Commercial Pomegranate (*Punica granatum* L.) Production in California

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Abstract

Commercial pomegranate production in California is found primarily in the southern San Joaquin Valley, a region with Mediterranean type climate. Pomegranates have been grown in California since 1792, spread by Christian missionaries from Spain, and in commercial production since 1896 when shipments of trees arrived from Florida. For decades in the late 1900s the statewide hectarage remained near 1000, but has increased dramatically to 11700 in 2007, most of which is less than four years old. Pomegranates are often grown in conjunction with other permanent crops such as stone fruit and nut crops. Planting systems range from rows 3.6 to 5.8 m and in-row spacing from 1.5 to 5.2 m, with row spacing often determined by equipment preferences for other crops. Training systems are typically free-form multiple trunks, although single trunk and trellised production is being used. Irrigation systems, like crop spacing, are often dictated by companion crops found on individual farms; flood irrigation is found on older trees with newer trees planted with micro irrigation systems. Organic production of pomegranates remains limited due to market acceptance; challenges for organic production are *Alternaria alternata* and *Aspergillus niger*, as well as omnivorous leafroller (*Platynota stultana*) and flat mite (*Brevipalpus lewisi*). Numerous herbicides are registered for use in conventional pomegranates and weed barriers and hand weeding in organic systems. Both fresh market and juice fruit continue to be commercially harvested by hand but attempts at mechanization for both uses are underway. Common yields for mature pomegranates are as low as 6-10 MT/ha when used exclusively for fresh market consumption, but can be as great as 25-35 MT/ha when grown for juice, with the fresh:juice ratio dependant on both market conditions and autumn weather patterns. Most pomegranates are sold through food retailers in North America, and their current preference for high sugar/high acid, dark red rind color and dark red aril color favors cultivars such as ‘Granada’ and ‘Foothill’ in early season, and ‘Wonderful’ in main season. The United States Department of Agriculture National Clonal Germplasm Repository in Davis, California, contains selected lines sent from Dr. Levin’s Turkmenistan collection as well as genetic variants found in California production; variation for fruit attributes may influence consumer acceptance to other fruit types already common throughout pomegranate consuming cultures.

INTRODUCTION

California, one of 50 states, is located on the western continental United States. It has a diversity of topography, population density, and weather patterns. California is the third largest state in size (423900 km²) and within an area separated only by 130 km has the highest elevation (4420 m) and lowest elevation (-86 m) in the lower 48 states (i.e., the continental US, excluding the states of Alaska and Hawaii). California has the largest population of any state - 36 million residents as estimated by the US Census Bureau in July of 2008 - which is 11.8% of the national population. The population is not evenly distributed within the state. The highest population density occurs along the coastal regions: northern coastal California, including the San Francisco bay region, and the southern coastal region encompassing Los Angeles, San Diego, and Orange Counties. Lower population density is more common in northern sections of the state and in the inland regions to the east.
California is classified as Mediterranean climate, with precipitation primarily occurring from autumn to spring. There is variation in precipitation totals within the northern California and southern California regions, as well as between mountainous terrain and plains-like valleys. In the alluvial fan region of Los Angeles (elevation 71 m) the average annual precipitation is 37 cm, while in the alpine Lake Tahoe area (elevation 1900 m) average precipitation is 95 cm. To alleviate the disparity between high precipitation regions and regions with low precipitation but higher population, California and US government agencies developed statewide water delivery systems in the 1950s and 1960s to move water from one zone to another. The interests of California’s agricultural industry were considered in the design of these water delivery projects, especially in the inland region referred to as the Central Valley. The Central Valley comprises the Sacramento Valley in the north and the San Joaquin Valley to the south. This area stretches from the cities of Redding to Bakersfield and is approximately 600 km in length and has zones of highly fertile soil. Relatively low rainfall, insufficient for commercial farming during the summer months makes supplemental water supplies necessary. California agricultural production in 2007 was $36.6 billion (USD) and represented 12.8% of the US total gross cash receipts (California Department of Food and Agriculture, 2009). The size and breadth of California’s agricultural industry is due partially to the success of transporting and efficiently utilizing water for crop irrigation from alternate storage locations. This supplemental irrigation strategy allowed widespread commercial farming to develop during the 20th century throughout the Sacramento and San Joaquin Valleys.

CALIFORNIA AND POMEGRANATE PRODUCTION

California’s Pomegranate History

Pomegranate’s arrival in California predates its inclusion into the United States. Starting in 1769 Franciscan missionaries from Spain, led by Father Junipero Serra, established Roman Catholic Christian centers of worship, commercial enterprise, and lodging throughout the southern and northern coastal regions of what was then called Alta California. Pomegranates were imported from other areas and planted at these missions (LaRue, 1977; Morton, 1987; Seelig, 1970). Even today there remain at remote mission sites, such as Mission San Antonio de Padua, untended pomegranate trees that grow near original structures.

The delivery of pomegranate cuttings for commercial use occurred quite early in the development of commercial farming in the southern San Joaquin Valley. The cultivar ‘Wonderful’ is the most widespread and commercially successful cultivar since the mid-20th century (Seelig, 1950) and is reported to have originated about 1896 in a commercial shipment of cuttings received in Porterville, California from the state of Florida (LaRue, 1964). Interestingly, Florida was also settled by Spanish explorers.

In 1927, 77 years after California was granted statehood in 1850, there were 749 ha of pomegranates in production (LaRue, 1977). The acreage fluctuated in following years: 211 ha in 1952, 520 ha in 1959, 245 ha in 1964 according to the Census of Agriculture data (LaRue, 1977; Seelig, 1970). This era saw pomegranate orchards established in the San Joaquin Valley in locations deemed too cool for citrus production, and were then marketed almost exclusively to ethnic groups located in the major metropolitan areas of the eastern US (Karp, 2002). During the mid-20th century pomegranates were also planted by fresh fruit growers where soils were of insufficient quality for grapes or stone fruit; thus pomegranate orchards were mainly found on poorer alkali-type soils while superior soils were planted and replanted to permanent crops with higher potential revenue (K.R. Day, pers. commun.). The 1970s found pomegranates still considered a rare species in the state (Riley, 1973), and there was little expansion of production in the San Joaquin Valley through the 1980s and mid 1990s when California’s production area remained near 1000 ha. This era found production and marketing conducted by organizations such as Slayman Farms, Ito Packing, and Simonian Farms, all companies with long histories of pomegranate production.
Modern Era of Pomegranate Production

Between 1996 and 2001, a single entity was responsible for an increase of 2300 ha of pomegranate in the southern San Joaquin Valley; dramatically increasing commercial production in California (Karp, 2006). Paramount Farming Company (PFC) inherited a 45 ha pomegranate orchard in 1986 of the cultivar ‘Wonderful’, originally planted in 1971, when they purchased a farming property in western San Joaquin Valley containing pistachios, olives and walnuts (Resnick, 2009). Pomegranates were expanded at this site for a total of 115 ha in 1989. By the end of 2001 total pomegranate production under PFC management was 2450 ha. This dramatic pomegranate increase was made by a farming organization until then known exclusively for almond and pistachio production. Favorable financial returns in comparison to the other two crops under PFC’s farm management, and the development of acceptable orchard sites with proper soil quality for pomegranates made the development possible.

Simultaneous to the expansion of hectare age in the mid 1990s, significant private investment was initiated by Stewart and Lynda Resnick, owners of PFC, to fund medical research to scientifically determine the health benefits of ‘Wonderful’ pomegranate. The $25 million (USD) investment in peer-reviewed research showed pomegranate products derived from ‘Wonderful’ had favorable effects on nutrition and health (POM Wonderful, 2009; Resnick, 2009), and spurned additional studies globally on the positive influences of pomegranate products.

Following the increases in hectare at PFC, the encouraging medical research results, and the innovative marketing of 100% pure pomegranate products by Resnick’s POM Wonderful - the packing-storage-sales-marketing entity for PFC ‘Wonderful’ pomegranates formed in 2003 - further hectares were planted by both large farming operations as well as small family farms throughout California. Current estimates of California production are 11700 ha (University of California, 2009). The expansion of these hectares has not been adequately documented through government reports, as the California Department of Food and Agriculture combines the pomegranate area with chestnut, persimmon, prickly pear, loquat and other “minor” species as ‘Miscellaneous Fruits and Nuts’ (California Department of Food and Agriculture, 2009) due to a lack of clear reporting from some local governmental bodies.

Farming Practices Found in Californian Pomegranate Production

Although microclimates exist throughout California, Mediterranean conditions in the primary pomegranate region of southern San Joaquin Valley (Table 1) lead to consistent pomegranate crop growth and development (Table 2). Despite a common phenology throughout the region, the shift from ‘Miscellaneous Fruit’ to significant crop volume has created a wide range of crop husbandry practices. The lack of California based research on farming techniques has often led farmers to develop strategies that are hypothesized to meet their needs for productivity and efficiency.

Commercial farms that produce pomegranates are usually diversified in their crops and may grow fresh market Prunus, nut crops such as pistachio, walnut or almond, table grapes, or citrus. Other pomegranate farmers may have expertise in row crops such as cotton, cantaloupe, alfalfa, field maize or processing tomatoes. Despite the large increase in hectares, pomegranates are typically not the dominant crop for the farming operations that produce them; pomegranates even at the largest operation represent less than 15% of the total farm size. The level of sophistication varies with farming entity and size. Some small pomegranate orchards are farmed using strategies of the bygone era of mid-20th century, while other more recently established orchards show advances in farming technology. However, few producers show technology implementation similar to that found in the high value California wine grape industry. A further distinction within farm strategies relates to the production and marketing of organic produce; there exist farming operations that have organically produced pomegranates, although the hectares remain small in contrast to total area.

Cultural practices used by farmers on companion crops have a significant bearing
on pomegranate cropping strategies. If farmers already produce grapes, then machinery management optimization will make pomegranate establishment with in-row spacing of 1.5 m and rows at 3.6 m prudent. For farms with large canopy permanent crops such as stone fruit, citrus, almonds or walnuts, pomegranate orchards are more commonly established at a wider spacing, such as in row spacing of 4 to 5.2 m with rows at approximately 5.8 m. Wider spacing better accommodates a common set of large farming implements such as disc harrows, and brush shredders already utilized for tasks on the other crops. Initial recommendations have been made to California growers for crop establishment (Ferguson et al., 2008a).

The major limitation to pomegranate expansion has been acceptable supply of nursery stock (Anon., 2008b). Some growers have opted to produce their own nursery stock for crop establishment. This decision minimized establishment costs as well as addressed the lack of stock from California’s commercial nurseries from 2002-2007. New orchard establishment is achieved with bare root trees that are 12 to 24 months old, or growers may purchase clonally produced trees in containers. Some farmers will establish new orchards with freshly harvested cuttings from dormant mature trees, but difficulty in managing these widely spaced cuttings to mature size can lead to higher initial production costs and less favorable tree development (LaRue, 1977).

Similar to the variation encountered in plant population and spacing, training of pomegranates is not standardized in California. Pruning and shaping recommendations mainly apply to the dormancy period (Ferguson et al., 2008b). The most easily achieved and most prevalent system is a free-form multiple trunk. This is especially common in older plantings. Strong multi-trunk development in sectors away from the crown favors maximum tree canopy and results in a bush-like appearance. Broken or missing trunks can be regrown from the crown or adjoining trunks to replenish the productive canopy, and provide some indemnification against frost damage (LaRue, 1977). A more intensive system is the single trunk strategy. This creates a traditional tree form and requires significant management for branch development. Delays in production capacity often occur while the trunk is grown to a sufficient diameter to bear total tree crop load on scaffolds and branches. The benefits of this system include the ease of sucker removal and the efficiency by which farming practices can be made close to the tree line. Suckering in a single trunk system can either be done manually with pruning shears or chemically with carfentrazone (Shark) since lower branches and canopy are removed in a process referred to as skirting.

Wire trellis systems are less common but gaining in popularity as some growers experiment with vertical single wire, vertical double wire and V trellis systems. These wire trellis systems are found both on narrow rows, less than 4 m, as well as in wider row spacing of approximately 5.5 m. In all of the aforementioned, concern for worker safety at harvest and high prices for mandatory workplace insurance commonly limit total crop height to less than 3.6 m when hand harvested by ladder for either fresh or juice purposes. The height of pomegranates is typically maintained by use of mechanical topping devices using rotating circular cutting blades or sickle bars. In several of these training systems growers are attempting to create fruiting walls: vertical canopy development that rejects traditional multi-dimensional tree development in favor of dense, flat canopies. These fruiting walls are developed by narrow pruning and hedging and increasing tree density. The higher plant populations inherent to fruiting walls can decrease the time required to reach profitable yield when compared to lower densities. Concentrating pomegranate trunk, scaffold or branch growth into a zone that can be more easily pruned, sprayed, thinned, and harvested has potential for improved efficiency and mimics the approaches already deployed for apple and pear production in many parts of the world. Vertical wire trellises fit well within the context of the fruiting wall strategy. It is possible to use free-form multiple trunks and single trunks in a fruiting wall approach but these forms would seem less apt to garner many of the benefits as quickly or easily.

Some growers, especially those specializing in fresh-market production, practice pre-harvest summer pruning to improve fruit color and compress harvest to a minimum
number of days. This is typically accomplished by removing non-fruiting shoots and suckers from the trees' centers and exterior about 3-5 weeks before harvest. The increase in light stimulates exterior fruit color and improves visual appearance of the fruit. In some cases, fruit size can be improved slightly since photosynthetic activity is enhanced on newly illuminated leaves adjacent to fruit.

As noted previously, irrigation via groundwater or water delivery systems is a critical component in coaxing pomegranate production from the hot dry summer climate of the San Joaquin Valley. Irrigation systems in orchards established prior to the widespread availability of micro-irrigation in the US (~1980) are flood irrigated, whereby water is delivered to trees via flat channels created by plowing next to tree rows and allowing water to gravity run between gently sloped head and tail ends of the orchard. In more recently established orchards micro-sprinklers or trickle emitter/drip emitters are usually chosen. The ongoing shortage of irrigation water, especially in federal and state government water systems, are likely to continue further the conversion of existing acreage to micro-irrigation technologies. Water application scheduling is conducted by water budget calculations, by monitoring soil moisture status via hand probe, using soil moisture monitoring techniques such as tensiometers or gypsum-block resistance meters, or by use of 'leaf water potential' strategies. Thresholds for these monitoring techniques have not yet been created for California pomegranates, and are likely to require significant effort and investment to take into account the various plant populations, row and tree spacing, as well as canopy development strategies being deployed commercially throughout the San Joaquin Valley.

Fertilizers and soil amendments for pomegranates are determined based on visual plant growth status and site-specific needs, and historical experience. Research performed in the late 1950s in Tulare County showed that mature ‘Wonderful’ pomegranates required only about 40 to 60 kg/ha of nitrogen annually to produce consistent and high quality crops (J.H. LaRue, unpublished). The same multi-year experiment indicated that phosphorus and potassium were of no benefit for improving yield, fruit size, or fruit quality. Most growers in the southern San Joaquin Valley apply 50 to 100 kg/ha N annually. There are reports that pomegranates benefit from annual applications of zinc, but this has not been experimentally confirmed, nor have observations of such treatments been found to be beneficial except when obvious deficiency exists (K.R. Day, pers. commun.). There are numerous private agricultural laboratories that service California farms’ needs for soil and plant tissue analysis and which can provide meaningful analysis of comparative samples; however, as a new crop, pomegranate critical nutrient values (CNV) and compositional nutrient diagnosis (CND) values have not been developed for California climate, soil types, farming practices and cultivars.

Quality and Yield Limitations in California Pomegranates

Various insect pests have been reported in California pomegranate production although entomological research has not been comprehensively conducted (Carroll et al., 2006). Omnivorous leafroller (OLR) (Platynota stultana) is a common pest of commercial crops in the San Joaquin Valley. Damage to pomegranates comes in the form of direct penetration of fruit rinds that leads to fruit diseases and reduction in fruit which otherwise would have been considered fresh market quality (LaRue, 1977). In organic farming systems the spraying of Bacillus thuringiensis can reduce infestations; OLR can also be influenced by use of pheromones that can be deployed under both organic and conventional systems. Leaf footed bug (Leptoglossus clypealis) is thought to be the only other significant pomegranate pest that directly affects internal fruit quality. Reported early in the 20th century (Quayle, 1938) it has less commonly been seen in California. However, massive infestations have been observed where pomegranates border commercial citrus groves; more than 50 nymphs per fruit were observed. Leaf footed bug is known to penetrate through rinds of immature fruit; deformed and discolored arils have been found on fruit documented as having been damaged by leaf footed bugs (Carroll et al., 2006). In California almonds leaf footed bug can lead to pathogen infections of yeast.
(Michailides et al., 2008b), although such transfer to pomegranates has not yet been proven. Removing mummy fruit from pomegranate trees and treating with pyrethrin (PyGanic®) are suggested methods of management. The filbertworm (Cydia latiferreana), a close relative to codling moth, can penetrate pomegranate fruit rinds and has been the focus of limited research (Davis et al., 1983).

Other insect pests in California generally affect external quality, and as such are not as significant a concern for fruit quality where juice production is the primary use. Citrus flat mite (Brevipalpus lewisi) can be responsible for disfiguring pomegranate rind. The russeted appearance eliminates damaged fruit from fresh market use. Research in the 1950s reported this pest's presence in pomegranate (Elmer and Jeppson, 1957; Michelbacher, 1956) and more recent work showed its effect on pistachios (Pickett and Pitcairn, 1999). Sulfur is commonly applied during and after bloom to orchards showing historical infection of flat mite. Cotton aphid (Aphis gossypii) has been found infesting pomegranate. Sooty mold and soft rot where companion fruit touch can be attributed to high aphid populations. Control by natural predation by lady beetles (Coccinellidae), or by use of imidacloprid (Admire) or methomyl (Lannate) limits fruit damage. Soft brown scale (Coccus hesperidum) can be present especially where fruit density or leaf density is high; parasitism and Lannate can be successfully deployed. Other insects found in pomegranate production include western flower thrip (Frankliniella occidentalis), Comstock mealybug (Pseudococcus comstockii) (Meyerdirk and Newell, 1979), grape mealybug (Pseudococcus maritimus) (Carroll et al., 2006) and ash whitefly (Siphoninus phillyreae) (Pickett and Pitcairn, 1999). The ash whitefly has been the focus of pomegranate-based research in California (Gould et al., 1992). Root knot nematodes have been reported in California pomegranates (LaRue, 1977) and elsewhere in the world (Darekar et al., 1989; Siddiqi and Khan, 1986; Sudheer et al., 2007) but the specific influence on California cultivars is not yet known.

Low relative humidity in the San Joaquin Valley precludes common development of foliar diseases in pomegranates. Fruit has been monitored for black heart (Alternaria alternata) and is the focus of ongoing research (Michailides et al., 2008a). Aspergillus sp. has also been detected in pomegranate fruit at maturity but appears to be present at low levels when present at all, and has not proven to be an important deterrent to fruit quality. Gray mold (Botrytis cinerea) does occur post-harvest in pomegranates and is a pathogen that influences fresh market quality dramatically (Ott, 2004), including fruit that is stored or shipped for long distances. Studies in California have led to the registration of fludioxonil (Scholar) for reducing gray mold (Adaskaveg and Forster, 2002; Tedford et al., 2005).

Weed control under Mediterranean climates with micro-irrigation is typically a combination of mechanical disturbance of soil between rows and chemical control within rows. Tillage in pomegranate orchards is accomplished with year round use of disc harrows. Chemical control can include application of post-emergent herbicides such as glyphosate (Roundup®) and oxyfluorfen (Goal®) on all pomegranates or flumioxazin (Chateau®) on non-bearing pomegranates. Pre-emergent herbicides including oryzalin (Surflan®) and napropamide (Devrinol®) are also used. In organic farming hand labor plus mechanical tillage is typically employed. Weed mat barriers, especially in row, are under study for organic farming to reduce the need for multiple hand weedings. A significant abiotic factor limiting pomegranate yield and quality is fruit rind cracking. Although rainfall during the October and November harvest period is relatively low (Table 1) unexpected storms from the Pacific Ocean can produce autumn rainfall totals over 5 cm. Harvest equipment moving through commercial orchards requires dry soil and irrigation is not provided during this period. There appears to be an acceleration of fruit cracking from the influence of high humidity or unscheduled soil moisture during the harvest window, especially for late maturing pomegranate cultivars.

Cold temperatures can also damage pomegranate trees. Both winter freezes and spring frosts can cause damage to trees in the San Joaquin Valley. In early March 2008 and again in 2009, frost events occurred where temperatures dropped to as low as -3°C.
Mature trees were unaffected but a number of young orchards suffered shoot dieback and growers were forced to re-grow trees from resulting ground suckers. An unusually hard freeze occurred in December 1990 where temperatures dropped to -6 to -8°C. A number of mature orchards were damaged severely with death of scaffolds occurring for several years afterwards, and some young orchards were killed outright. As a consequence of these events, concerned growers can practice frost protection similar to strategies used in citrus during critical periods.

Crop Utilization and Economics of Commercial Production

Although the US grants approximately 1 million individuals legal permanent resident status per year (Monger and Rytina, 2009) the domestic consumption of pomegranates in the US is determined by existing perceptions of the fruit. Only 5% of residents have tasted fresh pomegranates prior to 2006 (Karp, 2006), but it is estimated that there will be nearly 2 pomegranate fruit harvested for each person in the US by 2012. This has led to an effort to increase consumption domestically as well as fully develop export opportunities (Anon., 2008b). The current product profile for pomegranates by North American consumers and, more importantly, food retailers would be described as a high sugar/high acid flavor with dark red rind color and dark red aril color. Although there are no government grade standards for quality, retailers offer consumers whole pomegranates that are marketed for use in salads and desserts, in meat marinades, as well as toppings for breakfast foods such as waffles, pancakes or cereals; and as autumn and Christmas table decorations in North America, (Anon., 2009) where they can be pared with pumpkins, decorative cucurbit gourds, multi-colored maize and persimmons. Some pomegranates are sold directly from farmers to consumers at weekly Farmer’s Markets, where farmers who voluntarily request certification by local government can arrive with produce for sale at city parks or designated automobile parking areas of large retail stores.

Prior to harvest the crop must meet minimum maturity standards (<1.85% titratable acidity based on citric acid equivalent, darker than Munsell Color Chart 5R-5/12) (Anon., 2008a). The indeterminate flowering pattern of pomegranates necessitates repeated harvest passes through each pomegranate orchard until the supply of fresh fruit is exhausted or market conditions no longer justify harvest costs. Since the crop is selectively hand harvested, large groups of laborers are needed each autumn. Emigrants from Latin America - primarily Mexico and Central America - who are residents of the US provide the most widely available labor. The harvest process involves removing the fruit from the tree by either clipping or using a twist-snap procedure. Fruit is then placed into canvas bags, and can be loaded into small plastic totes (containing 8 to 10 kg fruit) or large bins (approximately 425 kg fruit) for transport to packing facilities. There is little direct tray pack fruit in California as consumers and retailers demand rigorous fruit cleaning after being picked from the tree. Transport from field to packing facilities is accomplished by large size tractor-trailer units suitable for public roads. Packing facilities vary in sophistication. Nearly all facilities pack other types of tree fruit so methods of conveyance and sorting depend on companion crops at a given farming operation. Fruit can be cleaned through dry brush beds or wet wash systems, and then sized by optical cameras or physically through roller systems. Hand or optical sorting is employed to remove fruit showing external defects such as sunburn, cracks, punctures, or inadequate rind color development. Retail stores receive fruit that have been sorted for uniformity of size in various packs: mini cartons containing 4-6 large (<100 mm diameter) fruit, standard boxes weighing 12 kg and containing 16 to 36 pieces of fruit, or display bins which are free standing produce boxes that accommodate 90 kg of fruit subdivided into small cartons for ease of handling and proper rotation of inventory.

A harvest of all remaining mature fruit is made once fresh market fruit have been removed from orchards, or if the produced fruit is under contract for juice. Juice fruit is removed by hand although efforts are underway by numerous agricultural engineering organizations to design equipment for feasible pomegranate juice harvest machines (Clíne, 2008; Parsons, 2009). The juice is extracted from these cosmetically challenged
fruit by various methods including modified citrus presses or wine grape presses. Other food processing machinery has been developed exclusively for pomegranate juicing use proprietary equipment designs that can process a million fruit per day (Resnick, 2009). The high quality California pomegranate juice, almost exclusively from ‘Wonderful’ (University of California, 2009) can be used directly for 100% fresh pomegranate juice, concentrated, or used as a 100% juice blend with other distinctive fruit juices (POM Wonderful, 2009). Alternative uses for pomegranate products in California include polyphenol antioxidant extracts (POM Wonderful, 2009), industrial uses (Steibs Pomegranate Products, 2009) and cattle feed (Richardson, 2009). Yields of 8 to 13 MT per hectare can be expected from orchards when used exclusively for fresh market consumption (Day et al., 2005), but purportedly can be as great as 35 MT per hectare when high density mature trees are grown for juice (Cline, 2008).

The establishment and production costs for pomegranates has been comprehensively addressed in a publication created by the University of California (Day et al., 2005). Although costs are well understood the revenue of pomegranates has not been favorable for growers now entering the market. The United States Department of Agriculture’s Fruit and Vegetable Market News reported fresh market prices during the peak of the 2008 harvest season ranging between $ 16 to 18 for a 12-kg carton of 36 fruit, to $ 26 per carton for a 12-kg carton of 16 fruit. However, a survey of producers in 2008 found price per metric ton of juice fruit at $ 110 to 165, falling from $ 385 to 495 per metric ton just two years earlier. A more rapid decline has occurred in pomegranate juice concentrate (65°Brix) from $ 12 per liter in March 2008 to $ 6 to 7 per liter in March 2009 (University of California, 2009).

Despite the financial challenges faced as production increases, growers in California are taking steps to guarantee that American consumers are reaping the fruits of their labor. The voluntary grower-based and grower-funded organization, PURE PJ, represents over half the total acreage of pomegranates being farmed in California. PURE PJ was created to legally ensure that products labeled as 100% pure pomegranate juice from either Californian or imported sources are unadulterated and contain only authentic pomegranate juice. Advanced fruit chemistry analytics (Fischer-Zorn and Ara, 2007; Zhang et al., 2009) were used by independent labs to test randomly collected samples from North American retail shelves. These PURE PJ funded tests revealed greater than 50% of products claiming to be 100% pure pomegranate juice were in fact adulterated. The president of PURE PJ indicated that most violating products appear to contain imported pomegranate juice concentrate (M.R. Tupper, pers. commun.). US federal court action has held an organization liable for over $ 1 million for selling a product to American consumers that was labeled as 100% pure pomegranate juice but which was later proven to be adulterated with various sweeteners and coloring agents. This product was made using imported pomegranate juice concentrate (US District Court Central Division of California, 2008).

Issues Relating to the Future of California Pomegranate Production

The last decades of the 20th century saw a replacement of late maturity cultivars in favor of cultivars with earlier maturity to avoid fruit cracking and loss of yield (K.R. Day, pers. commun.). The cultivars ‘Granada’, ‘Foothill Early’ and ‘Early Wonderful’ mature prior to autumn rains, and hectares of the late maturing ‘Wonderful’ were replaced with these cultivars throughout the 1970s and 1980s (Morton, 1987; Stover and Mercure, 2007). In the current era it is difficult to sell large volumes of early-maturity cultivars due to their lack of ‘Wonderful’ fruit quality, mainly inferior internal color. ‘Wonderful’ has set the standard in the consumer’s mind for exemplary pomegranate fruit, but there remains a wide range of phenotypes for potential commercialization. The United States Department of Agriculture’s National Clonal Germplasm Repository at Davis, California contains limb sports and unexpectedly hybridized pomegranates from California, as well as selected international material, which totals nearly 200 lines (Stover and Mercure, 2007). The repository received material from the Garrigala agricultural research station in
Turkmenistan by Dr. Gregory Levin, who hand selected 60 lines from the over 1117 accessions under his management (Baer, 2006). However, even with the Levin material, the NCGR’s moderately sized collection has not yet revealed itself as a significant source of genomic variation (Stover, 2006). It is difficult to envision North American consumers moving away from the sweet/tart flavor and dark aril and rind colored ‘Wonderful’ in the short term, especially with ever expanding medical studies based on this cultivar. But California farmers and American consumers may show interest in cultivars already established historically in California or globally if shown to have “unusual” or “unique” whole fruit attributes.

Historically pomegranates in the San Joaquin Valley were considered the orphan of tree fruit crops, relegated to establishment only on marginal soils. The expansion of production since 1996 has pomegranates planted on traditional alkali soils and on a wider range of highly fertile soil types previously reserved for favored crops such as peach, table grape and almond. Using appropriate farming practices over such a broad range of soil types may prove as important as the selection of genotype for maintaining yield and fruit quality of the California crop for domestic and international consumers.

Pomegranate is one of the most recent examples of evolution from specialty to commercial crop in California’s modern farming era. There remain many more questions concerning optimal crop husbandry practices than there are answers. Optimal farming strategies for large and small farming operations will undoubtedly range from historically proven techniques to revolutionary technologies. Governmental support for US and California public crop research via land grant universities and the local cooperative extension farm advisors remains stagnant at best in many regions. Pomegranate industry progress will be achieved when immediate crises demand collaborative response (i.e., pathogen outbreaks that threaten yield or quality), industry-wide voluntary funded research becomes available (e.g., California agricultural commodity board system), or through private initiatives by individual agribusinesses or partnerships. California pomegranate growers will need to utilize domestic and international expertise for fundamental understanding of crop biology. This knowledge will lead to advances in farming techniques, including such unique strategies as covering pomegranates with nets of various colors (Levin, 2006).

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**Tables**

Table 1. Average monthly maximum air temperature (°C), minimum air temperature (°C) and total rainfall (cm) in the southern San Joaquin Valley city of Hanford, California - 1899 to 2008 (provided by Western Regional Climate Center, Desert Research Institute, http://www.wrcc.dri.edu).

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<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>12.2</td>
<td>16.6</td>
<td>19.8</td>
<td>23.9</td>
<td>28.7</td>
<td>33.1</td>
<td>36.6</td>
<td>35.6</td>
<td>32.4</td>
<td>26.7</td>
<td>19.1</td>
<td>13.0</td>
</tr>
<tr>
<td>Min</td>
<td>1.8</td>
<td>3.6</td>
<td>5.6</td>
<td>7.9</td>
<td>11.3</td>
<td>14.6</td>
<td>16.9</td>
<td>15.8</td>
<td>12.9</td>
<td>8.4</td>
<td>3.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Rainfall</td>
<td>4.1</td>
<td>3.9</td>
<td>3.8</td>
<td>1.9</td>
<td>0.7</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>1.0</td>
<td>2.1</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 2. Average phenology of mature pomegranate trees, ‘Wonderful’, in southern San Joaquin Valley, California.

<table>
<thead>
<tr>
<th>Phenological stage</th>
<th>Month/week(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bud break/red tip</td>
<td>Weeks 2 to 3, February</td>
</tr>
<tr>
<td>First flower open/calyx open</td>
<td>Weeks 1 to 2, April</td>
</tr>
<tr>
<td>First fruit set</td>
<td>Weeks 3 to 4, April</td>
</tr>
<tr>
<td>First mature fruit</td>
<td>Weeks 1 to 2, October</td>
</tr>
<tr>
<td>Completion of fruit development</td>
<td>Weeks 1 to 2, November</td>
</tr>
<tr>
<td>Full dormancy/leaf fall</td>
<td>Weeks 1 to 3, December</td>
</tr>
</tbody>
</table>