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Breeding Potential of Lower Ploidy *Fragaria* Species

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Abstract

The recent discovery of the narrow genetic base of the cultivated strawberry has sparked a renewed interest in the use of wild *Fragaria* species in breeding programs. The two progenitor octoploid species, *F. chiloensis* and *F. virginiana* are the only species that have been predominantly used in strawberry breeding. There are however, several lower ploidy *Fragaria* species (2x, 4x, and 6x) with desirable characteristics such as unique flavors, vigor, disease and pest resistance, and adaptability to a wide range of habitats that also have potential for use in breeding programs. The development of the synthetic octoploid system has created the opportunity to efficiently incorporate lower ploidy wild species germplasm into the cultivated strawberry. A better understanding of the characteristics of the lower ploidy wild species may assist in the effective use of this valuable germplasm.

Modern strawberry cultivar and germplasm development

Strawberries are herbaceous perennials that belong to the genus *Fragaria* of the Rosacea family. The genus *Fragaria* consists of at least 15 recognized species with different chromosome numbers (ie. 2x, 4x, 6x and 8x) (10). The cultivated strawberry, *Fragaria x ananassa,* is an octoploid species and there is no evidence to suggest that any of the lower ploidy species were involved in its synthesis (4). The cultivated strawberry was originally derived in France around 1750 from the accidental hybridization of two wild octoploid (8x) species which were identified by Antoine Duchese in 1766 as *Fragaria chiloensis* and *Fragaria virginiana* (12,6). Duchese named this octoploid hybrid *F. x ananassa* because of the pineapple-like flavour of the fruit. In 1817, Thomas A. Knight in England used this hybrid as the basis of the first systematic breeding program in strawberries. He produced the first *F. x ananassa* cultivars which became the progenitors of the modern cultivated strawberry (6).

The success of the *F. x ananassa* cultivars resulted in breeding efforts with wild species being largely focused on *F. virginiana* and *F. chiloensis* (15). The relative ease with which these two octoploid species could be crossed with the cultivated types also contributed to the focus on these species. *F. chiloensis* and *F. virginiana* have been used to introduce genetic diversity and desirable traits such as disease resistance, fruit characteristics and vegetative vigor into the cultivated strawberry (12,13, 20). Although these and other traits could be found in the lower

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ploidy *Fragaria* species (2x, 4x, and 6x), these species were not widely used in breeding efforts as they were difficult or impossible to cross with the octoploid cultivars.

North American cultivars introduced since 1960 were descended from only 17 cytoplasmic sources (5). Recognition of this narrow range of diversity has renewed interest in the use of *Fragaria* species to enhance genetic diversity and to improve the cultivated strawberry (16). While the octoploid species *F. chiloensis* and *F. virginiana* offer unique genetic and horticultural traits (12,13, 20), the lower ploidy species should not be overlooked as a valuable resource for both genetic diversity and desirable traits.

Synthetic octoploids

The use of lower ploidy species to enhance strawberry cultivars is not a new concept. Attempts have been made for decades to introgress lower ploidy species, but have been met with very limited success (19). Research with lower ploidy species began at the University of Guelph in the 1970s with the development of a synthetic octoploid (SO) system. In the SO system, interspecific crosses between lower ploidy species are made resulting in tetraploid hybrids. These hybrids are then treated with colchicine resulting in octoploid hybrids composed of germplasm from several species. The ocotoploid hybrids or SOs can then be integrated into the cultivated octoploid strawberry (19). The development of SOs has allowed germplasm from wild species to be introgressed into modern cultivars (19).

The use of this method led to the creation of the first SO breeding clones, Guelph SO1 and Guelph SO2 (7, 8). Intense selection for two to three generations after the initial SO x cultivar hybrid resulted in genotypes performing at the elite germplasm or pre-cultivar level (19). Recent work at the University of Guelph has led to the creation of several more SOs that encompass nine species from 2x, 4x and 6x ploidy levels (2).

Breeding potential of lower ploidy Fragaria species

Efforts to incorporate the lower ploidy species into the cultivated strawberry have been driven by the desire to expand the genetic base of the strawberry, and to exploit several desirable characteristics that have been identified in these species. Horticultural, physiological, and vegetative characteristics as well as disease and pest resistance have been identified in the most promising of the lower ploidy wild species (Table 1).

Adaptability. Fragaria species can be found in a wide range of ecological backgrounds including, grassland, Mediterranean, subtropical, and temperate habitats (10). The habitat of a species can influence physiological characteristics such as CO_2 assimilation (A) and flower bud initiation. For example, the octoploid species *F. virginiana* is found in meadows of central and eastern North America where it is exposed to both high and fluctuating temperatures (11, 20). Adaptation to such a climate has allowed *F. virginiana* to maintain high rates of A under the same high temperatures which can cause the A rates of *F. x ananassa* to be reduced by an average of 42% (20).

Some of the species such as *F.orientalis* and *F. pentaphylla* are found in alpine habitats. Other species such as *F. moschata* are found primarily in forest habitats, characterized by shade or low light conditions (Table 1). A species adapted to shade might maintain higher A rates under low light conditions which could be beneficial in greenhouse production, in areas with lower light levels, and under higher plant populations. Adaptation to low light may allow increased flower bud initiation if the plant can efficiently carry out A under the lower light conditions that are often prevalent during the fall. This may also be beneficial to day neutral plants to allow increased fruit production in lower light periods or conditions.

There are yet other species that are native to a wide range of habitats. *F. vesca,* the most widely distributed species in the genus, inhabits North and South America, Europe, Asia, and Hawaii (18). The conditions in which this species can be found are very diverse; it is native to alpine, forest and coastal habitats. This can be beneficial in developing cultivars

Table 1. Origin and characteristics of selected *Fragaria* species.

Species	Origin	Habitat	Characteristics	Source
Diploids (2n = 14)				
F. vesca L.	Circumpolar, North Africa South American mountains	Variable	Highly adaptable High heat/drought tolerant Cold tolerant Resistant to verticillium wilt, powdery mildew, red core, crown rot	21 6 1 9 14 15
F. nilgerrensis Schlect.	South Indo-China	Light woodland, partial Shade Up to 1500m elevation	High runner production Resistant to aphids and leaf disease	11 3 21 16
F. pentaphylla Losinsk	Northern China	Grassy mountain slopes 1000-2000m elevation	Extremely vigorous Bright red, firm fruit Leaf disease immunity	3
F. viridis Duch.	Most of Europe, Eastern and Central Asia, Canary Islands	Open grassland hills Small forest areas and brush	Tolerant to alkaline soils Firmness Cold tolerant	11 6 16
Tetraploids (2n = 28)				
F. orientalis Losinsk	Euro-Siberia	Forests, mountain slopes Prefers full sun Often found in stoney soils Cold dry areas in Asia	Cold tolerant Drought resistant	6
Hexaploids (2n = 42)				
F. moschata Duch.	Euro-Siberia	Forests, scrub, tall grass Shade conditions	Highly shade adapted Tolerant to cold winters and water logged soils Resistant to powdery mildew Extremely vigorous Aromatic, musky flavour	6 3 17

that are capable of high yield potential under a wide range of environments or in areas that have extreme fluctuations in climate. There are also other species adapted to environments outside of the typical range of conditions for strawberry, such as saline or waterlogged soils, low light conditions and drought or cold conditions (Table 1).

Disease Resistance. Strawberries are susceptible to numerous pests and diseases that can cause serious damage and economic losses (17). With increased restrictions on pest control products available to growers, cultivars that are resistant to common diseases and pests play an important role in any management system. Resistance or tolerance to disease and/or pests has been observed in several lower ploidy species (Table 1). *F. vesca* has been extensively studied and has shown resistance to *Verticillium albo-atrum* (Verticillium wilt) (11), *Sphaerotheca macularis* f. sp. *fragariae* (powdery mildew) (14), *Phytophthora fragariae* (red stele) (15) and *Phytophthora cactorum* (crown rot) (9). *F. moschata* has resistance to powdery mildew and to leaf diseases (3, 17). In a study conducted in Ontario, *F. pentaphylla* was found to be immune to leaf diseases and *F. nilgerrensis* was found to have immunity to aphids and leaf diseases (3). These wild species represent new sources of genes for resistance to these diseases and pests.

Fruit and Vegetative Characteristics. Although many of the species do not produce high volumes of fruit there are some species that have characteristics that would be desirable to incorporate into the cultivated strawberry. *F. moschata* was cultivated in early European gardens and was known for its distinctive musky, highly aromatic fruit (6). *F. pentaphylla* has very bright red, firm fruit (3), ideal for strawberries that are shipped to different markets. *F. nilgerrensis* has prolific runner production (11) which is a valuable characteristic for propagation and establishing matted rows. Upright cymes, a characteristic of *F. moschata,* are desirable as they allow air movement around the fruit which can reduce disease such as botrytis fruit rot *(Botrytis cinerea)* and facilitate harvest.

Future use of wild species

A great deal of breeding potential has been identified in the lower ploidy species but it has yet to be utilized. Renewed interest in wild species and the refinement of the synthetic octoploid system (3) has created interest in lower ploidy *Fragaria* species. As there has been so little research carried out on these species, there are several avenues for future research. Perhaps the most efficient place to start is to develop a better understanding of the characteristics of these species such as physiological characteristics and the influence of ecological background. Knowing how they behave when combined into synthetic octoploids or used in breeding can allow more effective use of this germplasm.

Another avenue of research is to investigate the human health attributes that some of the wild species may possess. Strawberry cultivars are a good source of antioxidants (22). Further study is needed to identify the antioxidant capacity of the wild strawberry species. One subspecies of *F. nilgerrensis* has been found to have valuable anthocyanins present in all parts of the plant (11). Other wild species may also have high antioxidant capacity.

Lower ploidy *Fragaria* species hold a great deal of potential to improve modern strawberry cultivars by introducing traits such as unique flavors and disease resistance while increasing genetic diversity. By developing an understanding of the characteristics and breeding behaviour of this unexploited germplasm the potential will be realized and can be used in the development of future cultivars and germplasm.

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