) to 9 (heavily fruiting) when approximately 50% of the fruit appeared to be ripe. Using the same rating scale as in 2009, powdery mildew, fungal leaf spotting (leaf scorch/blight/spot) severity were rated on 7 July and 27 July. Fungal leaf spotting diseases appeared to include leaf scorch, leaf blight and leaf spot in 2010. As all three could be observed on one genotype, and necrotic lesions often coincided, a single fungal leaf disease score was given for each plot.

Berry weight was estimated based on random samples of 20 berries from a midseason harvest date (approximately 50% ripe fruit) from plots that fruited. Fruit shape was described as oblate, globose, globose conic, conic, long conic, necked, long wedge or short wedge according to the University of Florida key (17). External and internal fruit colors were described. Skin toughness was rated from 1 (very tender) to 9 (very tough) based on resistance to thumb abrasion when rubbed between thumb and forefinger. Firmness was rated from 1 (very soft) to 9 (very firm) when squeezed between thumb and forefinger. Flavor was characterized with descriptors and rated hedonically by JJL from 1 (very poor) to 9 (excellent).

Ratings were performed by SY and JJL in 2009 and 2010, respectively. Data for plant and fruit traits in each year were analyzed, where appropriate, using ANOVA with Statistix Software (Analytical Software, Tallahassee, FL). Mean separations were based on Fisher's protected LSD ($P \leq 0.05$).

## Results and Discussion

*Runner number, frost resistance and leaf disease resistance in 2009*

In 2009, most of the wild strawberries runnered vigorously and filled the plots (Table 2). *Fragaria iinumae* genotypes were sensitive to powdery mildew, leaf scorch, and frost injury and *F. nipponica* was resistant to powdery mildew and leaf scorch (Table 2). On 6 Aug. 2009, leaf scorch was common and leaf spot was rarely observed in this experiment**.** On 25 Sept. 2009, the powdery mildew on *F. iinumae* was worse than in August. Also, for all *F. iinumae* genotypes, we had difficulty differentiating damage due solely to leaf scorch or a combination of severe powdery mildew infection and leaf scorch.

Frosts in Oct. 2009 caused little or no visible injury to *F.* ×*ananassa, F. virginiana*, and *F. chiloensis* entries. Genotypes of *F. iinumae* were defoliated or became dormant after frosts in October. Most genotypes of *F. nipponica* likewise lost most of their foliage except for PI 637975(001) that was less affected.

*Winter survival, plant stand disease resistance and growth habits*

Analyses of variance indicated no significant effects of mulching treatments for stand and winter injury ratings so analyses were done using all plots and ignoring the mulching treatment. This was not unexpected as snow cover exceeded 30 cm from early December until late March and probably provided adequate insulation to negate the effect of the straw mulch that was applied in fall 2009.

*Fragaria iinumae* genotypes showed considerable winter injury and poor stand establishment and vigor following Winter 2009-10 (Table 3) even though all produced many runners in 2009 (Table 2). This species could have been subject to early frost damage and high foliar disease could have contributed to the lack of winter survival. PI 637967, PI

**Table 2.** Ratings of wild strawberry (Fragaria) genotypes for runner number, disease severity and frost tolerance in 2009 at Grand Rapids, MN. (LSD P≤0.05). See Materials and Methods for rating scales.

| Plant | Species | Runner rating | Powdery mildew | | Leaf scorch | | Frost tolerance |
|---|---|---|---|---|---|---|---|
| Introduction | | 6 Aug. | 6 Aug. | 25 Sept. | 6 Aug. | 25 Sept. | 13 Oct. |
| PI 637963 | *F. iinumae* | 5.0a | 5.0bc | 7.0a | 3.8de | 3.8ghj | 9.0a |
| PI 637964 | *F. iinumae* | 5.0a | 4.8bc | 7.0a | 1.6jkl | 2.8ij | 9.0a |
| PI 637965 | *F. iinumae* | 4.3abcd | 3.2def | 6.0c | 3.2efg | 4.0fg | 8.0abc |
| PI 637966 | *F. iinumae* | 5.0a | 6.8a | 7.2a | 2.8fgh | 4.0gh | 9.0a |
| PI 637967 | *F. iinumae* | 5.0a | 5.0bc | 7.0a | 1.2kl | 3.0hij | 9.0a |
| PI 637968 | *F. iinumae* | 5.0a | 4.8bc | 6.2bc | 1.0l | 1.8kl | 8.2ab |
| PI 637969 | *F. iinumae* | 5.0a | 3.6de | 6.0c | 2.0hijk | 3.6ghj | 9.0a |
| PI 637970 | *F. iinumae* | 5.0a | 5.6b | 7.0a | 2.6fghi | 3.6ghj | 9.0a |
| PI 637971 | *F. iinumae* | 5.0a | 5.0bc | 7.0a | 1.0l | 2.6jk | 9.0a |
| PI 637972 | *F. iinumae* | 4.8abc | 3.2def | 5.0d | 2.4ghi | 3.6ghj | 9.0a |
| PI 637973 | *F. iinumae* | 5.0a | 3.8d | 6.8ab | 4.0cd | 5.0cde | 9.0a |
| PI 637982 | *F. iinumae* | 4.9ab | 4.6c | 7.0a | 3.2def | 4.8def | 9.0a |
| PI 637974 | *F.* hybrid | 4.8abc | 1.0j | 1.0i | 1.0l | 1.0l | 8.0abc |
| PI 637980 | *F.* hybrid | 5.0a | 1.0j | 1.0i | 2.2hij | 5.2cd | 6.6cde |
| PI 637975(001) | *F. nipponica* | 3.9de | 1.0j | 1.6hi | 1.2kl | 1.0l | 5.2efg |
| PI 637975(002) | *F. nipponica* | 5.0a | 1.0j | 1.0i | 1.0l | 1.0l | 6.6cde |
| PI 637976 | *F. nipponica* | 4.9ab | 1.0j | 1.0i | 1.0l | 1.0l | 6.6cde |
| PI 637977 | *F. nipponica* | 4.9ab | 1.0j | 1.0i | 1.0l | 1.0l | 6.8bcde |
| PI 637979 | *F. nipponica* | 5.0a | 1.0j | 1.0i | 1.0l | 1.2l | 6.6cde |
| PI 637952 | *F. vesca* | 5.0a | 1.2ij | 2.2fg | 3.2def | 3.8gh | 7.0bcd |
| PI 602942 | *F. orientalis* | 4.9ab | 1.0j | 1.2hi | 4.8b | 8.0b | 6.0de |
| PI 637933 | *F. orientalis* | 4.5abcd | 1.0j | 1.0i | 1.0l | 1.0l | 3.6hi |
| PI 637934 | *F. orientalis* | 5.0a | 1.0j | 1.0i | 1.6jkl | 2.6jk | 3.8ghi |
| PI 637939 | *F. orientalis* | 4.3abcd | 1.0j | 1.0i | 1.0l | 1.0l | 2.6ijk |
| PI 637940 | *F. orientalis* | 4.1bce | 1.2j | 1.0i | 1.0l | 1.0l | 3.6hi |
| PI 637983 | *F. chiloensis* | 3.1e | 1.2j | 1.0i | 1.8ijkl | 1.2l | 1.0k |
| PI 641086 | *F. chiloensis* | 4.0cd | 2.2gh | 1.8gh | 1.2kl | 2.6jk | 1.8jk |
| PI 637951 | *F. virginiana* | 4.9ab | 2.8fg | 1.2hi | 5.2b | 9.0a | 4.2fgh |
| PI 637953 | *F. virginiana* | 4.9ab | 1.0j | 1.0i | 5.2b | 5.8c | 3.8ghi |
| PI 641087 | *F. ×ananassa* | 1.8f | 4.8c | 5.8c | 2.2hij | 2.8ij | 5.6def |
| PI 641088 | *F. ×ananassa* | 1.8f | 1.8hi | 1.0i | 6.2a | 5.6cd | 2.6ijk |
| PI 551927 (Jewel) | *F. ×ananassa* | 1.1f | 2.8ef | 4.2ef | 2.2hij | 4.2efg | 2.2ijk |
| PI 616936 (Mesabi) | *F. ×ananassa* | 1.9f | 3.8d | 4.6de | 2.6fghi | 4.2efg | 3.0hij |
| PI 641091 | *F. iturupensis* | 3.1e | 3.2def | 3.8f | 4.8bc | 3.6ghj | 3.6hi |

637969, PI 637971 and PI 637973 were rated as having a greater surviving stand and less winter injury than other genotypes of this species. *Fragaria nipponica* and *F. orientalis* genotypes suffered little or no injury and produced dense, vigorous plant stands in 2010 (Table 3). They likely represent well adapted diploid and tetraploid germplasm sources for the mid-western United States.

The two *F. chiloensis* genotypes were more winter hardy and resistant to fungal diseases than other *F. chiloensis* genotypes included in past evaluations in Minnesota (10, and unpublished data). PI 637983 was especially hardy compared to standard cultivars. *Fragaria chiloensis* PI 637983 may have potential as an ornamental ground cover in the eastern U.S. because it is relatively winter hardy and

**Table 3.** Ratings of wild strawberry (*Fragaria*) genotypes for winter injury, stand, vigor, growth habit and leaf disease severity in 2010 at Grand Rapids, MN. (LSD, p≤0.05). See Materials and Methods for rating scales.

| Plant identification | Species | Stand (%) May | Winter Injury | Stand (%) June | Vigor | Growth Habit | Powdery mildew July 7 | Powdery mildew July 27 | Fungal leaf disease July 7 | Fungal leaf disease July 27 |
|---|---|---|---|---|---|---|---|---|---|---|
| PI637963 | *F. iinumae* | 7.5ij | 6.8ij | 22.5 hijk | 2.9 hijk | 2.0 ij | 3.8cd | 5.2ab | 2.0fgh | 3.6efg |
| PI637964 | *F. iinumae* | 0.0j | 8.1k | 11.3 jkl | n/a | n/a | n/a | n/a | n/a | n/a |
| PI637965 | *F. iinumae* | 5.6ij | 6.5hij | 18.8 ijk | 3.3 ghij | 1.8 jk | 1.2jk | 2.6ghijk | 2.2fg | 2.8fghi |
| PI637966 | *F. iinumae* | 6.9ij | 7.3ijk | 18.8 ijk | 2.4 jk 1.2 | lm3.2 cdef | 4.8abcd | 1.6ghi | 2.6ghij | |
| PI637967 | *F. iinumae* | 12.5hij | 6.1ghi | 22.5 hijk | 2.9 hijk | 1.5 klm | 3.8cd | 5.2ab | 1.2ghi | 1.2k |
| PI637968 | *F. iinumae* | 0.8j | 8.4k | 3.8 i | n/a | n/a | n/a | n/a | n/a | n/a |
| PI637969 | *F. iinumae* | 11.3hij | 5.4fgh | 33.8 gh | 3.8 fgh | 1.4 klm | 4.0bc | 4.8abcd | 1.6ghi | 2.6ghij |
| PI637970 | *F. iinumae* | 5.6ij | 6.8ij | 20.0 hijk | 3.6 fghi | 1.4 klm | 3.2cdef | 5.0abc | 1.6ghi | 2.8fghi |
| PI637971 | *F. iinumae* | 5.6ij | 6.3ghi | 25.0 hij | 2.5 ijk | 1.4 klm | 3.6cde | 4.2bcde | 1.2ghi | 2.0hijk |
| PI637972 | *F. iinumae* | 6.9ij | 7.3ijk | 16.3 ijkl | 2.5 ijk | 1.6 jkl | 1.6hijk | 2.6fghijk | 1.6ghi | 3.8ef |
| PI637973 | *F. iinumae* | 5.6ij | 6.4hi | 21.3 hijk | 3.1 hij | 1.4 klm | 2.0ghijk | 2.8fghij | 3.0ef | 5.2bcd |
| PI637982 | *F. iinumae* | 3.5ij | 7.8jk | 8.8 kl | 1.9 k | 1.2 lm | 2.2fghij | 4.0bcdef | 1.6ghi | 3.0fgh |
| PI637974 | *F.* hybrid | 64.4de | 1.2a | 82.5 a | 7.8 b | 3.8 de | 3.6cde | 3.8cdefg | 1.0hi | 2.8fghi |
| PI637980 | *F.* hybrid | 83.8a | 1.0a | 90.0 a | 9.0 a | 5.0 a | 1.0k | 1.0l | 2.2fg | 5.0cd |
| PI637975(001) | *F. nipponica* | 78.1abc | 1.4a | 87.5 a | 8.5 ab | 4.6 ab | 3.0cdefg | 3.6defg | 1.6ghi | 1.8ijk |
| PI637975(002) | *F. nipponica* | 83.8a | 1.1a | 87.5 a | 8.9 ab | 4.9 ab | 1.2jk | 1.2kl | 1.0hi | 1.6jk |
| PI637976 | *F. nipponica* | 81.9ab | 1.8a | 81.3 ab | 8.9 ab | 4.8 ab | 3.8cd | 3.2efgh | 1.2ghi | 1.2k |
| PI637977 | *F. nipponica* | 85.0a | 1.0a | 90.0 a | 8.5 ab | 5.0 a | 2.0ghijk | 2.6ghijk | 1.0hi | 1.8ijk |
| PI637979 | *F. nipponica* | 78.1abc | 1.1a | 88.8a | 8.4 ab | 4.8 ab | 1.6ijk | 1.6jkl | 1.0hi | 1.2k |
| PI637952 | *F. vesca* | 40.0f | 3.3cd | 62.5cde | 4.4 eg | 1.6 jkl | 5.0ab | 5.0abc | 3.6de | 4.2de |
| PI602942 | *F. orientalis* | 70.6bcd | 1.5a | 82.5a | 7.9 ab | 4.6 ab | 2.6efghi | 3.8cdefg | 6.0ab | 6.2ab |
| PI637933 | *F. orientalis* | 78.0abc | 1.6a | 80.0ab | 8.6 ab | 4.5 bc | 1.0k | 1.8ijkl | 2.2fg | 2.8fghi |
| PI637934 | *F. orientalis* | 65.0de | 1.9ab | 80.0ab | 8.1 ab | 4.1 cd | 1.0k | 1.2kl | 5.2bc | 5.6ab |
| PI637939 | *F. orientalis* | 78.8abc | 1.5a | 83.8 a | 8.3 ab | 4.6 ab | 1.0k | 1.0l | 3.0ef | 3.8ef |
| PI637940 | *F. orientalis* | 54.4e | 1.8a | 77.5ab | 8.0 ab | 3.6 ef | 3.0cdefg | 3.0efghi | 1.6ghi | 1.6jk |
| PI637983 | *F. chiloensis* | 11.9hij | 4.2def | 42.5 fg | 5.5 cde | 1.3 lm | 1.8hijk | 2.0ijkl | 3.8de | 5.6bc |
| PI641086 | *F. chiloensis* | 5.4ij | 7.3ijk | 16.3 ijkl | 3.6 fghi | 1.0 m | 2.2fghijk | 2.8fghij | 1.6ghi | 3.0fgh |
| PI637951 | *F. virginiana* | 31.3fg | 3.3cd | 51.3ef | 5.1 de | 2.6 h | 2.2fghij | 2.6ghijk | 5.8ab | 6.2ab |
| PI637953 | *F. virginiana* | 66.9cde | 1.5a | 76.3abc | 8.1 ab | 3.3 fg | 1.2jk | 1.2kl | 6.6a | 7.0a |
| PI641087 | *F. ×ananassa* | 10.0lj | 5.2efgh | 30.0ghi | 4.8 def | 2.3 hi | 5.6a | 5.8a | 1.2ghi | 1.6jk |
| PI641088 | *F. ×ananassa* | 15.6hi | 4.1de | 43.8 fg | 5.6 cd | 2.5 hi | 1.2jk | 1.2kl | 2.8ef | 3.8ef |
| PI 551927 (Jewel) | *F. ×ananassa* | 36.3fg | 2.3abc | 67.5 bcd | 7.9 ab | 4.8 ab | 3.0cdefg | 3.0efghi | 2.2fg | 2.0hijk |
| PI 616936 (Mesabi) | *F. ×ananassa* | 23.8gh | 3.2bcd | 53.8def | 6.5 c | 3.1 g | 2.8defgh | 5.0abc | 2.2fg | 2.8fghi |
| PI641091 | *F. iturupensis* | 12.5hij | 5.1efg | 27.5 hi | 4.8 def | 1.8 jk | 3.0cdefg | 4.2bcde | 4.6cd | 5.0cd |

**Table 4.** Productivity ratings, berry weight and dates of first and 50% bloom and 50% mature fruit for wild strawberry (*Fragaria*) genotypes in 2010 at Grand Rapids, MN.

| Plant Identification | Species | Productivity | Berry weight (g)* | First bloom date | 50% bloom date | 50% mature fruit date (June)* |
|---|---|---|---|---|---|---|
| PI 637963 | *F. iinumae* | 0.1 j | n/a | 5/27 bc | 5/28 efghi | 17.4 m |
| PI 637964 | *F. iinumae* | n/a | n/a | n/a | n/a | n/a |
| PI 637965 | *F. iinumae* | 0.1 j | n/a | 5/28 b | 6/5 bc | 17.4 m |
| PI 637966 | *F. iinumae* | 0.1 j | n/a | 5/27 bc | 6/6 b | 15.0 |
| PI 637967 | *F. iinumae* | 0.0 j | n/a | 5/26 bcd | 6/1 de | n/a |
| PI 637968 | *F. iinumae* | n/a | n/a | n/a | n/a | n/a |
| PI 637969 | *F. iinumae* | 0.0 j | 1.0 | 5/17 ijk | l6/1 def | n/a |
| PI 637970 | *F. iinumae* | 0.0 j | n/a | 5/24 bcde | 5/28ghijk | n/a |
| PI 637971 | *F. iinumae* | 0.0 j | n/a | n/a | n/a | n/a |
| PI 637972 | *F. iinumae* | 0.2 ij | n/a | 5/21 defgh | 5/26 hijk | 18.0 |
| PI 637973 | *F. iinumae* | 0.1 j | n/a | 5/22 defg | 5/27 ghijk | 23.0 |
| PI 637982 | *F. iinumae* | 0.3ij | n/a | 5/23 cdef | 5/28 fghi | n/a |
| PI 637974 | *F.* hybrid | 0.6 hij | 1.0 | 5/18 ghijk | 5/25 ijk | 17.5 lm |
| PI 637980 | *F.* hybrid | 2.5 b | 1.2 ef | 5/19 fghij | 5/26 hijk | 20.5 ijkl |
| PI 637975(001) | *F. nipponica* | 1.1 | 0.7 | 5/19 fghij | 5/25 ijk | 18.3 lm |
| PI 637975(002) | *F. nipponica* | 1.0 fgh | 0.9 | 5/18 hijk | 5/25 ijk | 17.6 lm |
| PI 637976 | *F. nipponica* | 2.0 bcd | 0.7 ef | 5/16 jkl | 5/24 jk | 21.6 ijkl |
| PI 637977 | *F. nipponica* | 2.1 bc | 0.9 ef | 5/19 fghijk | 5/25 ijk | 22.3 ghij |
| PI 637979 | *F. nipponica* | 1.4 | 0.9 ef | 5/18 hijk | 5/26 hijk | 23.3 efgh |
| PI 637952 | *F. vesca* | 1.1 | 0.0 g | 5/18 ghijk | 5/27 ghijk | 21.1 ijkl |
| PI 602942 | *F. orientalis* | 0.0 j | n/a | 5/14 kl | 5/24 k | n/a |
| PI 637933 | *F. orientalis* | 1.5 | 0.7 ef | 5/18 hijk | 5/26 hijk | 26.6 abcd |
| PI 637934 | *F. orientalis* | 0.0 j | n/a | 5/30 efghij | 5/29 efgh | n/a |
| PI 637939 | *F. orientalis* | 1.8 cde | 0.8 ef | 5/19 fghij | 5/25 ijk | 29.4 ab |
| PI 637940 | *F. orientalis* | 0.0 j | n/a | 5/20 efghi | 5/28 ghij | n/a |
| PI 637983 | *F. chiloensis* | 0.0 j | n/a | 6/7 a | 6/14 a | n/a |
| PI 641086 | *F. chiloensis* | 0.0 j | n/a | n/a | n/a | n/a |
| PI 637951 | *F. virginiana* | 1.3 | 0.5 | 5/16 jkl | 5/26 ijk | 20.9 ijkl |
| PI 637953 | *F. virginiana* | 0.9 ghi | 0.9 | 5/12 l | 5/25 ijk | 21.4 ijkl |
| PI 641087 | *F. ×ananassa* | 1.6 | 3.0 e | 5/21 efghi | 5/31 efgh | 23.8 efgh |
| PI 641088 | *F. ×ananassa* | 1.3 | 3.2 | 5/24 bcde | 5/30 defg | 24.9 cdef |
| PI 551927 (Jewel) | *F. ×ananassa* | 5.1 a | 14.5 a | 5/25 bcd | 6/2 cd | 30.5 a |
| PI616936 (Mesabi) | *F. ×ananassa* | 4.6 a | 11.2c | 5/24 bcde | 5/31 defg | 27.8 abc |
| PI 641091 | *F. iturupensis* | 0.9 ghi | 0.2 g | 5/16 ijkl | 5/24 jk | 19.3 klm |

* If a genotype has only a value for a trait without letter(s), it had less than 4 out of 8 replicates producing fruit so the number was the average of fruiting replicates but this genotype was not included in the statistical analysis.

resistant to fungal diseases compared to other genotypes of the species that we have evaluated in Minnesota (unpublished data). The *F. iturupensis* PI 641091 was weak in establishing a stand, suffered winter injury, and was moderately susceptible to diseases in this trial. Plants of *F. orientalis* and *F. nipponica* were highly vigorous and upright in growth habit, similar to 'Jewel'. Plants of *F. iinumae, F. iturupensis, F. chiloensis,* and F. *vesca* were prostrate (Table 3).

Powdery mildew was less severe in 2010 than in 2009. Though there was some variation within species, *F. orientalis* genotypes were less severely infected by powdery mildew than genotypes of *F. iinumae* or *F. nipponica* (Table 3). The severity of powdery mildew infection on *F. orientalis* genotypes was similar to that of 'Mesabi' and 'Jewel.' Severity of fungal leaf spotting diseases varied considerably among accessions of *F. orientalis*, *F. iinumae*, and *F. nipponica* and several apparently resis-

**Table 5.** Descriptions of fruit traits of wild strawberry (*Fragaria*) genotypes at Grand Rapids, MN in 2010.

| Plant identification | Species | Shape | External Color | Internal Color | Skin toughness | Firmness | Flavor |
|---|---|---|---|---|---|---|---|
| PI 637963 | *F. iinumae* | Necked pinched | Orange-red | Orange | 7 | 5 | 5 sweet, mild |
| PI 637964 | *F. iinumae* | No fruit | | | | | |
| PI 637965 | *F. iinumae* | No fruit | | | | | |
| PI 637966 | *F. iinumae* | No fruit | | | | | |
| PI 637967 | *F. iinumae* | No fruit | | | | | |
| PI 637968 | *F. iinumae* | No fruit | | | | | |
| PI 637969 | *F. iinumae* | No fruit | | | | | |
| PI 637970 | *F. iinumae* | No fruit | | | | | |
| PI 637971 | *F. iinumae* | No fruit | | | | | |
| PI 637972 | *F. iinumae* | Globose | Orange red | White | 2 | 2 | 3 tart |
| PI 637973 | *F. iinumae* | No fruit | | | | | |
| PI 637982 | *F. iinumae* | Oblate | Orange red | White | 3 | 4 | 3 tart |
| PI 637974 | *F.* hybrid | Long conic, necked | Orange red | White | 2 | 4 | 4 |
| PI 637980 | *F.* hybrid | Short wedge | Orange Pink | White | 2 | 3 | 4 tart |
| PI 637975(001) | *F. nipponica* | Necked | Orange red | White | 2 | 4 | 5 tart, aromatic |
| PI 637975(002) | *F. nipponica* | Long wedge | Orange red | White | 2 | 5 | 6 aromatic |
| PI 637976 | *F. nipponica* | Necked-long wedge | Orange red | White | 2 | 3 | 5 sweet-tart, aromatic |
| PI 637977 | *F. nipponica* | Conic-necked | Orange red | White | 2 | 4 | 4 tart |
| PI 637979 | *F. nipponica* | Globose | Orange red | White | 2 | 4 | 4 tart, aromatic |
| PI 637952 | *F. vesca* | Globose | Red | White | 3 | 4 | 4 powdery mildew on fruit |
| PI 602942 | *F. orientalis* | No fruit | | | | | |
| PI 637933 | *F. orientalis* | Conic wedge | Very dark Purple | white | 8 | 6 | 6 sweet, aromatic, seedy indeterminate flowering habit |
| PI 637934 | *F. orientalis* | No fruit-male | | | | | |
| PI 637939 | *F. orientalis* | Globose | Pink Red | white | 5 | 5 | 7 sweet, aromatic, candy flavor |
| PI 637940 | *F. orientalis* | No fruit-male | | | | | |
| PI 637983 | *F. chiloensis* | No fruit-male | | | | | |
| PI 641086 | *F. chiloensis* | No fruit-female | | | | | |
| PI 637951 | *F. virginiana* | Globose | Pink-red | White | 4 | 4 | 5 sweet, mild |
| PI 637953 | *F. virginiana* | Oblate | Red | Red | 2 | 4 | 3 tart |
| PI 637954 | *F. virginiana* | Oblate | Orange | Orange | 3 | 3 | 5 bland |
| PI 641087 | *F. ×ananassa* | Globose conic | Red | White | 5 | 5 | 4 |
| PI 641088 | *F. ×ananassa* | Oblate, lumpy | Red | White | 5 | 5 | 6 sweet, mild, powdery mildew on fruit |
| PI 641089 | *F. ×ananassa* | Conic, pinched | Red | Light red | 5 | 5 | 6 sweet, mild |
| PI 551927 (Jewel) | *F. ×ananassa* | Short wedge | Red | Red | 8 | 8 | 8 balanced |
| PI 616936 (Mesabi) | *F. ×ananassa* | Conic-short wedge | Dark red | Red | 7 | 7 | 8 balanced, aromatic |
| PI 641091 | *F. iturupensis* | Globose conic | Pink | White | 5 | 4 | 4 tart |

tant genotypes having few or no lesions were identified (Table 3).

*Productivity, blooming date and mature date*

In this region, early spring bloom can predispose strawberry plantings to frost injury in many years. Dates of first bloom extended over a two week period from 12 May to 28 May for most genotypes (Table 4). Most wild genotypes bloomed earlier than the cultivars (24-25 May). Bloom of *F. iinumae* may have been delayed by winter injury. *Fragaria chiloensis* PI 637983 did not begin blooming until almost two weeks after the cultivars. *Fragaria orientalis* PI 637933 has an indeterminate inflorescence habit that results in an extended period of flowering similar to the habit observed on some genotypes of *F. virginiana*.

Few of the wild strawberries exhibited heavy fruit production (Table 4). *Fragaria orientalis* PI 602942, PI 637934, PI 637940 and *F. chiloensis* PI 637983 appeared to be functionally staminate. Most *F. iinumae* were probably too badly winter injured to produce fruit, however, fruit of PI 637963 were notable for relatively good skin toughness and firmness. 'Mesabi' and 'Jewel' ripened most of their fruit during the last week of June while most of the wild genotypes reached 50% ripe fruit about 5 to 10 days earlier.

Mean berry weights for 'Jewel' and 'Mesabi' were 14.5 and 11.2 g/berry, respectively, while weights of wild genotypes that fruited ranged from 0.2 g for *F. iturupensis* PI 641091 to 1.2 g for *F. nipponica* PI 637979. Feral or introgressed *F.* ×*ananassa* such as PI 641087 and PI 641088 had berry weights of approximately 3 g.

*Fruit characters*

Fruit of the wild genotypes were very small, tender and soft compared to fruit of the standard cultivars. The fruit of *F. nipponica* was the most tender (Table 5). Photos are available at the USDA-ARS Germplasm Resources Information Network (http://www.ars-grin.gov/). Fruiting genotypes of *F. orientalis* and some *F. nipponica* were notably aromatic while *F. nipponica, F. iturupensis* and *F. virginiana* genotypes were simply tart and unremarkable. Fruit of *F. orientalis* PI 637933 and PI 637939 were notable for excellent flavor and aroma. All the wild strawberries had less pigment in the flesh, ranging from white to orange and light red, compared to 'Mesabi' and 'Jewel' which have deep red, heavily pigmented flesh.

## Conclusions

Genotypes of wild strawberry species recently acquired by the USDA National Clonal Germplasm Repository vary considerably for plant and fruit traits. The feral *F.* ×*ananassa* genotypes PI 641087 and PI 641088 may have greatest immediate utility with their combination of winter hardiness and excellent disease resistance for improvement at the octoploid level. In addition, *F. chiloensis* PI 637983 may also have value as a landscape plant or for incorporation in *F.* ×*ananassa* breeding programs. Among the lower ploidy species, we do not recommend *F. iinumae* for strawberry breeding for colder climates due to its lack of winter hardiness. *Fragaria orientalis* PI 637933 and PI 637939 and *F. nipponica* PI 637976 displayed excellent winter hardiness with less severe foliar disease and had desirable fruit characters which may be useful to improve strawberry at lower ploidy levels.

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