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Introduction

The pomegranate (*Punica granatum* L.) represents an economically vital fruit species that has maintained its appeal through the ages due to its medicinal properties, nutritional contents, and ornamental qualities. Understanding the biological identity and agricultural potential of the species depends on examining its taxonomy as well as its distribution and ecological relationships because pomegranates hold deep ties to human history. *P. granatum* belongs to the Plantae kingdom where it displays autotrophic multicellular characteristics together with Streptophyta phylum representatives link closely related green algae and land plants (Simpson, 2019; Turmel & Lemieux, 2018). The scientific class of *P. granatum* has progressed through molecular analysis which moved it from Punicaceae to Lythraceae classification thus placing it among fundamental economic plant species.

The taxonomic background of *P. granatum* is introduced to explain its evolutionary position in the plant taxonomy. The monograph investigates how the species moved from its Middle Eastern origin to spread across continents throughout history to the present day. Researchers have explored how different environmental factors at various altitudes under specific climatic conditions and soil conditions shape the cultivation and production characteristics of the species. The study integrates knowledge from taxonomy and ecology and plant biology and horticultural practices to present an

extensive perspective on pomegranates as ecologically diverse elements in nature and agriculture. The biographical understanding of *P. granatum* along with environmental factors serves both academic and commercial needs as well as conservation management opportunities.

Agroecology 1

Distributional Context 1.1

Taxonomy 1.1.1

Rank	Classification
Kingdom	<i>Plantae</i>
Phylum	<i>Streptophyta</i>
Class	<i>Equisetopsida</i>
Subclass	<i>Magnoliidae</i>
Order	<i>Myrtales</i>
Family	<i>Lythraceae</i>
Genus	<i>Punica</i>
Species	<i>Punica granatum</i>

Pomegranate (*Punica granatum* L.) exists within the *Plantae* kingdom together with all eukaryotic multicellular organisms that display tough rigid cell walls. These living creatures generate food through photosynthesis (Plant Kingdom - Classification and Characteristics, n.d.) since they are autotrophic. The phylum *Streptophyta* includes *P. granatum* among its members which contains all freshwater green algae, embryophytes, and land plants (Simpson, 2019; Turmel & Lemieux, 2018). Organisms in this phylum range from unicellular forms such as *Euglenoidea* to multicellular filamentous forms like *Nocardia*.

Equisetopsida constitutes the scientific classification for Pomegranate together with other ancient spore-bearing vascular plants that predominate with extinct specimens. This plant group can be identified through its solid stems and internal hollow canals with whorled microphyll, joined sporangia, and having elaters (Simpson, 2010) as shown in Figure 1. The subclass *Magnoliidae* exists within this class where it groups with dicotyledonous flowering plants. This subclass is made up of families with a high concentration of primitive characteristics. With three of the most important attributes of this subclass that are, its *apocarpic*,¹ *acyclic*² or *hemicyclic*³ flowers which its pollen is uniaperturate, meaning the grains have one opening and are pollinated by beetles and cantharophily (Facultad de Ciencias Exactas y Naturales y Agrimensura, 2009).

The pomegranate tree stands as part of *Myrtales* which represents multiple flowering plants including economic important species including shrubs and trees and spices and

¹ Apocarpic is a condition where the reproductive organs of a flower are not joined together

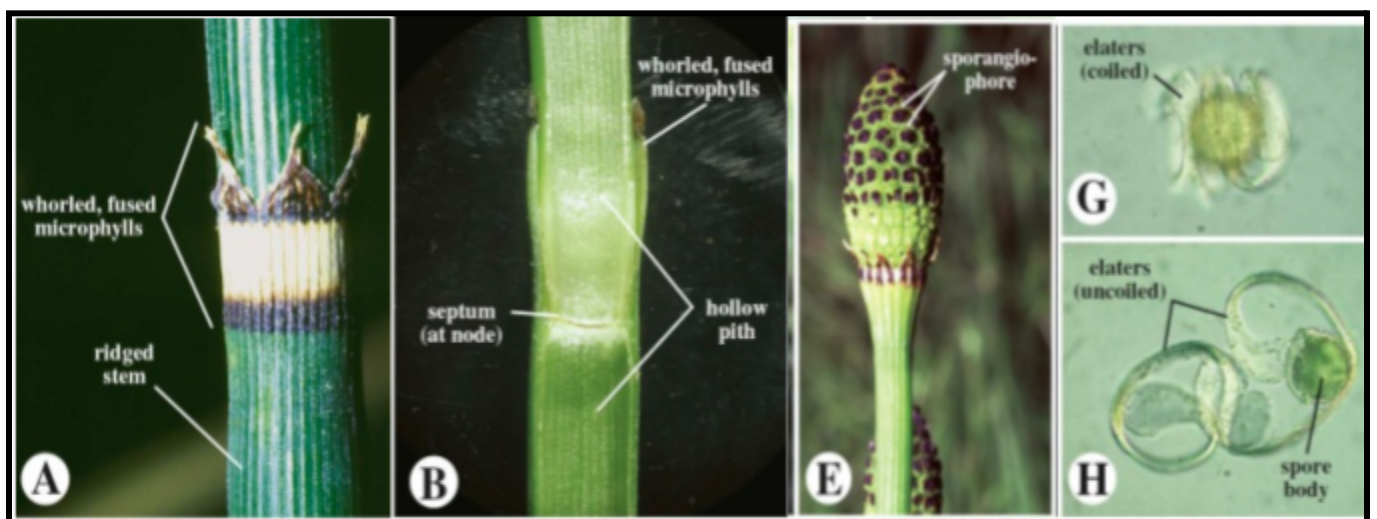
² Acyclic is used when flowers parts are arranged in spirals

³ Hemicyclic is having floral leaves partly in whorls and spirals

fruits (Britannica, 2019). Inside the *Lythraceae* family this plant shows leaf whorls starting straight from the stem base with tiny stipules and individual or clustered small flowers. Their flowers are solitary or arranged in clusters, also actinomorphic which means they are symmetrical, have spikes and they grow terminal or axillary buds, near the tip or the stem (Diversidad Vegetal, Facultad de Ciencias Exactas y Naturales y Agrimensura [UNNE], n.d.). The genus *Punica* includes small trees or shrubs that produce white to deep red flowers with numerous stamens, which develop into fruit, and its species is *Punica granatum*.

Figure 1:

Equisetopsida characteristics: picture A consists of whorled fused microphyll which is that the leaves are fused forming a collar around the stem and pointing out the rigid stem. Picture B shows another example of a whorled fused microphyll, hollow pith, and septum on the stem. Picture E is an example of a sporangiophore in a plant and pictures G and H are the elaters, G being coiled and H uncoiled. (Simpson, 2010)



Affinities 1.1.2

The affinities of the plant *Punica granatum* are slim because it is the only one of its species, so moving up the classification is the genus. Pomegranates share a genus with *Punica protopunica*, these are the only two species from the genus *Punica*. *P. protopunica*, unlike *P. granatum*, is part of the family *Punicaceae*. Before being considered part of the *Lythraceae* family, pomegranate was part of the *Punicaceae* family but later on discovered with lots of molecular investigation that it belonged to the *Lythraceae* family (*Punica Protopunica (Socotran Pomegranate)*, n.d.). By sharing the same genus they both have characteristics that are similar to one another. For example, the red flowers produce a fruit with the same shape but a different color as shown in Figure 2 below. dx

The *Lythraceae* plant family includes *Punica granatum* pomegranates as one of 30 genera from its 620 species spread worldwide (Brown, 2023). Studies linking pomegranates to *Lythraceae* members through genetics and physical characteristics resulted in scientist merging *Punicaceae* family with *Lythraceae* family (Brown, 2023).

The pomegranate resides in the taxonomic group which includes crape myrtle and loosestrife plants. Both deciduous and small-tree pomegranates possess edible aril-enclosing seeds inside leathery round fruit as their main identifying feature.

Pomegranates along with other *Plantae* organisms utilize photosynthesis and

chlorophyll to convert sunlight into ATP (Brown, 2023). All members of this plant species fall under Tracheobionta subkingdom bringing them vascular plant classification due to their special water and nutrient transport systems. The morphological changes enable *P. granatum* plants to thrive in their dry and semi-dry geographic habitats. As pomegranate develops flowers inside its fruit it becomes part of the Magnoliophyta plant grouping. The scientific community assigns *Punica granatum* to the Rosidae taxonomic group together with various other significant floral species. Commercial cultivation of *Punica granatum* species takes place because they produce health benefits alongside aesthetically valuable flowers which are significant elements in many cultural traditions (Brown, 2023).

Figure 2: *Punica protopunica* (*Punica Protopunica* (Socotran Pomegranate), n.d.)



Origin 1.1.3

The homeland of the pomegranate (*Punica granatum L.*) is the territory of Iran to the North of India, mostly the whole Middle East with parts of southwest Asia. It was first domesticated in 4000 and 3000 BC, one of the oldest fruits in history. The natural habitat of the pomegranate is the regions of Iran, Afghanistan, and Azerbaijan as seen in Figure 3. Through ancient trade networks, this fruit originated at its starting point and moved west until it reached Mesopotamia Egypt and the Mediterranean region becoming intimately connected with their cultural practices medicine and eating customs. Punica emerged as the genus name through Latin Carthage terminology because Romans linked this plant to Carthaginians who distributed the food throughout the Mediterranean region (Zeynalova, 2019).

Figure 3:
Map of Pomegranate origin (Zeynalova, 2019)



Fossil Records 1.1.4

There are no current fossil records of this existing species.

Present Distribution 1.1.4

Though this fruit is originally from the Middle East, it was first introduced in the Mediterranean and East Asia. Then it was brought to Europe, North Africa, East Asia, and the Indian Peninsula (Zeynalova, 2019). Further on it extended to the Arabic Peninsula, Afghanistan, and then introduced to America, all the warm regions that extend from the United States and the way down to Chile, this considers all Central American countries and some South American countries. (Britannica, 2024)

Environmental Factors in Distribution 1.2

Elevation and Climate 1.2.1

Pomegranates could grow in altitudes up to 500 m (National Horticulture Board, n.d) but perform best when exposed to temperatures above 85 degrees Fahrenheit or 29.5 degrees Celsius 120 days of the year. These trees are drought tolerant and can resist very high temperatures but without good irrigation drought for a prolonged time can cause fruit production loss. Whilst hotter climates are more recommended for the growth of the pomegranate, these trees can grow in climates of -15 degrees Celsius (BBC Gardeners'

World Magazine, 2022), but very cold climates cause frost damage in the tree bark.

(*Pomegranate Production Circular 997*, 2011)

Geology and Soils 1.2.2

Pomegranates need deep, loamy soils with good drainage because they will be harmed when exposed to too much moisture. However, these plants are very resistant to extreme measures, so they will grow fine in sandy and clay soils and with an irrigation of water containing 2,00-2,500 ppm salt (*Pomegranate Production Circular 997*, 2011).

The soil pH has to be between 5.5 and 7.2 but could go up to 7.5 (*BBC Gardeners' World Magazine*, 2022).

Punica granatum as a vegetation component 1.3

Community Composition 1.3.1

Pollination, bee pollination is key for pomegranate fruit production. Without proper pollination, the fruit will not grow. For this reason, there must be various plants surrounding pomegranates that attract bees, for example, herbs like basil, cilantro, dill, parsley, and mint. Some flowers like daisies, Queen's Anne's, sunflowers, and lavender

will also help the pollination process and captivate bugs like ladybugs and lacewings, who eat aphids that damage the trees. (Wolf, 2012)

Biology 2

Reproduction 2.1

Chromosomes 2.1.1

. *P-granatum* has two types of chromosomes. It might sound odd, but because of different types of evolutions that regard the chromosome numbers, this fruit species may have 16 or 18 diploid chromosomes. In some cultivars such as the Baghawa, and Tunisia, $2n=16$, had a major chromosome evolution because these diverged from the Taishanhong cultivar which pomegranate chromosomes are $2n=18$. Davenzi cultivar also diverged from Taishanhong but in this case, the chromosome number stayed the same having $2n=18$. Some studies say that pomegranates have the diploid chromosome of $2n=16$ but it has been researched and studied that most wild and cultivated pomegranates diploid chromosomes are of $2n=18$. Even though it might sound like a total change in the genetic sequence some genomes do change but there is highly conserved genetic content across the cultivars. As there are not many changes between these two types, they can cross. (Akparov et al., 2021)

Sexuality 2.1.2

Pomegranate has a flower structure that is andromonoic (Yilmaz & Caliskan, 2024.). This means that the flowers on the tree are hermaphrodites, which are both sexes, but being andromonoic also means that it has male flowers. The tree's buds differentiate from male buds to bisexual buds by its level of care. If a tree has good sunlight, water and enough nutrients most of its buds would be bisexual, which later on are the ones that produce fruits. The trees that don't get enough sunlight, water, or nutrients will make more male buds which are the ones that don't turn into fruit. The weather impacts the creation of fruit because in rough conditions this plant would not get and do photosynthesis as it has to do to power the whole tree and create fruits. (Yilmaz & Caliskan, 2024,)

Pollen and Flower Production 2.1.3

The pomegranate male and functional flower pollen is shaped like an oval, which is called prolate. Its surface is not completely smooth, it has ridges and the pollen from the male flowers has even more ridges that are in straight and parallel lines. Male flowers have stronger pollen, which makes them have higher viability. Bisexual flowers create better-growing pollen, meaning they have better germination and these have ridges but not holes, the visual difference of both is that the male flower pollen has more detailed ridges than the bisexual flower pollen. They are also pretty much the same size, they vary from a maximum length of 28.5 μm and a minimum of 26.8 μm and the width ranges from 15.9 μm to 17.1 μm . Germination begins when the pollen made and stored in

the microsporangium is released, after this the pollen undergoes mitosis, and then the pollen cytoplasm and vegetative nucleus are transported within the pollen tube. (Engin, H, 2019, 188-193) Self and cross-pollination can be observed in the pomegranate, though cross-pollination is more favorable for the tree because it increases its fruit yield.

(Jambagi & K, 2022, 129) The trees' flowering commences due to environmental cues and endogenous pathways. It usually flowers from February through October but if flowering is not controlled it creates low-quality yield and unsynchronized maturity.

(Kumar & Saroj, 2019, 151)

Figure 4: Pomegranate flower on a tree (Chenlu, 2020)



Development 2.2

Life Cycle and Phenology 2.2.1

The life cycle starts when it is planted, and pomegranates are mostly planted by seeds and not by taking a stem from another pomegranate tree. The seeds germinate in 14 to 28 days and take from 2 to 3 years to grow fully to their mature state where they can flower and produce fruit. (Eden Brothers, n.d.) When the plant gets to this point its annual cycle begins which is the phenology of the fruit. Phenology is the study of key characteristics or timing of biological events in growing a plant. The annual cycle starts with the bud dormant stage and in 9 or 8 months it goes from that to the leaf fall where the cycle ends. The pomegranate crops have their microclimate which can differ from the outside one that depends on the development of the tree. The timing for flowering and vegetative growth depends mostly on the care and conditions of the tree, fertilization, good nutrients, sunlight, no diseases, irrigation, etc. A very timed action is, pomegranate leaves are bright green during fruit set until the fruit ripens but after harvest, they change to green with yellow during mid-October. This indicates that the plant's leaves will fall meaning it will rest until the next crop. Another specific timing observed is that the lower part of the midrib and petiole turn red during autumn. Throughout the year pomegranates tend to flower multiple times which leads to having multiple crops but not high quality. Depending on the climate and region pomegranates will flower in different seasons, for example in places where it annually only flowers once like India it can happen either from February to March, June to July, or September to October. From flowering to harvest there is a period of 120-210 days and after it the

period of rest is prolonged for 4 to 6 months. Even though there is no specific time of the year when each phenological stage happens in Figure 5 we can see the different stages it goes through. (Kumar et al., 2021, 3)

Figure 5: Table for the phenological stages of a pomegranate during an annual period.

(KUMAR et al., 2021, 7)

BBCH code	Growth stage	Description
0	Bud in winter dormancy	Bud color grayish brown, entirely closed, connected to the twig, tip sharply pointed
1	Bud swelling	Bud begins to swell, later turns paler and round
9	Red tip	Bud opens with a spear-shaped new shoot with a red tip
10	Sprouting of the first leaves	First furled bright red leaves with pale green midrib appear
10	Leaf separation	New leaves begin to separate
11	Leaf growth	Leaves grow up in size and change color from bright red to light green
31	Lengthening of internodes	Internodes elongate and steadfast shoot growth
51	Appearance of the flower buds	Sepals are visible and close together. Greenish flower buds turn into red color
55	Swollen calyx	Buds swelling, attain pear shape; differences between male and hermaphrodite flowers noticeable in the shape and the color of the calyx
59	Opening of the calyx	Sepals unfold and exhibit the folded red petals within. Petals open and the pistil/anthers become visible toward the end of this stage
61	Open flower	Calyx unfolds entirely and the protruding petals, which are folded and purple, unfold over the sepals. The petals appear inserted between every two sepals on their inner side, thereby giving the impression of alternating petals and sepals. The anthers of the stamen change to deep yellow when the pollen is ripe, capable of fertilizing, and pollination occurs
67	Petal fall	Petals fall following drying and shriveling; the calyx color changes from red to orange-red; stamens curved toward the longitudinal axis of the flower and the anthers turn grayish-yellow. The terminal part of the style withers
69	Fruit setting	The fertilized ovary and the base of the calyx swells; the stamens are dried up and shriveled and the fruit color changes from orange-red to greenish-brown
71	Young fruit	Fruit size increases rapidly and the color turns from greenish-brown to green
73	Fruit growth	Fruit attains nearly its final size; the sepals form a crown, the dry stamen being inside
39	Second bud sprouting	The recommencement of shoot growth
81, 85	Fruit ripening	The fleshy seeds turn white to pinkish-red or red; the peel of the fruit changes from green to greenish-yellow and to brownish-yellow with reddish patches
93	Leaf fall	Leaves become yellowish and fall; onset of winter dormancy

Fruit development and seed set 2.2.3

The fruit development commences when the tubular-shaped flowers appear like small buds. The flowers that are trumpet-shaped are the ones that have to be taken out because they consume lots of nutrients and will not produce fruits. The product will come out of the tubular flowers, being buds and then becoming a flower, which are the first two stages of fruit production. After this comes the early fruit which will only occur in the flowers that are fully developed. Later on, came the mid-growth stage, when a tree has much fruit growing it will have a consequence in the quality of each fruit produced and will affect the later full size the fruits will develop, also in this stage is where fruits are more likely to get pests and diseases being very vulnerable to them. Finally, the next stage is maturity, when the fruit is ready to be harvested. (Zhao et al., 2023, 2)

Propagation and Management 3

Propagation 3.1

Pomegranates can be sexually propagated but can also be cultivated by using softwood and hardwood cuttings.

Softwood cuttings 3.1.1

Softwood cuttings are mostly used for tender perennials, the plants that need help but survive over winter, like Anthemis, Bidens, and Petunia. But this technique is also used for deciduous shrubs. For this method, the cuttings are taken from the wood late in the spring and early summer. For cutting the root, the plant requires being misted and in a greenhouse. Softwood has the highest rooting potential out of all the root cutting methods (The Royal Horticultural Society, n.d.;

Hardwood cuttings 3.1.2

Hardwood cuttings are trimmed from one year old trees, placed on a nursery floor, and then transplanted a year later with their roots. However, some are planted with unrooted cuttings on an orchard floor. (University of California, n.d.)

Sexual Propagation 3.1.3

Sexual propagation is with seedlings that later germinated, but are not an exact copy of the mother tree, they can vary in size, and fruits can vary in flavour, they could be sweeter or sour. (University of California, n.d.)

Planting 3.2

Pomegranates can be taken by hardwood cuttings, as said before in Propagation, should be taken in winter, they should measure approximately 25 cm long and be from a year-old tree that has a diameter of 6 mm-1 cm, the cutting can be seen in Figure 6. The

roots later on have to be developed in a greenhouse or it could be directly planted on the ground where it ought to be planted, although this should be a sunny, well-drained location. The lower end of the cutting should be inserted into the soil, but leaving the top node above the soil. The next cutting should be planted a meter away from the other, in case of wanting to grow only shrubs, but for the whole tree the cuttings have to be planted about 6 meters apart. (Spengler, 2022)

Figure 6: Pomegranate hardwood cutting (Spengler, 2022)



Management 3.3

For a Pomegranate to grow full and healthy as previously talked about in chapter one the plant needs to be grown in loamy soil, temperatures above 85 degrees, and good irrigation. For good management, there has to be control of diseases and pests that can

damage and kill the tree. Some examples of pests are whiteflies, aphids, scales, and fruit borers. There are many different ways of controlling these like cleaning and removing dead/ infected branches or leaves, checking the plant often for signs of diseases, avoiding overwatering because it can create fungi, and applying fungicides. (StarkBro's, n.d.)

Fertilization of products with high potassium of 10-10-10 or 12-12-12 on the soil around the tree but not on the trunk to avoid rootburn. (Indigo Garden Centre, 2024)

Fruit Production 3.4

Fruit production within mature pomegranate trees expands considerably during each growth year. According to Texas A&M research (Stein et al., 2010) pomegranate trees in their fourth year produce their best results with 20 to 25 fruits on each tree. A pomegranate tree yields 100 to 150 fruits during its ten-year general establishment timeframe along with corresponding 50-pound fruit weights (Stein et al., 2010). Ideal conditions with proper orchard care lead trees to produce 200 to 250 fruits yearly resulting in around 75 pounds of marketable fruits. The creation of representative farm models requires analysts to anticipate 150 marketable fruits from each tree for revenue and production determination.

Diseases 3.5

Some very common diseases in pomegranates are leaf and fruit spots, fruit rot, and stem cankers. Anthracnose are leaf and fruit spots caused by *Colletotrichum* which we can see

in Figure 7 below. The symptoms of this disease are spots, blotches, defoliation, shoot blight, twig canker,s and dieback. On the fruit this is seen as a dark brown to black lesion and spores that look orange and slimy and on the leaves it causes brown spots. These penetrate the surface and cause damage to the rind and arils *Pseudocercospora punicae* also cause fruit spots but these are only superficial, the spots are dark but turn gray and can expand to 1.2 cm which we can observe in Figure 8. *Dwiroopa punicae* is caused by fungi in the *Diaporthales* species, and as seen in Figure 9, these create spots up to 1.5 cm in diameter, when the lesion increases it causes fruit rot, creating damage and causing early fruit drop. In Figure 10 we can see *neofusicoccum parvum* and *Lasiodiplodia theobromae* diseases which cause stem cankers and shoot blight. This disease creates small and dark lesions on stems, if it expands it creates swollen cankers and cracks which in one or two years will make the tree die. (Xavier, 2019)

Figure 7:

Spots on fruit caused by *Colletotrichum* (Xavier, 2019)



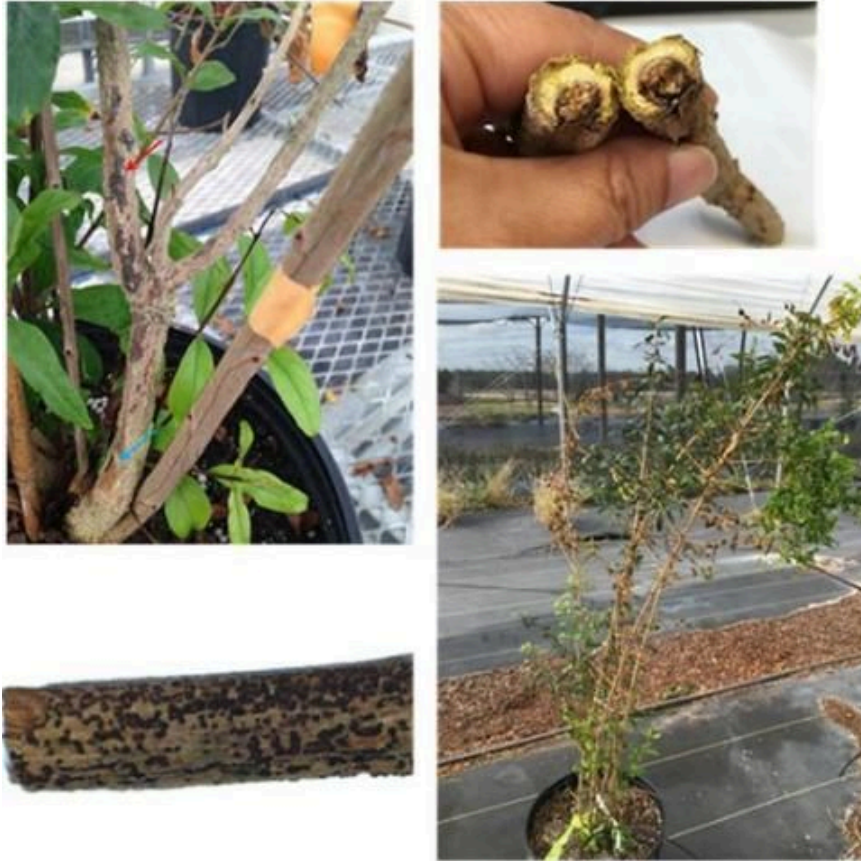
Figure 8: Spots on leaf and fruit caused by *Pseudocercospora punicae* (Xavier, 2019)



Figure 9: Fruit rot caused by *Dwiroopa punicae* (Xavier, 2019)



Figure 10: Stem canker caused by *Neofusicoccum parvum* and *Lasiodiplodia theobromae* (Xavier, 2019)



Marketing and Economy 4

Markets 4.1

In the last few decades, the pomegranate market has grown because of consumption has grown rapidly. The leading producers of pomegranate are India, China, Iran, Turkey, US,

Pakistan, Iraq, Syria, and Spain. In the EU between 2013 and 2017 imports have increased from 67,000 to 95,000 tonnes. 50,000 tons were cultivated in Spain, mainly in Valencia, Alicante and Murcia, Germany, Italy, France, and the United Kingdom, which are the main importers. (United Nations Economic Commission for Europe, 2022)

The analytical test market began its journey at \$5.6 billion in 2023 and will grow to \$10.6 billion while maintaining an annual growth rate of 6.7% until 2033 as Allied Market Research predicts. Verified Market Reports indicate that the market value will grow from \$1.5 billion in 2024 to \$3.2 billion in 2033 while maintaining a 9.2% CAGR. (Allied Market Research, 2024)

Exports Imports 4.2

Pomegranate plants (*Punica granatum*) demonstrate increased market value because their arils together with juice extracts carry multiple essential nutrients which contain strong antioxidative potential along with polyphenolic substances. The global pomegranate production surpassed 4 million metric tons on a yearly basis for 2016 - 2021 while spreading across more than 600,000 hectares of farming lands in 30 plus countries (Singh, Kumar, & Sharma, 2022). The worldwide pomegranate production reaches half of its total quantity through the joint efforts of India and Iran according to data from Singh et al. (2022). Kumar and Patel (2023) predict that India will lead global harvests for 2024/2025 by manufacturing 2.5 million metric tons of product yet Iran will produce 1.1 million metric tons and China will yield 0.6 million metric tons. According

to FAO estimates in 2024 the United States particularly California and Turkey rank among the key pomegranate producers alongside Spain and Egypt.

Statistical analysis indicates consistent pomegranate market growth which is projected to raise its worth from \$8.4 billion in 2024 to \$9.1 billion in 2025 with an annual compound growth rate of 8.3% (AgriMarket Insights, 2023). The pomegranate market continues to grow because consumers learn about health benefits of the fruit along with their interest in natural antioxidants and the product's food beverage pharmaceutical applications (AgriMarket Insights, 2023).

The international trade market recognizes pomegranates through the UAE along with Russia and the Netherlands as its major importers. Records from FAO in 2024 yield that the Netherlands acquired more than 65,000 metric tons of pomegranates throughout 2021. Worldwide pomegranate trading happens when the cultivation period matches the market demand and satisfies the trade limitations in essential production locations (Singh et al., 2022). Global pomegranate cultivation and market behaviors adopt principles of evolution in consumer health trends together with international agricultural development practices (Hynes, 2024).

Uses 4.3

For centuries pomegranates have been used in many culinary, medicinal, and cosmetic contexts because of their rich nutrients. It has lots of antioxidants, vitamin C, vitamin K,

and fiber polyphenols making them popular for dietary consumption. The fruit has major health benefits especially in cardiovascular and anti-inflammatory health (Jurenka, 2008). Not only for internal health but pomegranate extraction is well known for being used in skincare products for its skin regeneration and UV protection properties (Aslam et al.,2006). Pomegranate juice is well consumed, and most properties like the peel, bark, and roots are used in modern medicine to treat diarrhea, intestinal parasites, etc. (Ismail et al.,2012).

Figure 11: Pomegranate Juice (Juicers.co.uk, n.d.)



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