Journal of the American Pomological Society 66(3): 153-163 2012

Needs Assessment for Future US Pear Rootstock Research Directions Based on the Current State of Pear Production and Rootstock Research

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Abstract

The area devoted to pear production in the United States (U.S.) is declining due to lack of precocity and high cost of production. The U.S. pear industry currently lacks "modern" orchard systems characterized by compact trees that produce early, high yields of large, high quality fruit. Tall, shaded canopies are not economically sustainable and are at a competitive disadvantage for attracting and sustaining a labor supply. There is broad and deep consensus in the pear industry that developing size-controlling rootstocks is imperative to remain competitive nationally and globally. Currently employed rootstocks in the U.S. are *Pyrus communis* seedlings and clones, none of which achieve more than about a one-third size reduction, and *P. betulifolia* seedlings. Quince (*C. oblonga*), used with interstems in Europe and South America, is utilized commercially (without interstems) in the U.S. only for 'Comice' in southern Oregon and northern California. This is due primarily to a lack of cold hardiness needed in more northern production areas, a lack of graft-compatibility with the other major scion cultivars, fire blight and iron chlorosis susceptibility, and relative lack of productivity versus other rootstocks, especially in California. Current evaluative trials rely on older U.S. and imported selections, and include the NC-140 Multistate Rootstock Research Project and several individual programs in California, New York, Oregon and Washington. A fundamental deficiency is the lack of a mature pear rootstock breeding program, despite access to the USDA-ARS National Clonal Germplasm Repository (NCGR), which holds a major worldwide collection of *Pyrus* and related genera. International breeding programs focus on increasing yield efficiency, but also graft compatibility, fruit quality and size, high soil pH tolerance, winter hardiness, warm climate/low chilling adaptation, drought and salt tolerance, and resistance to fire blight, pear decline, and pear scab. An intensive planning and implementation effort is needed to develop the necessary contacts, collaborations, explorations, and importation logistics to acquire the most promising clonal selections for propagation and testing. Basic research needs include effects of dwarfing rootstock on tree architecture and fruiting, the underlying mechanisms of dwarfing functional in pear, the inheritance of key traits, and selection criteria for breeding. Propagation and orchard systems have also been identified as major research needs.

Introduction and Statement of Need

As of 2010, there were 22,800 hectares (57,000 acres) of commercially-grown pears (*Pyrus sp.* L.) in the United States (U.S.), with a total crop value of $382 million (48). Major pear producing states (hectares) are Washington (9,600), Oregon (6,480), and California (5,600). New York (480), Michigan (320) and Pennsylvania (320) are minor production states (48). Total U.S. pear production includes Asian pears, which are also grown in several Eastern states, mainly for the direct market. Major cultivars, in descending order of acreage, are 'Bartlett', 'D'Anjou', 'Bosc', 'Red D'Anjou' and other red skinned pears, 'Comice', and 'Seckel'. Only 'Bartlett' is grown for both the fresh and processing markets. The industry has been stagnating due to declining consumption of processed pears and competition from imported pears and other fruits, as reflected in the loss of 4,000 hectares (10,000 acres), or 15%, since 2000.

The major factors contributing to acreage decline are lack of precocity and high cost of production. Newly planted trees are

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slow to bear, discouraging orchard renewal (10,14,15). The U.S. pear industry currently lacks "modern" orchard systems characterized by compact trees that produce early, high yields of large, high-quality fruit. Existing orchards comprise mature trees that are large and widely spaced. Further, high-density plantings on standard rootstocks are difficult to confine without access to vigor management tools (i.e., acceptable dwarfing rootstocks or bio-regulators, neither of which are presently available in the U.S.). Alternatively, tighter in-row spacing between pear trees on an array of commercially available *Pyrus* rootstock genotypes markedly improved yield, and reduced tree size; however, fruit size was negatively related to tree density (37).

Pear orchards are labor intensive; pruning, fruit thinning, and harvest of low density plantings are time-consuming and costly. Eventually, these tall, shaded canopies produce lower financial returns (7). Growers rely mainly on seasonal and largely immigrant (mainly Mexican, but also Central American) labor for pruning, thinning, and harvest operations (26). However, pear plantings in close proximity to apples, cherries and grapes are at a competitive disadvantage for attracting, and sustaining a labor supply. In apple, size-controlling rootstocks produce shorter trees, which are more conducive to efficient and labor-friendly production practices. In the case of cherries, recent developments in dwarfing rootstocks, pedestrian orchard systems and mechanization have markedly improved labor efficiency (43).

In addition to production and economic demands, regulatory and social constraints now demand systems that offer a desirable environmental "footprint" (pesticides, water, nutrients and energy use). Pear trees are inefficient and costly to spray, requiring ample spray volumes to displace air within large canopies. Varying growing sites require resistance to various biotic and abiotic "stresses", i.e. fire blight, pear decline, dry or wet soils, low or high pH soil, and extreme cold, requiring a suite of superior rootstocks which are both efficient and possess appropriate traits for particular sites, as previously characterized (23).

The U.S. pear orchard situation is in contrast to European, and to a lesser extent, South American orchards, which successfully utilize dwarfing rootstock clones of quince, with or without a *P. communis* L. interstem ('Beurre Hardy', 'Old Home') for graft-compatibility (49). The use of quince has enabled high-density plantings of 3,000 to greater than 10,000 trees per hectare, versus a maximum of about 500-1800 trees per hectare in the U.S. It is widely accepted that high density orchards bear fruit and repay establishment costs sooner. They can also be planted as narrow trellised V or "wall" systems which can be managed from the ground, platforms, stepstools, or short (0.6 to 1.8 m) ladders. This creates a labor environment attractive to a wider pool of potential workers. Pesticides can also be applied efficiently with less drift and wasted chemical and water (12).There is broad and deep consensus among all sectors of the U.S. pear industry, i.e. growers, nurseries, and academics, that developing efficient (precocious, good yield, fruit size), size-controlling rootstocks is imperative for the pear industry to remain competitive nationally and globally.

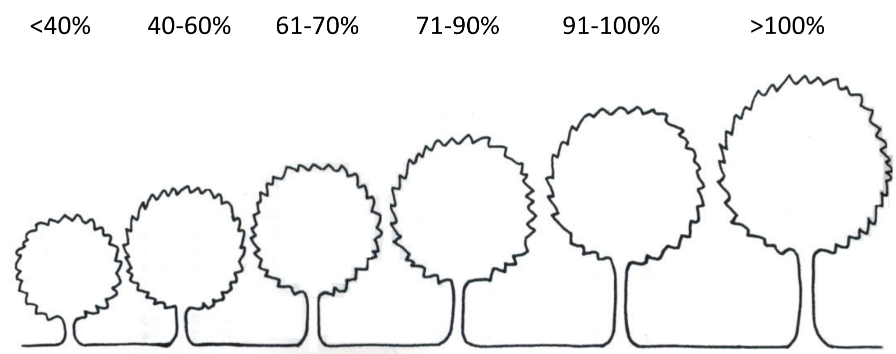
Currently Used Rootstocks

The main rootstocks currently employed in the U.S. are *Pyrus communis* seedlings (e.g. 'Winter Nelis', 'Bartlett' seedling), *P. betulifolia* seedlings on heavy clay soils, and more recently, several *P. communis* hybrid clones, e.g. 'Old Home × Farmingdale (OH×F) 69', 'OH×F 87', 'OH×F 97', 'OH×F 217', 'OH×F 333', and 'OH×F 513'. Of these, 'OH×F 87' and 'OH×F 97' are the most widely utilized. Quince (*Cydonia oblonga* L is used for commercial production only for 'Comice' (44). The most vigor-inducing selection, 'BA29', is the preferred selection. Even with an interstem, quince has thus far been found to lack desirable horticultural characteristics, e.g. cold hardiness in the Pacific Northwest, long-term vigor and productivity in California, and tolerance to fire blight and calcareous soils (51) . Nurseries and growers have also been reluctant to incur the added time and cost of grafting an interstem needed for ‘Bartlett’, Beurré Bosc’ and ‘Beurré d’Anjou’, and which may then only provide incremental benefit. Further, and irrespective of rootstock lineage, nurseries demand a high survival rate, uniform and consistent performance (i.e. clonal rootstocks), easy and efficient propagation, universal graft-compatibility, good anchorage, and minimal suckering (35).

There are also limited commercial sales of two German *P. communis* rootstocks, ‘Pyrodwarf’ (‘Old Home’ × ‘Bonne Luis d’Avranches’, syn. ‘Rhenus1’) and Pyro 2-33 (‘Old Home’ × ‘Bonne Luis d’Avranches’, syn. ‘Rhenus3’) (16). ’Pyrodwarf’ and ‘Pyro 2-33’ performance varies depending on macro- and microsite factors, scion cultivar, and management, though ‘Bartlett’ yield efficiency on ‘Pyro 2-33’ was equivalent to ‘OH×F 87’ in Washington trials (Tim Smith, personal communication). However, none of the *P. communis* clonal stocks achieves more than about a one-third size reduction versus a “standard” tree grafted onto seedling *P. communis* or *P. betulifolia* (51) (Fig 1).

Available Rootstocks for Dwarfing

Globally, there is a limited number of *Pyrus* rootstock cultivars and selections which may be available for continuing or new trials in the U. S., for example, ‘Pyriam’ from INRA in France, the Fox series from the University of Bologna in Italy, the 708 series from East Malling Research in the U.K., and the Pi-BU series from Germany (Table 2). There is a limited number of quince selec-



Amelanchier	Adams Quince	Fox 11	OH×F 217	Bartlett sdlg.	*P. betulifolia* sdlg.
Brossier series	BP10030	Fox 16	OH×F 220	BM2000	
Sorbus	*Crataegus*	Horner 10	OH×F 267	Horner 4	
W. B./M.26	Eline Quince	OH×F 40		Winter Nelis sdlg.	
	OH×F 51	OH×F 69		OH×F 97	
	Pi-Bu 3	OH×F 87		*P. calleryana* D6	
	Pyrodwarf	OH×F 230		*P. calleryana* sdlg.	
	QR517/9	OH×F 333			
	QR719-3	OH×F 513			
	Quince EMA	Pi-BU 2			
	Quince BA29	Pyro 2-33			
	Quince EMC				
	Quince C132				
	Quince EMH				
	Sydo quince				

Fig 1. Relative size of pear trees on different rootstocks as a percentage of pear tree size on *Pyrus* seedling. Adapted from (51). W. B./M.26 = ‘Winter Banana’ apple grafted onto M.26 apple rootstock.

tions in commercial use, namely 'Adams', 'BA29', 'EMC', 'EMH', and 'Sydo'. These are graft-incompatible with most commercial pear cultivars without use of an interstem (35). There are several other quince rootstocks which have been developed in Europe, and which are deserving of trials in the U.S.

U.S. Breeding Programs

A fundamental deficiency in the U.S. is the lack of an active pear rootstock breeding program. The 'OH×F' clonal series was crossed by Oregon nurseryman Lyle Brooks in the 1960s (52). The 'Horner' series, originally crossed by Oregon nurseryman Dave Horner, currently resides at Oregon State University's Mid-Columbia Agricultural Research and Extension Center [MCAREC] (31); however, pear breeding is not conducted at Oregon State University. There is a fledgling breeding program at Washington State University (WSU) (Dr. Katherine Evans). The pear breeding program at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia (Dr. Richard Bell) has made preliminary crosses of 'OH×F' selections and some 'US' series fire blight resistant scion selections which possess semi-dwarf tree stature. Both of these programs are now acquiring germplasm.

NC140 Multistate Rootstock Research and Similar Trials

Other than these two incipient breeding programs, most U.S. pear rootstock research has focused on evaluating 1) commercially-available rootstock cultivars from the U.S. or other countries, and 2) advanced selections from international sources. Several replicated, evaluation trials were established in California, New York, Oregon, Washington, Chihuahua, Mexico, and Nova Scotia, Canada under the auspices of the NC140 Regional Research Project in 1988, 2002, 2004, and 2005. Individual trials comprised a varying number of locations and scions ('Bartlett', 'Golden Russet Bosc', 'Taylors Gold Comice', 'Concorde', 'D'Anjou') (http://nc140.org). The NC140 trials have provided much of the database for decision making by nurseries and growers thus far (2,11).

Continual evaluation of these trials, in addition to other replicated non-NC-140 field evaluation trials in the U.S. have been, or are being, performed at OSU-MCAREC ('Horner' series), OSU-Southern Oregon Research and Extension Center (SORAC) (quince and *P. communis*), University of California Cooperative Extension ('OH×F' series), WSU Cooperative Extension ('OH×F' series), and Cornell's New York State Geneva Agricultural Experimental Station (NYSAES) ('OH×F' series, 'Pyrodwarf', 'Pyro 2-33'). These trials have generally concluded that the 'OH×F' series and 'Pyro 2-33' are thus far the most promising of the currently available *P. communis* rootstocks, particularly 'OH×F87',' OH×F97', and in some cases, 'OH×F69' (10,11,45). While variable, 'OH×F87', 'OH×F69', 'Pyro 2-33', and 'Pyrodwarf' produce trees larger than quince, and 'OH×F97' produces a nearly standard size, but more precocious, tree than *P. communis* seedlings or *P. betulifolia* (Fig 1).

These rootstocks, while more acceptable than seedlings, do not provide sufficient size control and precocity for ideal high density orchard systems. Additionally, many clones are difficult to propagate, rendering them undesirable to nurseries (30, 33), despite possessing desirable traits.

International Breeding and Evaluation Programs

International breeding programs and germplasm collections offer potential sources of rootstocks to evaluate, as well as germplasm for breeding. There is considerable effort in Europe to evaluate new rootstocks, for example the EUFRIN Rootstock Group which consists of 21 fruit research institutions from 16 countries, in which a total of 51 *Pyrus* and *Cydonia* rootstocks are under evaluation (20). 'Pyrodwarf' and 'Pyro 2-33' are examples of accessions from overseas (Germany) obtained privately and licensed to commercial nurseries (16). While much literature is in the language of origin, a cursory search, as well as personal knowledge (R. Bell), revealed at least somewhat active and inactive breeding programs in Western Europe: France (41), Germany (13, 16), Greece (42), Italy (3, 21), UK (18), Spain (1, 38), and Netherlands. There are several programs in Central and Eastern Europe: Belarus (19), Czech Republic, Estonia, Hungary (46), Lithuania (20), Poland (22), Romania (28), Russia, and Ukraine (40). Rootstock evaluation has been conducted in the Middle East (Egypt, Israel, Syria, Turkey), South America (Brazil, Uruguay), and Africa (South Africa). In Asia, rootstock breeding and evaluation is a major activity in China (17), and has received attention in Japan (36, 47). There was one breeding program in Australia (24). Most programs utilize *P. communis*, but others utilize other *Pyrus* species, *Cydonia* (quince), *Amelanchier, Sorbus*, and the intergeneric hybrid *Pyronia* (Table 2).

Most breeding efforts focus on the primary deficiency impeding industry progress and profitability, i.e. yield efficiency (derived from precocity, productivity, and dwarfing). Induction of precocious fruit bearing is a key trait, since the lack thereof inhibits replanting of existing cultivars in more profitable higher-density systems, and likewise inhibits the adoption of new scion cultivars which possess unique fruit quality and other postharvest traits desired by the consumer, the producer and others in the marketing chain. Such traits may help to stimulate pear consumption and reduce costs, contributing to the economic sustainability of the industry. In contrast to apple, for example, on 'Malling 9', it is rare for pear to bear fruit in the second season of growth, or even the third to fifth in many cases. Other major sought after traits include graft compatibility, fruit quality and size, high soil pH tolerance, winter hardiness, warm climate/low chilling adaptation, drought and salt tolerance, and resistance to fire blight, pear decline and pear scab (5,50).

Few candidates from international programs have been adequately tested in the U.S., with the exception of, 'BU-2', 'BU-3', 'BM2000', '708-36', 'Fox 11', 'Fox 16', 'Pyrodwarf' and 'Pyro 2-33' (refer to Table 2 for origin). Of those, only 'Pyro 2-33' and to a lesser extent, 'Pyrodwarf', which has a propensity for suckering, are considered commercial candidates. Performance data for other selections indicate poor survivability, low or high vigor, expression of pear decline or decline-like symptoms, and/or poor compatibility as major factors limiting advancement (see reports http://nc140.org). Several additional genotypes possess interesting traits, but are so far inaccessible to U.S. researchers due to logistical, financial, diplomatic, or intellectual property issues, underscoring the urgency of increased exploration and collaboration. Additional genotypes may exist at the USDA-APHIS quarantine facility and the National Clean Plant Network (NCPN) at the Washington State University experiment station in Prosser, but that information is proprietary. At the least it is imperative that interested parties network and collaborate to hasten testing, propagation, and distribution of potential rootstocks. An intensive planning and implementation effort is needed to develop the necessary contacts, collaborations, explorations, and importation logistics for U.S. acquisition of the most promising selections for propagation and testing.

Current Research Using Other Genera

The USDA-ARS National Clonal Germplasm Repository (NCGR) in Corvallis, Oregon (http://www.ars-grin.gov/cor/pyrus/pyrinfo.html) holds the major U.S. (and perhaps the world) collection of *Pyrus* and related genera, including *Cydonia, Amelanchier* (service berry) *Pyronia* (*Pyrus* x *Cydonia*), and *Sorbus* (mountain ash). A multi-year project tested 57 accessions of quince (2009-2011) for cold-hardiness, elucidating a group of 24 that tolerated low temperatures of -30°C with less than 50% oxidative browning of phloem, cambium and xylem tissue when fully dormant (9). This work is continuing and will result in new opportunities for inclusion of quince in wider evaluation through NC-140 and other field trials.

In addition to evaluation of *Cydonia*, several selections of *Amelanchier* have been privately imported into the U.S. and are currently being tested for graft-compatibility and propagation potential. Preliminary field evaluations of three *Amelanchier* rootstock clones are underway in Oregon and California (Einhorn and Elkins, unpublished). All three clones have been observed to possess high freeze-resistance (to -40°C; Einhorn, unpublished). Besides *Cydonia* and *Amelanchier*, other Rosaceae genera might have potential as pear rootstocks; *Crataegus* (hawthorn), *Pyronia*, and *Sorbus*. However, considerably less is known about pear performance on these genera. Known graft-compatibility between *Pyrus* and alternative genera is shown in Table 1.

Need for an Intensive Rootstock Research Effort

The dearth of research on pear rootstocks in the U.S. is long-term. There have been limited efforts since the pear decline crisis of the 1960s, when it was learned that *P. pyrifolia* and *P. ussuriensis* rootstocks were susceptible to infection and alternative rootstocks were evaluated and planted. Notably, extensive federal funds were committed to this critical effort. Indeed, the pear decline crisis could only be resolved and the pear industry saved from rapid and certain demise because research into alternative rootstocks was supported. While the current need for a rejuvenated effort is based more heavily on long-term economic factors, the need to reinvest remains critical. Researchers in combination with stakeholder input from both the Pacific Northwest and California have identified a number of basic and applied research (and ultimately extension) needs.

Table 1. Genus	Graft-compatibility
Amelanchier	Fair to good
Aronia	Poor
Chaenomeles	Poor
Cotoneaster	Insufficient data
Crataegus	Poor to good
Cydomalus	Insufficient data
Cydonia	Poor to good
Docynia	Insufficient data
Malus	Generally poor
Pryonia	Good?
Sorbopyrus	Insufficient data
Sorbus	Poor to good

Basic research needs include: a detailed analysis of the effects of dwarfing rootstocks on scion *vis* a *vis* tree architecture and fruiting; underlying mechanisms of dwarfing expressed in pear (i.e. graft-incompatibility, water relations, nutrient assimilation, photosynthate and carbohydrate synthesis and partitioning, phytohormone metabolism and transport, etc.); inheritance studies of key traits; molecular markers for these traits; selection criteria for breeding (e.g., is tree architecture, or precocity, of self-rooted trees a predictor of performance as a rootstock?).

Two major applied rootstock research foci have been identified: propagation, and orchard systems. During stakeholder meetings held in 2010 and 2011, nursery representatives expressed clear preference for propagating *Pyrus* rootstocks from hardwood or softwood cuttings versus micropropagated material. The authors are aware of interest and activity in stooling of quince rootstocks (35). However, micropropagation offers a means to improve survival and vigor of clonal rootstock material, particularly those that are difficult to propagate with cuttings due to declining juvenility or poor rooting ability. There are currently several industry-supported projects within USDA-ARS and at WSU focused on developing and improving micropropagation protocols that should be greatly expanded.

Two other important areas of research are adventitious shoot regeneration and genetic transformation. Adventitious shoot regeneration is a necessary component for isolation

Table 2. Compilation of active and inactive pear rootstock breeding programs and rootstocks.

Country	Institution/Breeder	Genus and species	Primary Traits	Rootstocks
Australia	B. Morrison	*Pyrus communis*	Yield efficiency	BM2000
Belarus	Belorussian Res. Inst. for fruit growing	*Pyrus communis*	Yield efficiency	Seedling rootstocks
Brazil	EMBRAPA Uva e Vinho	*Pyrus communis*	Climatic adaptation	Seedling evaluation
France	INRA	*Pyrus communis*	Yield efficiency	Pyriam
		Pyrus species	High soil pH tolerance	Interspecific hybrid selections
Germany	Fruit Genebank, Dresden-Pillnitz	*Pyrus communis*	Yield efficiency	Pi-Bu series
Germany	Geisenheim Research Institute	*Pyrus communis*	Dwarfing	Pyrodwarf, Pyro 2-33
Italy	CIV, Ferrera	*Pyrus communis*	Yield efficiency High soil pH tolerance	Many selections
Italy	University of Bologna	*Pyrus communis*	High soil pH tolerance	Fox series
Poland	Research Inst. of Horticulture	*Pyrus communis*	-[1]	Elia, Belia, & Doria
Poland	Warsaw Agricultural Univ.	*Pyrus communis*	-	GK seedling series
Russia	Michurin All-Russia Res. Inst. Hort.	*Pyrus communis*	-	No. 10, 3-21-32
Sweden	SLU, Balsgärd	*Pyrus communis*	Yield efficiency	BP 10030
UK	East Malling Research	*Pyrus communis*	Yield efficiency	708 series, 517-9
USA	Oregon State University	*Pyrus communis*	Yield efficiency Dwarfing	OHF series, Horner 4, Horner 10
Syria	Damascus University	*Pyrus syriaca*	High soil pH tolerance	Seedling evaluation
Russia	Vserossiyskij Sci. Res. Inst. Hort.	*Pyrus uss.*[2] *hybrids*	Cold hardiness	17-16, 218-2-2
China	Several institutes and universities	Asian *Pyrus* species	Dwarfing	Several selections
Japan	Gifu University	*P. bet. & P. call.*	Dwarfing	SPRB & SPRC series
Spain	IRTA	*Pyrus* species	High soil pH tolerance	Interspecific hybrid selections
USA	Washington State University	*Pyrus* species	Dwarfing Yield efficiency	Acquiring germplasm
USA	USDA, ARS, AFRS	*Pyrus* species	Dwarfing Yield efficiency	US selections, OHF×US selections
Armenia	-	*Cydonia*	-	Arm 21
Belarus	Belorussian Institute of Fruit Growing	*Cydonia*	-	1/9, 1/22, 1/33
Brazil	EMBRAPA Uva e Vinho	*Cydonia*	Climatic adaptation	Seedling evaluation
Greece	NAGREF, Pomology Institute	*Cydonia*	High soil pH tolerance	PI1 PI5, PI27 Komorius seedlings
Italy	University of Pisa	*Cydonia*	Yield efficiency	Ct.S series
Lithuania	LIH-Babtai	*Cydonia*	Yield efficiency	K series
Netherlands	Flueren	*Cydonia*	Yield efficiency	Eline
Poland	Research Institute of Horticulture	*Cydonia*	Cold hardiness	Pigwa series: S-1, S-2, S-3
Romania	UASVM-Iasi	*Cydonia*	Yield efficiency	BN-70
Russia	-	*Cydonia*		Anzherskaya, Peridskaya, Teplovskaya
Turkey	Ankara University	*Cydonia*	Yield efficiency	S. O. series
Ukraine	Ukrainian Academy of Agrarian Sciences	*Cydonia*	Drought tolerance High soil pH tolerance	IS, SI, and R series

UK	East Malling Research	*Cydonia*	Yield efficiency	C132, EMA, EMC, EMH
Russia	-	*Pyronia*	-	VA2
Germany	Bavarian Center for Fruit Crops	*Amelanchier*	Precocity, dwarfing	Various selections

[1] - = undetermined. Some information is from secondary literature sources that do not mention the program or targeted traits.

[2] Species abbreviations: *P. uss. = P. ussuriensis; P.bet. = P. betulifolia; P. call. = P. calleryana.*

of useful somaclonal mutants and for genetic transformation, and is a relatively unexplored area of opportunity for many rootstocks. Published results for rootstocks have been limited to 'OH×F 333' (32, 53), BP10030 (53), 'Pyrodwarf' (27) and quinces (4). However, research to optimize additional clones is ongoing. Mutant 'Quince A' clones with increased tolerance to high pH (6, 8) and NaCl (25) have been recovered. Increased juvenility and consequent improved rooting ability may also result, but also with the potential for chimeras and genetic instability leading to somaclonal mutants.

Genetic transformation, though controversial at the marketing level, is a rapidly evolving and long-term strategy. At present only the rolB gene for improving rooting has been inserted into 'OH×F 333' (53) and Lithuanian quince selections (34). A technique known as cisgenics (39) presently exists for manipulating genes without inserting genes of different species. Breeding programs should be actively increasing competence in this area to take advantage of future opportunities and needs. Successful application of this approach depends on the identification of candidate genes that control tree architecture, dwarfing and precocity.

The NC-140/Pacific Northwest regional field trials are an excellent model for preliminary evaluation of promising rootstocks. Larger, more complex "systems" trials (i.e. rootstock x training system x spacing x scion cultivar) under various site and management scenarios are necessary for more advanced selections in order to gain "real-world" results and determine the most suitable role(s) for different rootstocks. There are several examples of individual trials in California, New York, and Washington that have provided beneficial information. A new coordinated multi-state systems trial for 2013 includes California, Oregon, New York, and Washington. Stakeholders have expressed a clear desire for large systems trials. These can and should be conducted under the umbrella of NC-140.

Evaluation of the Corvallis USDA-ARS NCGR Collection and Importation and Evaluation of Germplasm and Rootstocks

In depth evaluation of the *Pyrus* and related genera collection for their specific suitability directly as pear rootstocks or as parental germplasm would be of great benefit. The USDA-ARS NCGR is one of the largest pear germplasm collections in the world, a collection whose diversity must be exploited and characterized using current molecular and genetic techniques. As previously discussed, there are immediate opportunities for finding and accessing *Pyrus* and related genera from other countries to expand the NCGR and breeding program collections. Foreign colleagues have expressed interest in collaborating with U.S. counterparts (Bell and Dhingra, personal communication). However, additional resources will be required to take advantage of these opportunities given the current economic climate. Nursery stakeholders have also expressed willingness to work with researchers, and the *Pyrus* Crop Germplasm Committee (http://www.ars-grin.gov/npgs/cgclist.html#Pyrus) has initiated efforts to collaborate with the private sector to hasten germplasm acquisition and advancement (field trialing through industry adoption), utilizing all available means, including NC-140.

Conclusion

New pear rootstocks are fundamental to the modernization of an outdated and increasingly untenable U.S. pear production culture. Pear consumption continues to decline for a multitude of reasons, and growers face rapidly increasing costs while profiting less from aged systems. Imports have reduced market share, furthering the decline of both fresh and secondary markets such as canning, drying, and juice.

While fruit quality, market strength, and consumption are critical issues, the ability to farm competitively and profitably largely hinges on production issues. U.S. pear production is antiquated compared to apple production systems. Although high-density apple systems rely to a large extent on M.9, apple growers have access to a wide range of rootstock selections developed from a worldwide group of long-standing breeding programs, including two in the U.S. (USDA-ARS/Cornell University, New York), and now Washington State University at Wenatchee. The availability of size-controlling rootstocks has enabled new training systems (e.g., tall spindle and vertical axe that allow fruiting in the second season after planting), improved labor conditions, more environmentally-friendly pesticide and fertility practices, and efficient irrigation management (29). While total apple acreage has decreased from 2000 to 2010, the total number of individual apple trees had increased, reflecting the successful adoption of efficient, high density orchards. In contrast, pear acreage and total number of individual pear trees both decreased, indicating a declining industry lacking the incentive or tools to modernize.

The survival of the pear sector carries societal significance as well. The U.S. pear industry, while much smaller than the apple industry ($382 million vs. $2.22 billion nationwide in 2010), is of major socio-economic importance where it exists. It is more concentrated geographically in certain states and counties due to climactic adaptation, and in those communities it plays a unique historical, cultural, and economic role. Given pear's unique adaptations to climates and soils in which other perennial orchard crops fail to do well, pear orchards are not easily replaced in some areas. Conversely, if recently proposed NIFA-SCRI and industry research efforts to improve fruit quality and increase consumption succeed, producer opportunities will increase, provided growers can quickly recoup establishment costs and remain profitable.

In summary, it is imperative that size-controlling rootstocks are both developed and rapidly transferred to industry in order to modernize U.S. pear production. It is not far-fetched to conclude that if this fails to occur, the U.S. pear industry will continue its inevitable decline and become a minor orchard crop, while fresh and processed imports from Asia, Australia, Europe, New Zealand, South America, and South Africa increasingly dominate the U.S. market.

Acknowledgements

The authors thank the many individuals who contributed to this paper, particularly those who actively participated in the Root2Fruit Initiative stakeholder meetings held in Provo, Utah, November 2, 2010, and Pasco,Washington, March 2, 2011. We also thank the participants in the NC140 Regional Research Project, the members of which have diligently pursued this effort in rootstock trials since 1988.

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

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