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Chaenomeles: Potential New Fruit Crop for Northern Europe

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INTRODUCTION

A number of plant species, that have only rarely been cultivated in the past, are now being investigated for possible domestication in northern Europe. Species within the Rosaceous genus *Chaenomeles* (also referred to as the common name of these species) have received increased attention because of their high yield of fruits, which are rich in juice, aroma, and dietary fiber, and because of their presumed potential for cultivation with organic production methods. In the Baltic region, development of Japanese quince (*C. japonica*) started in Latvia 1951. In 1993, the interest for growing Japanese quince reached a peak. Plantations in Latvia and Lithuania at that time comprised more than 400 ha. However, the seed propagated plants were very variable in several traits, including important fruit characters. This heterogeneity made field management difficult, cultivation less profitable and prevented the development of high quality products. At the same time the shift in economical system in the independent Baltic countries contributed to a strong competition on the market from import of exotic juice concentrates. Consequently the interest in growing Japanese quince dropped drastically. The need for improved plant material became obvious and a joint Latvian-Lithuanian-Swedish plant breeding program was therefore initiated. In this paper, the genus *Chaenomeles* is introduced, and its potential and utilization as a fruit crop is reviewed.

THE GENUS *CHAENOMELES*

Systematic Position

The genus *Chaenomeles* Lindley (chaenomeles) is assigned to the subfamily Maloideae of the ecologically and economically important Rosaceae (Phipps et al. 1990). Within Maloideae, *Chaenomeles* is most closely related to the genera *Cydonia* (quince), *Docynia*, *Malus* (apple) and *Pyrus* (pear). *Chaenomeles* has obtained its name from the Greek *chaino*, "to gape," and *melon* "apple," based on Thunberg's 1784 description of the type species for the genus: *C. japonica* (Thunb.) Lindl. ex Spach (Weber 1964). This description is not considered correct, since the fruit very seldom splits (Weber 1964), but is a phenomenon that has been noticed occasionally.

Taxonomy

Four species, *C. cathayensis* (Hemsl.) Schneider (Chinese quince), *C. japonica* (Thunb.) Lindl. (Japanese quince or dwarf Japanese quince), *C. speciosa* (Sweet) Nakai (flowering quince), and *C. thibetica* Yü (Tibetan quince) are now recognized in *Chaenomeles* (Phipps et al. 1990). Four hybridogenous taxa, resulting from successful ornamental plant breeding, are also discriminated (Weber 1964): *C.* ×*superba* (Frahm) Rehder (*C. japonica* × *C. speciosa*, Superba group), *C.* ×*clarkiana* Weber (*C. cathayensis* × *C. japonica*, Clarkiana group), *C.* ×*vilmoriniana* Weber (*C. cathayensis* × *C. speciosa*, Vilmoriniana group), and *C.* ×*californica* Clarke ex Weber [*C. cathayensis* × (*C.* ×*superba*), Californica group].

Taxonomic confusion has throughout the history been extensive for the genus *Chaenomeles*. The separation of the four chaenomeles species from the two quince species (*Cydonia oblonga* and *Cydonia sinensis*) is now supported by morphological studies of the fruits (Rataru and Ponomarenko 1993) and by molecular studies (Campbell et al. 1995; Kaneko et al. 2000). The taxonomic confusion and the fact that not all *Chaenomeles* species had been thoroughly studied were two reasons to re-investigate the genus by morphology and by various molecular markers (Rumpunen 2001). A large collection of wild Chinese and Japanese *Chaenomeles* accessions was therefore assembled and studied. In agreement with previous studies on cultivated *Chaenomeles* material (Bartish et al. 1999; Garkava et al. 2000) *C. japonica* was clearly differentiated from *C. speciosa* and *C. cathayensis* (Bartish et al. 2000a). The recently recognized species *C. thibetica* appeared to be rather closely related to *C. cathayensis*. Populations of *C. japonica* and *C. speciosa* were considerably more diverse than populations of *C. cathayensis* and *C. thibetica*. Correspondingly, most of the total variability could be attributed to within-population differentiation in the case of *C. japonica* and *C. speciosa*, and to between-population differentiation in the case of *C. cathayensis*. Differences in mating systems among the species was suggested as a possible explanation for these results (Bartish et al. 2000a). Furthermore, analysis of diagnostic RAPD markers and of chloroplast DNA haplotypes supported the notion of spontaneous hybridization between *C. cathayensis* and *C. speciosa* in some wild populations (Bartish et al. 2000b).

Cytogenetics, Mating System, and Patterns of Inheritance

The basic chromosome number of $x = 17$, and the diploid count $2n = 34$ for *C. cathayensis*, *C. japonica*, and *C. speciosa* was reported by Moffett (1931) and has later been confirmed (Weber 1964; Saito and Kaneko 1975; Singhal 1990). The same chromosome number has recently been obtained for *C. thibetica* (S. Kauppinen, unpubl. data). Tetraploidy has been reported only in one cultivar with very large flowers (Weber 1964). A large number of *C. japonica* polyploids have however been developed within the ongoing plant breeding program (unpubl. results).

Distribution and Ecology

Chaenomeles japonica is a dwarf shrub (0.6–1.2 m) which occurs in central and south Japan at elevations from 100–2100 m on hillsides, and on riverbanks and lakeshores (Weber 1964). The other three species are mainly distributed in China, with a presumed center of origin in Yunnan and Tibet, but their precise distribution and ecology is not yet fully known. *Chaenomeles thibetica* is a large shrub (1.5–3 m) and wild-growing populations have been reported from 2700 m. It has, however, been reported in cultivation at the remarkable altitude of 3760 m (Yü and Kuan 1963). *Chaenomeles cathayensis* is a large shrub or a small tree (up to 6 m) which grows at 900–2500 m, and *C. speciosa* is a large shrub (2–5 m) which grows at 200–1700 m (Weber 1964). The Chinese species grow on hillsides, in open thickets, on rocky slopes, in ravines, and in forests. From the distribution of the species and from their performance in cultivation, it may be concluded that the Chinese species are mainly continental and the Japanese species is coastal. All species normally have abundant thorns, terminating short or long shoots. However, mass selection has considerably reduced the frequency of thorns in the plant material presently cultivated in Latvia and Lithuania. A few thornless cultivars of *C. japonica*, *C. speciosa*, and *C. ×superba* are also known (Buchter-Weisbrodt 1992; Weber 1964).

Floral Biology

On plants of *C. cathayensis*, *C. japonica*, and *C. speciosa* (*C. thibetica* not yet thoroughly studied), 1 to 6 flower buds occur in clusters, on two-year-old or older branches. The flower buds are normally formed during late summer and autumn, but may develop as either short shoot type (in the spring and in the late autumn) or long shoot type (from late spring to late autumn).

The showy flowers of *Chaenomeles* are usually classified as perfect and homomorphic (Kaufmane and Rumpunen 2002a). Nevertheless, when screening collections and breeding populations, it was noticed that almost every plant also had several “imperfect” flowers with stunted, sterile pistils. This is in agreement with previous observations (Weber 1964) where every studied species were reported to also form unisexual flowers (female and male, respectively). The size and shape of the hypanthium forming the base of the flowers may be used to distinguish unisexual flowers, a short cup-shaped hypanthium being typical for functionally male flowers (Weber 1964; Kaufmane and Rumpunen 2002a).

The flowers of all species within the genus *Chaenomeles* normally have five sepals and five petals. The petals can vary from white to darkest red through pink, orange, and scarlet, and bi-colored petals are frequent (Weber 1964). The number of stamens is usually large, 40–60. The stamens are of somewhat varying length, and are placed in two circles. The female gametophyte develops in the deeply inferior ovary at the base of the pistil (Kaufmane and Rumpunen 2002b). In general 5 styles are fused for 1/3 to 2/3 of their length and the column formed by the styles is characteristic for the genus *Chaenomeles* (Weber 1964). The stigma is of the wet type, group III, following the classification of Heslop-Harrison and Shivanna (1977) and is receptive at anthesis (Kaufmane and Rumpunen 2002a). Pollinating vectors are honeybees and bumblebees, which are attracted to the nectar-rich but scentless flowers. Each locule in the ovary contains up to about 20 ovules (arranged horizontally in two rows), of which about 6–10 functional ovules develop in *C. japonica*. Within Maloideae, multiovulate carpels are also found in *Cydonia* and *Docynia* (Rohrer et al. 1994), which results in the development of numerous seeds in each fruit.

Fruit Morphology

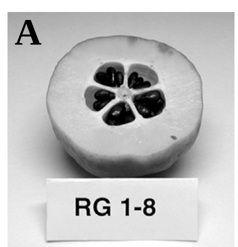
The fruits of *Chaenomeles* are pomes and very diverse in shape (Weber 1964; Mezhenskij 1996; Yü and Kuan 1963) (Fig. 1). The fruit of *C. japonica* is usually the smallest in the genus. It is apple-shaped, about 4 cm in diameter, with a weight below 50 g. By contrast, *C. cathayensis* has the largest fruit in the genus. It is ovoid, up to 15 cm long and 8 cm broad, with a weight of about 180 g, occasionally up to 600 g or more (Shao and Lu 1995). The fruit of *C. thibetica* is oblong and pear-shaped, typically 6–11 cm long and 5–9 cm in diameter. The fruit of *C. speciosa* vary in size and shape. It is typically 4–7 cm long and 3–6 cm in diameter, with a weight of up to 140 g but usually smaller. Typically up to 80 seeds develop in the fruit of *C. japonica*, up to 100 in *C. speciosa* and up to 120 in *C. cathayensis* (no information yet available for *C. thibetica*) (Fig. 2).

The sticky cuticle of *C. japonica* fruit, and some of its interspecific hybrids, is a sign of maturity, as are brown seeds (Weber 1964). The fruit of *C. japonica* is usually the earliest ripening (at the end of August in the Baltic climate). The fruit of *C. speciosa*, and especially *C. cathayensis*, needs more heat to develop the typical yellow color (sometimes yellowish green and somewhat red) and does not normally ripen in the Baltic climate. Fruits of all *Chaenomeles* species become more or less fragrant during ripening, but do not soften, and must therefore be processed before consumption.

Utilization as a Fruit Crop

The high content of organic acids in the juice, distinctive aroma, and high amount of dietary fiber, make the fruits of *C. japonica* well suited for industrial processing (Lesinska 1986, 1987, 1988). Furthermore, the fruit is not sensitive to oxidative browning during processing, and the juice contains a high level of vitamin C and phenolic compounds (Lesinska and Kraus 1996) that act as antioxidants. The antioxidant activity of flavonoids in *C. japonica* is just somewhat lower than the antioxidant activity of flavonoids in *R. rugosa* (Gabrielska et al. 1997). The phenotypic variation in content of organic acids, soluble solids, and total antioxidant activity is large (Rumpunen and Kviklys 2001). The flavor components of *C. japonica* are considered partly similar to apples and quince, and partly similar to citrus fruits (Lesinska and Kraus 1996; Lesinska 1988). Based on the chemical composition and characteristics of the fruit, several products have been proposed and developed (Lesinska 1986; Lesinska and Kraus 1996). It is for instance possible to produce juice, wine, purée, aroma-extracts, pectin, dietary fiber, etc. Syrup, liqueur, carbonated soft drinks, marmalades, and candies are the main products that have been available in Latvian and Lithuanian markets (Ruisa 1996). Furthermore, a sugar-juice aroma extract has recently proven to provide excellent flavor in ice cream and yogurt.

Fig. 1. Typical fruit of *C. speciosa* (flowering quince), *C. japonica* (Japanese quince), and *C. cathayensis* (Chinese quince), respectively.



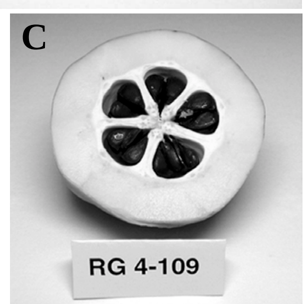


Fig. 2. Dissected fruit of A) *C. speciosa* (flowering quince), B) *C. japonica* (Japanese quince), and C) *C. cathayensis* (Chinese quince), revealing the numerous seeds in each locule. The length of the paper strip is 5 cm.

Propagation

Chaenomeles species can easily be generatively propagated. Germination rates between 95% and 100% are frequently obtained, provided that seeds are not allowed to dry out before being properly stratified. A month at 2° to 4°C in moist substrate is sufficient (Tiits 1989) but in commercial propagation a period of 2–3 months or longer is commonly used. Cultivars must be vegetatively propagated. Whereas chaenomeles cultivars can be grafted, as well as propagated by root pieces, by layering or by hardwood cuttings, softwood cuttings are preferred for commercial scale enterprises. There is, however, much variation in rooting ability among genotypes (Wells 1955; Eley 1970; Kviklys and Rumpunen 1996). Rooting percentage can be strongly increased by use of growth regulators (typically 30 ppm IBA for 18 h, or a quick dip in 1000 ppm IBA) but size of the cutting is also important. Large cuttings (above 20 cm) root rapidly, produce more roots, and show better winter survival (Wells 1955; Kviklys 1998). Etiolation of shoots may retard rooting (Blain and Dixon 1984) and should therefore be avoided. Protocols for micropropagation have also been successfully developed (Panavas 1994; Stanys 1996, unpubl. data). Due to high costs, micropropagation may be limited to production of stock material for later propagation of cuttings.

Diseases

There are only few reports of plant pathogens and pests attacking chaenomeles plants. Diseases caused by *Monilinia* species (syn. *Sclerotinia*, conidial state: *Monilia*) are the most frequently reported (Creelman 1962; Eliade and Barbu 1963; Heaton 1979; Penrose et al. 1976). Leaf spots may be caused by *Coryneum foliicola* and *Phyllosticta chaenomelina* (Eliade and Barbu 1963), *P. chaenomelesicola* (Yu and Bai 1995), and *Entomosporium eriobotryae* (Horie and Kobayashi 1979). Grey mould, *Botrytis cinerea*, has been reported on flowers (Eliade and Barbu 1963) and on twigs causing cankers (Moore 1949). Eliade and Barbu (1963) also reported fruit fungi: *Septoria cydoniae* and *Cytospora piricola*, and a leaf rust fungus, *Gymnosporangium confusum*. The fire blight bacteria, *Erwinia amylovora* (Zeller 1979), and a virus, apple chlorotic leaf spot virus (Sweet 1980), have also been reported. Among known pests are *Grapholita (Cydia) dimorpha* (Oku et al. 1988), *Caliroa cerasi* (Raffa and Lintereur 1988) and in China the root-knot nematode *Meloidogyne incognita* (Ying et al. 1994).

In Sweden symptoms of several fungi, causing leaf spots, fruit spots, and rotting of fruits, have been noticed (I. Norin, unpubl. data). On fruits *Septoria cydoniae*, *Phlyctaena vagabunda*, *Phoma glomerata*, *Phoma exigua*, *Alternaria tenuissima*, *Alternaria alternata*, and *B. cinerea* have been isolated. In addition, common storage fungi of apple, *Penicillium* sp., *Phlyctaena vagabunda*, and *B. cinerea* have been found on stored fruits, and *Monilia fructigena* has been found on fruit in the field. Die back of shoots, and sometimes of whole plants, has also been noticed, possibly caused by *B. cinerea*. *Botrytis cinerea* has been observed to sporulate on flower parts, on fruits in all stages, and on twigs. Furthermore, a severe attack of grey mold occurred on seedlings in a greenhouse, when the fungus infected and even killed young plants of all *Chaenomeles* species. Among pests, leaf weevils (*Phyllobius* sp.), larvae of *Yponomeuta* sp., and *Operophtera* sp. have been noticed feeding on the plants during spring and early summer. Later in the season, larvae of *Orgyia antiqua* and red spider mites (possibly *Panonychus ulmi*) were found on some plants.

Among diseases and pests, fungal diseases appear to predominate. Nevertheless, *Chaenomeles* is a genus with comparatively healthy plants, amenable to organic growing systems. Despite that chaenomeles fruits are attacked by some fungi which also cause serious storage diseases on apple, the plants seem not susceptible to scab or powdery mildew. Unless field resistant genotypes are selected, fungal diseases may, however, become a problem if clones of various chaenomeles species and hybrids are more widely cultivated.

DOMESTICATION

Chaenomeles species have long been appreciated because of their ornamental value. In Japan, to which *C. speciosa* was introduced from China around 1550, several ornamental cultivars, and cultivars of hybrid origin (also with the endemic *C. japonica*), were soon selected because of the showy and variable flowers (Weber 1964; Kaneko et al. 2000). *Chaenomeles speciosa* was introduced to Europe (England) in 1796, *C. japonica* in 1869, and *C. cathayensis* in 1880. Through intra- and interspecific crosses, more than 500 ornamental cultivars have been developed (Weber 1963). *Chaenomeles thibetica* was not described until 1963

(Yü and Kuan 1963) and has not been used in breeding, and not until recently become introduced to Europe.

Fruits collected in native populations of *C. speciosa* (and possibly also of *C. cathayensis* and *C. thibetica*) have for a long time been used for medicinal purposes in China (Anon. 1989; Weber 1964; Yü and Kuan 1963). These species have also been cultivated in gardens in China but only recently has research aimed at developing *C. speciosa* into a fruit crop been reported (Wang et al. 1997, 1998). Attempts to grow *C. cathayensis* for production of pectin and malic acid have previously been made in Geneva, New York (Slate 1941). However, two cold winters destroyed the plantation and no more trials were conducted. Later research and development of *C. japonica* as a fruit crop has instead taken place in some European countries, as described below.

In Poland, research was initiated in 1978 (Lesinska 1986). The studies focused on biochemical composition, processing and potential products. Fruits of *C. japonica* and *C. speciosa* were considered most useful for processing, however, lack of sufficient fruit quantities hampered further development (Lesinska and Kraus 1996, pers. commun.).

In Finland, a breeding project was initiated in 1979 with the primary objective to select high yielding and winter hardy cultivars of *C. japonica*. Selected genotypes have been propagated by tissue culture and are presently being compared in clone tests (Tigerstedt 1996, pers. commun.).

In Ukraine, domestication of chaenomeles began in 1913, which resulted in the first industrial plantation in 1937. However the crop never became very popular, and in 1981 a new project was started for reintroduction of chaenomeles. In this new project, variability was measured for several fruit morphological and chemical characters, and possibilities for early selection were estimated through calculation of correlation coefficients between characters and years (Mezhenskij 1989, 1996). Besides studies on interspecific (*C. japonica*, *C. speciosa*, and *C. cathayensis*) and intergeneric hybridization (*Pyrus*), research was conducted on propagation and marketable products. The crop was considered promising but so far this has not resulted in any new commercial plantations (Mezhenskij 1996, pers. commun.).

In Moldavia, research on intraspecific variation in morphological characters and in some fruit biochemistry characters of *C. japonica* was initiated in the 1980s. Correlation coefficients and variability coefficients were estimated and it was concluded that *C. japonica* had good possibilities for improvement through breeding (Ponomarenko 1996, pers. commun.). So far no commercial plantations have, however, been established.

In Latvia, research on *C. japonica* was initiated in 1951 (Tiits 1989; Tics 1992) and the first large plantations were established in the 1970s. In 1993 the plantations in Latvia covered approximately 300 ha, with a maximum yield of 20–30 t/ha (Ruisa 1996) and an average yield of 12–15 t/ha. The interest in *C. japonica* as a fruit crop had also spread to Lithuania (Ratomskyte 1996; Rumpunen and Kviklys 1996). The plant material used in the Baltic countries was propagated only by seed and very heterogeneous. A few generations of mass-selection, however, succeeded in reducing the frequency of plants with thorns (to about 4%), promoting early ripening, and increasing the yield (Ruisa 1996). Nevertheless, fruit quality was not sufficient to enable production of high quality and competitive products. The need for improved plant material became obvious, and a joint Latvian-Lithuanian-Swedish plant breeding program was initiated in 1992 (Rumpunen et al. 1998). A link between the Swedish-Latvian-Lithuanian program and the Finnish plant breeding project was established in 1998, and multidisciplinary research was at the same time started, aimed at studying the potential of *C. japonica* as a fruit crop (Rumpunen et al. 2000).

In the current plant breeding program, selection has taken place in orchards, the selected plants have been micropropagated, and clone trials have been established in Finland, Italy, Latvia, Lithuania, and Sweden. In addition, breeding populations have been created, including offspring from interspecific and intergeneric crossings. Floral biology (development of micro- and macrogametophytes, pollen viability, pollen germination, pollen tube growth, embryo sac viability, fertilization, the effective pollination period, period of flowering, functionality of flowers with stunted pistils, fruit set following self-pollination, the effect of emasculation, and bagging on fruit set) has been studied (Kaufmane and Rumpunen 2002a,b). The content and composition of dietary fiber of the fruit of *C. japonica* has been investigated (Thomas et al. 2000), and a method for screening of pectin in chaenomeles fruits has been developed (Rumpunen et al. 2002). The chemical composition of the fruit fragrance and flavor, and the characteristics of the fruit juice, have been investigated during development and storage. In addition, consumer preferences have been evaluated for a number of products based on chaenomeles fruits. Furthermore, an ideotype has been defined for the fruit crop *C. japonica,* and breeding strategies have been developed (Rumpunen 2001). Important traits to be specifically considered during selection and breeding of *C. japonica* are: adaptation and hardiness, disease resistance, thorns, suckering, growth, rooting of cuttings, time of ripening, yield, amenability for mechanical harvesting, and fruit quality.

FUTURE PROSPECTS

The large phenotypic and genetic diversity in the genus *Chaenomeles,* as inferred from morphological and biochemical traits, and from molecular markers, is advantageous for crop improvement through breeding and selection. The high content of dietary fiber and pectin in the fruit makes *C. japonica* a promising candidate for the manufacture of dietary fiber-containing food products and pectin. The pleasant flavor and high acidity of the fruit, make the crop interesting as raw material for development of a range of sweetened food products. At present, the absence of selected cultivars limits the possibility for large-scale product development. The first cultivars should be available for marketing within a few years. It will then be possible to establish pilot plantations, yielding high quality fruits for further product development and marketing of this new crop.

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