Increasing Global Supply of *Punica Granatum*

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Executive Summary

Do you enjoy eating the delicious vibrant bright red fruits known as pomegranates? Pomegranates contain many beneficial medicinal properties and have been regarded as a super fruit in many different cultures around the world. Pomegranates contain many beneficial compounds and natural sugars, so they taste good too! Unfortunately, pomegranate production is very limited to certain parts of the world due to the specific growth requirements of the plant. There are many parts of the world where fresh pomegranates are very hard to find. Luckily, a solution has been tested and created within this paper. There are greenhouses all around the world that can host the correct growth requirements for pomegranates. The current pomegranate supply chain is a very large global distribution chain which also attributes to the pomegranate deserts where it is hard to find the fruits. Pomegranate greenhouse production could potentially fill these gaps and create access to the fruits all over the world. Pomegranate greenhouse growers would be encouraged to sell their crops to local grocery stores and farmers markets which would generate new locally grown crops in various areas. Local production of these crops would also make the fruits much more affordable because the long and complex global distribution chain would be eliminated, and the fruits would be locally sourced. This would overall be much better for the environment too because less fossil fuels would have to be consumed to transport the fruits over long distances. Local growers could also set up an agreement with fruit juice companies in the area to produce local pomegranate juice! Pomegranate greenhouse production could be very beneficial for many communities around the United States because it would create more jobs and produce fresh locally sourced fruits.

Introduction

Taxonomy

The fruit bearing deciduous shrub known as pomegranate has never been utilized in a greenhouse production setting. There are many potential benefits to growing pomegranates in a scheduled and controlled environment. The shrub is only able to grow in warmer climates which can limit some parts of the world access to the fruit. The plant requires a very specific climate to flourish and produce its bright red fruits. Pomegranate belongs to the kingdom plantae and the order of the plant is Myrtales (Chandra et al., 2010). The family of pomegranate is Lythraceae, the genus is *Punica* and the species is *granatum*. The taxonomic name for pomegranate is *Punica granatum*. Aerogenesis of the species *punica* resulted from evolution of the xerophilic and cryophilic lines of development. Punicaceae contains a single genus *punica* of two different

species, *Punica granatum L.* and P. *Protopunica* Balf. F. (Chandra et al., 2010). A synonym for the species P. *Protopunica* is *Socotria protopunica.* There are many different varieties of *Punica granatum* as it has been domesticated by humans' multiple times throughout human history and for a long time in certain parts of the world. The Turkmenistan Experimental Station of Genetic Plant Resources, Turkmenistan Academy of Agricultural Sciences has a collection of 1157 accessions of the plant. Iran has 760 different germplasms and China grows 238 different cultivars in different provinces. There are commercially produced varieties of *Punica granatum* and ornamental varieties. Recently hybridization and polyploidy work, have resulted in a few new commercial cultivars available to the market (Jalikop, 2010). The names of these new varieties are 'Hongmanaozi', 'Taihanghong', 'Yushiliu 4', 'Hongyushizi', 'Shani-Yonay', 'Nasimi', 'Vurgun', 'Aleko', 'Mengliaihong', 'Zaoxuan 018', 'Zaoxuan 027', 'Taishan Dahongshiliou', '87 Qing 7', 'Linxuan 8', 'Lington 14', 'Azerbaijan', 'Desertnyi', 'Baiyushizi', 'Qingpiruanzi', 'Tiepitian', 'Mirdula', 'Bhagwa', and 'Ruby' (Jalikop, 2010). There are also some varieties of *Punica granatum* that have ornamental value and there are 2 main types of ornamental forms that growers try to produce. These 2 different ornamental varieties are dwarf form of the plant or a double flower form of the plant (Jalikop, 2010.). The double flowered ornamental varieties have numerous modified stamens that are turned into petals, but some of these double flowered varieties do not set fruits. The modification of the stamen does create ornamental value though because the flowers become very large and attractive. The functionally sterile flowers on some of these ornamental varieties can produce fruits through manual pollination, and some double flower forms even have advantages such as larger fruit sizes, with lower acid contents (Jalikop, 2010). There is still currently a good amount of debate and confusion about the number of chromosomes that the *Punica* genus has, there has been reported

diploid varieties of pomegranate with 16, 18 and 19 chromosome pairs and there has even been a tetraploid identified (Chandra et al., 2010).

Geographic Distribution

Wild types of *Punica granatum* grow in Transcaucasia, Central Asia, Iran, Turkmenistan, and Northern India (Chandra et al., 2010). Researchers have found that there are 3 mega centers in the world where *Punica granatum* has been cultivated by humans, and 5 other macro centers; each of these locations has had an influence on the genetics of the species. The areas of the world where the genetic diversity originated are the Middle East, Mediterranean, Eastern Asia, America, and South Africa (Chandra et al., 2010). The Middle Eastern part of the world is considered the most substantial for *Punica granatum* because the Middle East is in the plants native range. *Punica granatum* is not an invasive species, it requires a very specific climate for growth so that is why the plant is only grown in certain parts of the world. Due to the limited areas this crop can be grown putting the crop into greenhouse production could increase the global supply of the fruits. The macro centers are known for having non-uniform growth patterns for *Punica granatum* due to the specific climate the plant requires and the differences in varieties of the plant. By the 13th century Arabic people had identified and described many different native varieties in Arabia and Mesopotamia (Chandra et al., 2010). The first cultivated varieties were grown in northern Africa before the Romans caused extensive erosion and damage to the land due to the extensive agricultural practices used in the region at the time (Chandra et al., 2010). In the Uzbekistan region of the world some of the first frost tolerant varieties of *Punica granatum* were introduced into agricultural practices. It wasn't until the 20th century that the plant was first introduced into the United States. The American pomological society recommended several varieties to be planted in Florida, Alabama, Mississippi, Louisiana, and

Arkansas. All the varieties grown in the Mediterrean region are the original gene pool of the plant, and the varieties are maintained through vegetative propagation. There is also still hybridization currently taking place between the wild type forms and cultivated forms of *Punica granatum*. There are over 500 varieties of *Punica granatum* that are known throughout the world but only about 50 of them are ever cultivated (Chandra et al., 2010). There is currently a global effort for the collection, evaluation, characterization, and *ex situ* conservation of pomegranate germplasms in the countries, Italy, Spain, Israel, Russia, Tunisia, Turkey, Ukraine, India, Syria, USA, Uzbekistan, Portugal, Hungary, Germany, France, Cyprus, Turkmenistan, Albania, Morocco, Greece, Egypt, Tajikistan, Iran, and China (Chandra et al., 2010).

Crop History

Punica Granatum has been produced by humanity for thousands of years and the plant can be found on several different continents but there is still a lack of understanding on pomegranates genetic centers of origin (Chandra et al., n.d.). The ancient civilization of Sumers was one of the first known groups of people to cultivate the crop around 2600 BP (before the present). The crop was brought into the area through their migration from the Zargos mountains around 4600 BP and historians suggest that the domestication of the crop started around 5000 BP. There is other history that suggests *Punica granatum* was cultivated in modern day Israel around 6000 BP. The history of pomegranate is unclear though and it has been suggested that the crop was domesticated a few different times throughout human history starting even as long as 12,000 years ago at the beginning of the neolithic era (Chandra et al., 2010). Sites of natural pomegranate can be found in central Asia to, which suggests the crop was domesticated in this area during 3000 BP. Pomegranate made its way to China in 4000 BP and history also suggests the crop made its way to various tropical and sub-tropical regions of the world around this time

too. *Punica granatums* arrival into California predates the crops arrival in the United States because in 1769 AD Franciscan monasteries from Spain spread pomegranate culture into the southern and northern coastal regions of California (Chandra et al., 2010). The crop has important significance and is used a symbol in many different ancient cultures. In Greek mythology pomegranate was seen as the indissolubility of marriage, in Persian mythology Isfandiyar ate a pomegranate and became invincible, in Judaism the number of seeds in the pomegranate is said to be the number of commandments; in Buddhism the pomegranate is one of 3 blessed fruits; Chinese pottery sees the pomegranate as symbols of fertility abundance, and prosperity; in Christianity the pomegranate is associated with fertility, and in Islam the Koran describes a heavenly paradise with pomegranates growing everywhere. There is also a large debate between historians who think the pomegranate tree, or the date palm tree were seen as the tree of life in artifacts from ancient Mesopotamia (Chandra et al., 2010).

Uses for *Punica granatum*

Many recent studies have suggested that pomegranate is a "super fruit" because of the various health benefits that are produced from the fruits (Kahramanoglu, 2019). This caused production to increase all over the world due to the increased demand for the fruit, but production is still limited by physiological disorders, pest and disease problems, post-harvest problems, and storage problems (Kahramanoglu, 2019). *Punica granatum* trees are known for being very highly

Table 1. Global availability of pomegranates

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
India												
Iran												
Turkey												
USA												
Spain												
Israel												
Argentina												
Peru												
S. Africa												
China												
Egypt												
Afghanistan												
Tunisia												
Azerbaijan												
Australia												
Italy												

Figure 1: This table depicts when pomegranates are available in producing countries each year. The darker gradient means more pomegranates are available compared to the lighter gradient. As the figure shows there are some large gaps in certain parts of the world when pomegranates are available to consumers (Kahramanoglu, 2019).

sensitive to their environments. Climatic conditions such as water scarcity, heavy rain, high salinity, and heat (Kahramanoglu, 2019). Due to the increasingly more extreme weather conditions across the globe there has been more struggles to produce *punica granatum*.

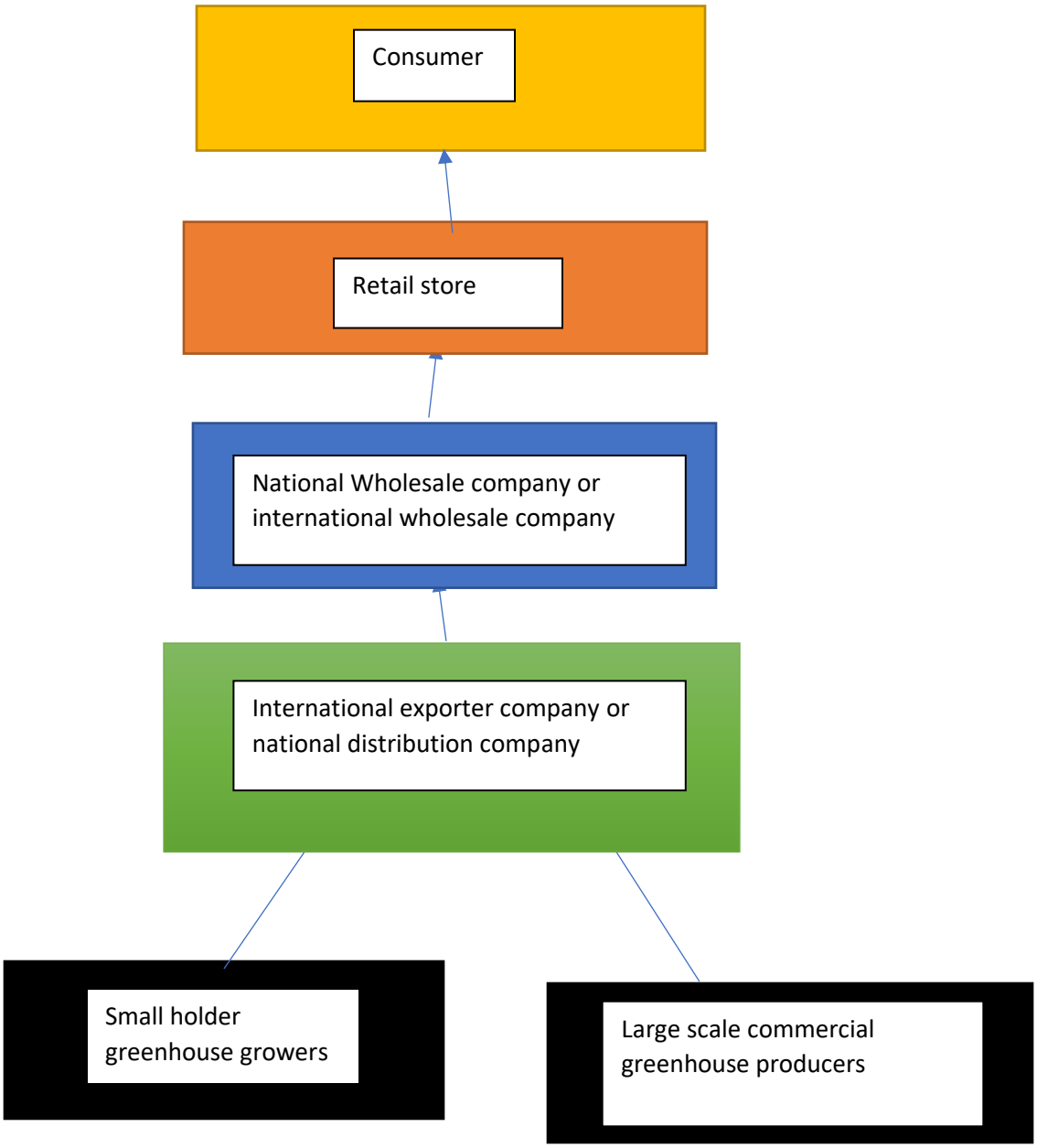
Due to the increasing human population and decrease of fertile lands for the crop there has been a lot of emerging research about how to increase the yields of the crop to meet the demand for the fruits. Some researchers have focused on using high density planting systems to increase the yields of the crop in smaller areas of land. Pruning of the trees is also a very important factor

when it comes to the yields produced because the fruits generally form of the spurs of the tree on 2–3-year-old branches (Kahramanoglu, 2019).

The demand for the fruit has been ever increasing as more research is conducted on the plant. There are many beneficial compounds and bioactive nutrients found within the fruits of *punica granatum* (Khwairakpam et al., 2018). Pomegranate possess, antioxidant compounds, antibacterial properties, anti-inflammatory compounds, anti-proliferative compounds, anti-angiogenic compounds, and anti-metastatic compounds. Along with the variety of beneficial compounds found in the plant it is also known to induce apoptosis, and new research has suggested that it could even be used for cancer treatment therapies (Khwairakpam et al., 2018). Besides all these beneficial compounds and properties found within the plant pomegranate fruits are very beneficial for human consumption and the fruits are known for tasting good. An aspect of pomegranate production that has never been addressed is scheduled greenhouse production. Little to no research has been conducted on the plant because it has always been grown outdoors in the very specific climate the tree requires. There is already a large global supply chain in place for production of the crop and many countries export the fruits around the world so creating a new supply chain for scheduled pomegranate production would not be an issue. The largest issue the industry currently faces is not being able to produce enough supply of the fruit for the entire global population. Below is an example of what a greenhouse horticultural supply chain for pomegranate would look like.

Potential Supply Chain Diagram

Figure 2: This figure depicts the potential steps pomegranate produced in a greenhouse would have to take to reach the consumer, at a national or international level (Mohalkar et al., 2018).



Anticipated Cultural Requirements

Life Cycle

In natural outdoor wild conditions, a pomegranate tree needs 2-3 years to reach full maturity before the tree can start producing fruits. Since *Punica granatum* is a tree, it is a perennial crop. Once the tree has reached full maturity it can then produce more fruit every 5-7 months. The tree first starts of as a small seedling with 2 leaves. As the seedling grows more leaves appear to conduct more photosynthesis and the stem starts to thicken. Once the seedling has fully developed into a tree the continuous cycle of the tree bearing fruits can begin. The normal phenological stages of the plant when at maturity starts with the buds of the tree in winter dormancy where the bud is deeply linked to the branch and pointy at the tip. The buds of the tree then begin to swell and the tips of the branches containing the buds turn a red color. The first leaves on the tree then begin to appear and the leaves are furled and bright red with a pale green midrib (Melgarejo et al., 1997). The leaves of the tree then begin to separate and grow and as the leaves grow, they change from a red color to a green color. The internodes on the branches of the tree then begin to elongate quickly and then the flower buds start to appear. The buds are greenish in color at first but then become red a few days later. The calyx then begins to swell and opens eventually soon after. During this stage the difference between male and hermaphrodite flowers becomes more apparent based off the shape and color of the calyx. The terminal branches bud and flower together with several flowers and the flower type seen on the tree is abscises. (Melgarejo et al., 1997). The flower and calyx of the tree then opens and reveal a purplish red flower with yellow anthers and stamens, and the petals alternate with every two sepals, so the flower has alternating petals and sepals. Pollination takes place when the anthers and stamens are yellow so after pollination the petals then begin to fall, and the fruit begins to set

on the tree. The ovaries and calyx swell and they start to change from an orangish red color to a green color. The fruit then begins to grow and enlarge and as this happens new shoots form on the tree to produce even more fruit. The fruit of the tree then begins to ripen, and it turns from a green color to red and the seeds within the fruit change from white to a pinkish red color. Once the temperatures are colder again, the tree drops its leaves when they start to turn yellow in color and winter dormancy of the plant begins (Melgarejo et al., 1997).

Plant Characteristics

Punica granatums growth form is either an evergreen or deciduous perennial tree or shrub. In warmer climates the trees can be grown as an evergreen tree, and they produce fruits for most of the year. In slightly cooler climates the tree may be deciduous and drop its leaves each year for the winter. Pomegranates fruits are highly edible and consumed by many people all over the world and the fruit color generally indicates the flavor, the darker the fruit, the better the flavor (Glozer & Ferguson, 2011). In greenhouse production dwarfed varieties of the tree would be easier to produce in a controlled environment so the dwarfed variety would be more of a woody shrub. The fruits produced are generally smaller in dwarfed varieties but with the right genetic research the plant could potentially produce full sized fruits on a dwarfed plant. Since the fruits of pomegranate are highly valued and can only be grown in certain climates there are a lot of places in the world that do not have the best access to the fruits. In states like Florida, Alabama, and California, pomegranate trees could be grown in people's yards so nursery production could be utilized in places with warmer climates. Pomegranates prefer USDA hardiness zones 7-10 so they require very warm temperatures all year-round (Stein et al., 2015). Dwarfed varieties could be produced in greenhouses in places where the USDA hardiness zone is not 7-10 which would increase access to the fruit for the public. These dwarfed varieties could

also be sold to consumers interested in trying to produce pomegranate fruit of their own. With a growing operation large enough to accommodate for many pomegranate plants, producers could produce fruits in any part of the world if they have access to the necessary controlled environment. Pomegranate trees also prefer USDA heat zones 10b-11 so these trees need to remain above 40 degrees Fahrenheit year-round (Stein et al., 2015). Pomegranates are also very valuable for the juices the fruits can produce. The juice contents of each fruit can vary from 20-50% in each fruit and the juice contains natural sugars, glucose, fructose, and sucrose. The juice also contains simple organic acids and a variety of essential ammino acids (Kahramanoglu & Usanmaz, 2016).

Potential Production Environment

Punica granatum trees require large amounts of heat and sunlight but also prefers a cooler winter climate. The plant is considered a mild subtropical fruit so in a controlled environment the grower would want temperatures above 40 degrees Fahrenheit for the cooler season and 70-85 degrees Fahrenheit for the warmer season (Kahramanoglu & Usanmaz, 2016). Larger changes in temperature between night and day will produce larger, brighter, and better tasting fruits. Pomegranates also prefer lower elevations anywhere from 600m-1000m in elevation because at higher elevations pomegranates are less productive. The plants are susceptible to frost and drought tolerant, but drought conditions do decrease fruit production (Kahramanoglu & Usanmaz, 2016). Pomegranate trees have been found to be highly adaptable to various soil conditions and can withstand slightly alkaline soils of pH 7.5 but the trees prefer slightly acidic soils with a pH around 6.0-6.5. Increased salinity may cause damage to the fruits and decrease the overall production of the tree. Water salinity used to water the plants should not exceed 3.5 ppm. Trees grow best in a heavy loam alluvial soil, so a grower may want to use a heavier more

compact substrate when growing pomegranates in a controlled environment (Kahramanoglu & Usanmaz, 2016). The best production practices in a controlled environment would be to use slightly acidic soils with water around a neutral pH. The plants would produce better fruits if they were cooled for a few months out of the year, but the temperature must remain above 40 degrees Fahrenheit. In a controlled environment the pomegranates will be more of a shrub then a tree but pruning the branches that are not producing fruits will also be essential to the health of the plants. Pruning can only be done when the plant is in its cooler environment for the winter months.

Pomegranate Marketing

Depending on how the grower or producer would have their pomegranate operation set up the fruits could be readily available all year round. Having the trees in a rotation where some were producing fruits and other plants were cooling would allow for constant fruit production year round. If all the trees were put into cooling each year the trees would only produce fruits twice a year, once in the spring and another time in the fall. The grower could also never cool the pomegranate plants and allow them to fruit all year, but this would most likely decrease the quality of the fruits. Since this is a fruit producing crop, it would be ideal to have plants in different life cycle stages so fruit could constantly be produced. The northern hemisphere of the world generally has access to pomegranates from September to February, and the southern hemisphere normally has access from March to July (Kahramanoglu & Usanmaz, 2016). A grower or producer could also set up a contract with a fruit extract or fruit juice company because pomegranate juices and extracts are also very profitable products.

Programmability and Limitations

Punica Granatum could produce fruit year-round in a greenhouse-controlled environment. The quality of the fruit is the best when the plants can experience a cool season. A producer could have the greenhouse arranged so some of the shrubs would be fruiting while others are cooling, and the crop could be placed in a rotation so a greenhouse producer could produce quality fruits all year. The main problem with the current pomegranate supply chain is the lack of fruits available to certain parts of the world all year. So, programming the crop to produce fruit constantly would generate the most profit and lower the overall prices of pomegranates in the local market. The biggest limitation to producing large quantities of pomegranates in a controlled environment would be getting all the shrubs established and acclimated to the climate of the greenhouse. Currently there are not commercial varieties of the plant specifically bred for controlled growing conditions. Getting the plants to grow in a year-round rotation would take some trial and error from the grower. Some of the trees also may not produce fruit every time they complete a normal life cycle because this happens in outdoor commercial production some years too based off certain environmental stresses.

Competitive Crops

There is currently already a large fruiting tree and shrub market in the United States, even in colder states like Minnesota, cold tolerant varieties have been developed for these areas. Many of these fruit tree nurseries are outdoors and can generate good yields even while experiencing the frigid northern winters. The southern parts of the United States and California have larger established nurseries and can even produce pomegranates outdoors. Producing pomegranates in a controlled environment would be best suited for places where the USDA hardiness zone is lower than 7-10 which contains a large part of the United States. In these areas

the controlled production would be much more profitable because it would not have to compete with outdoor nurseries and the storage transportation costs would be substantially lower.

Marketing Story

Punica Granatum also commonly known as pomegranate is a super fruit that more humans need to consume due to the various health benefits the fruit and juices contain. Pomegranates are loaded full of antioxidants, natural sugars, and anti-inflammatory compounds. New research has even suggested that pomegranates could be beneficial for treating cancer. Throughout history pomegranates have been viewed as a divine fruit in many different cultures and religions because of all its beneficial properties and great taste. Unfortunately, pomegranates are a very intensive and sensitive plant in orchard production, and they can only be produced in very warm climates. There is also limited availability of the fruits throughout the year in certain areas and the fruits can be very expensive. Fortunately, there is currently a solution to this problem in progress. At the University of Minnesota *Punica Granatum* is currently being trialed in a controlled and scheduled environment production setting. Producing these fruits in a controlled environment would allow growers to keep the sensitive plants in the correct climate and produce fruit all year long. The plants being trialed are a dwarfed variety that produce slightly smaller fruits, but the dwarfed variety is more convenient because of the space it saves by not growing an entire tree in a greenhouse. The plant is currently being trialed from seed and vegetative propagule, but seed seems to be the best option for the proposed crop schedule. Once the shrubs are established some can be cycled into their cool dormant season will others are producing fruits. The first fruits from the trialed crops should be available in 4-5 months, but once the plants are fruiting, others will be in earlier growth stages to produce a constant flow of fruit. There are already a variety of cold hardy fruit tree nurseries even in the colder parts of the

United States and other countries but cold hardy varieties of pomegranate do not exist so this would be a good solution to supply chain shortages. Since pomegranates hold higher value per fruit versus, apples, cherries, plums, apricots, peaches, citrus fruits, and berries producing them in a controlled environment would be economically viable.

Crop Schedule and Information Guide

Crop Scientific and/or	Series/Cultivar	Source	Recomme	Days to G	Covered/	Pack Size
Punica Granatum		BC	72	20-35	lightly co	Mini Jr to
Punica G	Orange I	Baker Cree	72	20-35	lightly co	Mini Jr to

Figure 3: Purposed crop schedule for *Punica granatum*. Double click on the table to view the entire spreadsheet.

Information Guide

The production schedule generated for *Punica granatum* in this paper is intended for the crop to be grown only in greenhouses in locations that are not USDA hardiness zones 7-10. Dwarfed varieties like the ones in figure 3 are also best in greenhouse locations. The crop will take about 58 weeks to produce fruit in these conditions. Once the pomegranates have been produced the plants must be moved to an area with a lower temperature around 55-60 degrees Fahrenheit. It is best to grow 2 different cultivars near each other so the trees can cross pollinate but self-pollination is also achievable by pomegranate trees. The container sizes needed are included in figure 3 but pomegranate seedlings germinate well in 72 flats. Once roots have been

established in the flats the seedlings can be transplanted into 2–3-inch pots and be moved to a capillary matt. Once the seedlings have grown and have produce multiple branches they can be transplanted into jumbo senior square pots. After the rootstock has developed in the jumbo senior square pots the pomegranate trees can be transplanted into 3–5-gallon pots where they will finish their growth cycle. To achieve constant year-round pomegranate production a grower should stagger the dates when they germinate seeds by every 1-2 months so there are trees at various growth stages. Once a grower has multiple established trees, they can be cycled from their cooling stage to flowering and fruiting stages every 3 months. New seeds can be collected from the fruits, but the seeds must be dried first. Scarifying the seeds may also help increase the germination rates of the seeds. Once the plants are in a constant cycle a grower could harvest and sell pomegranates every 2 months. The goal of this production system is to produce local pomegranates in areas where pomegranates are less common so the pomegranates could be sold at local grocery stores and marketed as fresh local produce. Shipping in local areas would be much more achievable and could be done in a much more cost-effective way.

Increasing the Sustainability of Pomegranate production

The best method to increase production of pomegranates inside greenhouses while decreasing the cost and use of resources would be to create a rapid fruiting cultivar. Current pomegranate production even in greenhouses with dwarfed varieties requires about 59 weeks for fruit production. Creating a cultivar that grows and fruits in 30-40 weeks would allow for much more rapid fruit production in a greenhouse setting. Another purposed variety could be a variety that constantly produced fruit and a variety that doesn’t need the long cooling period like current pomegranate varieties on the market.

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