Solanum lycopersicum

Agricultural Science 2025-2026

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Introduction chapter 1

Tomato (*Solanum lycopersicum* L.) is one of the most important and widely cultivated horticultural crops in the world, valued for its nutritional, economic, and agricultural significance Originally domesticated in Latin America, particularly in regions corresponding to modern day Peru and Mexico, the tomato has undergone an extensive process of selection and breeding, transforming it from small wild species into the diverse range of cultivars grown today. Its adaptability to different climates and production systems has made it a key component of both small-scale and industrial agriculture.

From a nutritional perspective, tomatoes are considered a functional food due to their high content of vitamins, minerals, and bioactive compounds such as lycopene, which has been associated with various health benefits. In addition, the crop plays a crucial role in global food security and agricultural economies, contributing significantly to both fresh consumption and the processed food industry.

The study of tomato biology encompasses multiple disciplines, including plant philosophy, genetics, ecology, and agronomy. Understanding its growth, development, and environmental requirements, such as soil conditions, water availability, and climate, is essential for optimizing production and ensuring sustainability.

This monograph provides a comprehensive analysis of tomato plants, covering their taxonomy, ecological characteristics, physiological processes, and agronomic management. By integrating scientific research and practical knowledge, this work seeks to highlight the importance of *Solanum lycopersicum* and its role in modern agricultural and sustainable food systems.

Agroecology chapter 2

2.1 Taxonomy

2.1.1 Affinities

The taxonomy of a plant is separated into several parts,

Table 1
Taxonomy of *Solanum lycopersicum* (Harvey, 2025)

Taxonomic Rank	**Taxon Name (Authority)**
Kingdom	*Plantae*
Subkingdom	*Tracheobionta*
Super division	*Spermatophyta*
Division	*Magnoliophyta*
Class	*Magnoliopsida*
Subclass	*Asteridae*
Order	*Solanales*
Family	*Solanacea*
Genus	*Solanum L*
Species	*Solanum lycopersicum*

As shown in Table 1 above, there is an order to taxonomy, starting with the highest division, the **Kingdom**, a level that has all forms of life with similar characteristics. The kingdom ***Plantae*** includes all living plants, from tiny mosses to massive trees. (Harvey, 2025).

Secondly comes the **Subkingdom**, ***Tracheobionta***, which includes vascular plants that have a well-developed system of xylem (The xylem is the vascular tissue in plants that leads water and dissolved minerals from the roots to the rest of the plant and provides physical support. Xylem tissue also contains fibres, which add strength, and has parenchyma cells. These cells store substances. In woody plants, the secondary xylem makes up most of the trunk or stem, the outer sapwood conducts water, while the inner heartwood is dead but provides structural strength. Annual growth rings are produced as new layers of secondary xylem form each year (Petruzzello,2025) and phloem, which is the vascular tissue that distributes sugars produced in photosynthesis throughout the plant (The Editors of Encyclopaedia Britannica, 2022), allowing them to move water and nutrients efficiently through the plant (Harvey, 2025).

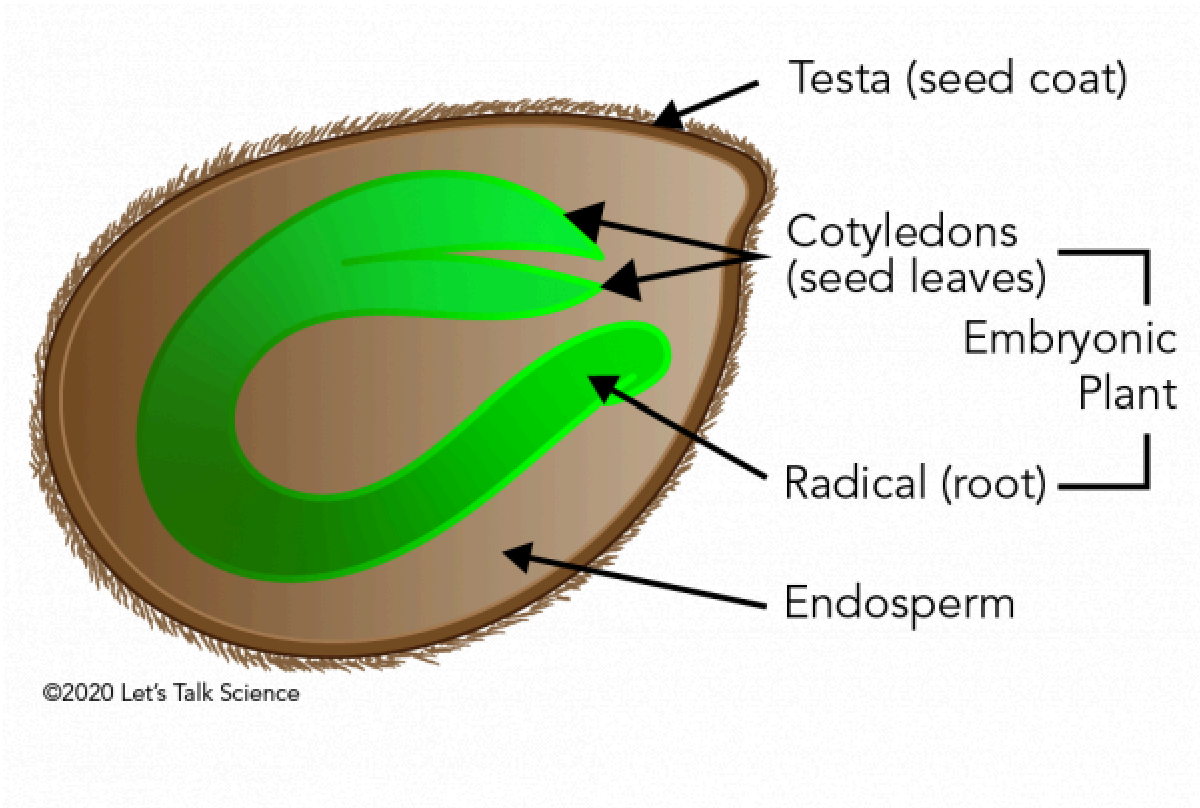
The **Superdivision** in which *S.lycopersicum* is situated is the ***Spermatophyta***; these are plants that reproduce by seeds and are contained inside them. This also ensures protection and dispersal of the fruit (Harvey, 2025).

The **Division** is ***Magnoliophyta***, the flowering plants. *Solanum lycopersicum* is here because it makes flowers that, after pollination, turn into fruits containing seeds (Harvey, 2025).

Next is the **Class**, ***Magnoliopsida,*** which includes dicotyledons or dicots. *Solanum lycopersicum is* a dicot because its seeds germinate with two embryonic leaves, cotyledons, as you can see in Figure 1 (Harvey, 2025).

Figure 1:

Diagram of the inside of a tomato seed (Let's Talk Science, 2016)



The **Subclass** is **Asteridae,** which is characterized by many tubular-flowered plants or inflorescences. *Solanum lycopersicum* falls under this category, as it has small, yellow, star-shaped flowers, as shown in Figure 2 (Harvey, 2025).

The **Order** is **Solanales**. It includes truly economically important flowering plants. Members of this order produce alkaloids and show unique floral structures. *Solanum lycopersicum* belongs to this order because it follows these characteristics (Harvey, 2025).

The **Family** is **Solanaceae**. It includes crops such as potatoes, eggplants, peppers, and tobacco. These plants have tubular flowers and fruits that are berries or capsules. In *Solanum lycopersicum*, the fruit is a fleshy berry, and as illustrated in Figure 2, it has a tubular flower (Harvey, 2025).

Figure 2:

Picture of the flowers from *Solanum lycopersicum* (Tilley, 2023)

The **genus** is **Solanum**, which includes edible and non-edible plants. Other plants are the potato (*Solanum tuberosum*) and the eggplant (*Solanum melongena*). Plants in this genus normally have leaves with several parts (compound leaves) and berry-like fruits (Harvey, 2025).

Lastly, there is the **species**, **Solanum lycopersicum**, also known as the tomato. It was once classified as *Lycopersicon esculentum*, but genetic studies have demonstrated that it belongs in the genus Solanum, as shown above (Harvey, 2025).

The cultivated tomato (*Solanum lycopersicum)* shows different affinities because of its domestication history. The tomatoes we know today come from 2 ancestors, the *Solanum pimpinellifolium* (Figure 3) and *Solanum lycopersicum var. cerasiforme*(Figure 4)*,* in South America, before spreading to Mesoamerica and further expansion. During this expansion of *Solanum lycopersicum,* there were centuries of human-guided breeding that have produced a wide variety of tomatoes, optimizing the size, shape, and flavor (Blanca et al., 2015; Lin et al., 2014; Razifard et al., 2020). These traits highlight the impact of both natural evolution and human influence on tomato development.

Figure 3:

Picture of *Solanum pimpinellifolium,* known as the "tomatillo de campo"(iNaturalist Colombia, n.d.)

Figure 4:

Picture of *Solanum lycopersicum var. cerasiforme,* known as the "tomate cherry" (PictureThis, n.d.)

Chemically, the *Solanum lycopersicum* has some important bioactive compounds. Most notably, lycopene is a pigment responsible for the red color of ripe fruits. Lycopene and other phytochemicals contribute to the tomato's antioxidant properties that have been linked to reduced risks of some cancers and cardiovascular diseases (Giovannucci, 1999; Canene-Adams et al., 2005). But, the amount of these compounds depends on each cultivar, with breeding and processing affecting their nutritional values (Parisi et al., 2022).

In terms of ecology, *Solanum lycopersicum* is one of the biggest crops grown around the world. Its adaptability to different climates and cropping systems has ensured that it has become one of the world's main food crops. Meanwhile, tomatoes are also worth their nutritional value as functional foods. Besides being in a balanced diet, they have health-promoting attributes. Also, the strong antioxidant capacity of tomatoes and their products emphasizes their role in the human diet for sustenance but also for their possibly protective health effects (Canene-Adams et al., 2005; Giovannucci, 1999).

More recently, human intervention, domestication, and breeding have drastically altered the phenotypic traits, such as increasing fruit size and sweetness, and disease resistance and storability traits of agricultural and consumer markets. Tomatoes still have a genetic connection to their ancestors, but under the influence of human selection, their properties have been altered to suit agricultural and eating preferences (Lin et al., 2014; Razifard et al., 2020; Blanca et al., 2015)

2.2 Fossil record

Although the fossil record of *Solanum lycopersicum* is limited, the discovery of fossilized seeds and fruits related to the Solanum species in South America from over 50 million years ago tells us that their ancestors lived in this region before domestication (Bai & Lindhout, 2007).

2.3 Origin and current distribution

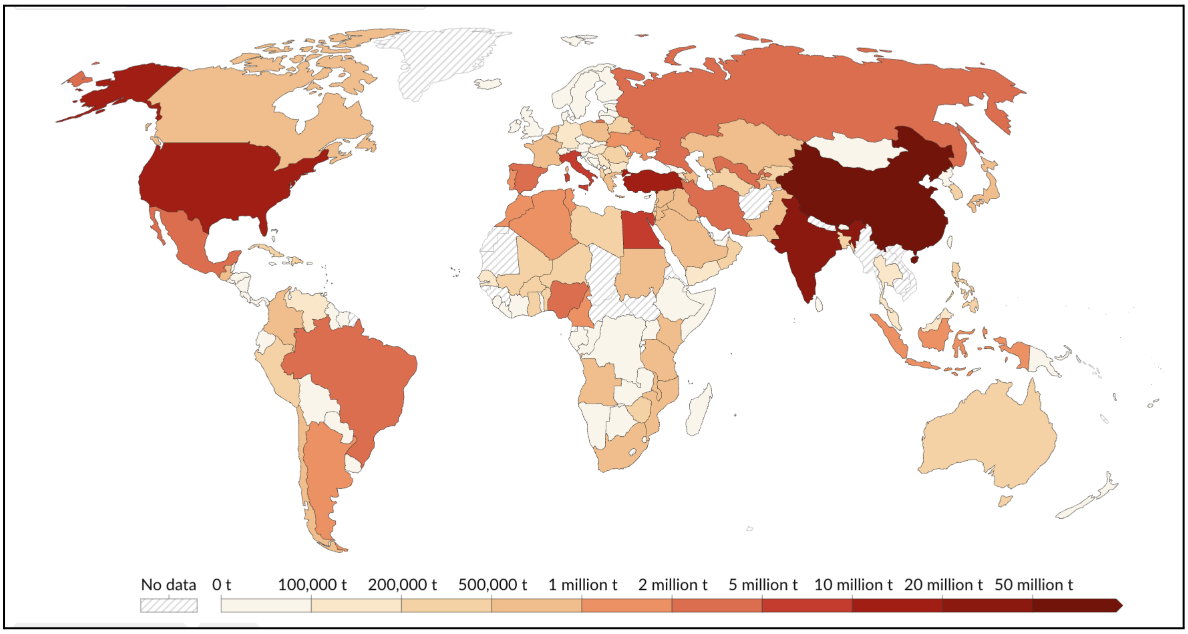
2.3.1 Origin and Domestication

The *Solanum lycopersicum* (tomato) originated in the Andean región of South America, which is now known as Peru, Ecuador, and some parts of Chile, from its wild relatives such as *S. pimpinellifolium* (Bai & Lindhout, 2007; Razifard et al., 2020). Genomic studies show that the domestication process involved a massive reduction in the genetic diversity of the cultivated tomato while comparing it to its wild ancestors (Bai & Lindhout, 2007). After its origin, domestication continued in Mesoamerica (known as Mexico) before it spread to Europe in the 16th century (Bai & Lindhout, 2007), through human domestication, trade, and agricultural evolution and adaptation. The shift from South America to cultivated varieties in Mesoamerica and later to Europe and Asia shows how human selection and global transport reshaped the species' ecological and geographical distribution.

2.3.2 Global expansion and Cultivation

Following its domestication in the Americas, the tomato has gone through a massive global expansion, becoming one of the most cultivated and economically important vegetable crops worldwide. Production rates of tomato production have surpassed 87 million metric tons in 2020, with dominant contributions from countries such as China, India, Turkey and the United States (Ritchie, H., & Rosado, P., 2023, and Branthôme, F.-X., 2023), as we can see in Figure 5 as we can see in Figure 5 which supports the claim of those countries being dominant in world wide tomato production.

Figure 5
A map that shows the tomato production in 2023 (Ritchie, H., & Rosado, P., 2023)



Analyses on market dynamics show the tomato industry being deeply integrated with trade policies and price and price sensitivities. For example, a comparative study of Mexico, Türkiye, and the U.S. reveals that production volumes respond strongly to both domestic support schemes and international market conditions (Govindasamy, R., Ceylan, R. F., & Özkan, B., 2025)

2.4 Ecorregión

Ecoregions are areas that share a similar climate, geology, and soil conditions that determine the type of plants and animals that can live within them. Even if two locations are geographically far away from each other, if they belong to the same ecoregion, they tend to host comparable ecological communities due to similar non-biological factors (World Wildlife Fund, n.d.).

2.4.1 Elevation and Climate

The wild tomato species, which include Solanum lycopersicum and others, are all found over South America, in a variety of temperatures and at a variety of elevations. They inhabit a wide range of habitats, from dry coastal plains to humid montane forests in the Andes, and can be found anywhere from close to sea level to around 3,300 meters above sea level. This wide distribution demonstrates their adaptability to many environmental circumstances. Researchers have used soil data from the Harmonized World Soil Database and 19 bioclimatic variables from WorldClim 2.1 to model the ecological niches of this species, revealing the factors that influence their growth and dispersion across diverse elevations and climates (Ramírez-Ojeda et al., 2021).

2.4.2 Type of Ecoregion

As mentioned above, the tomato has a great adaptability to the environment; for instance, many species in the *Lycopersicon* section are found in dry coastal deserts and inter-Andean dry valleys, often on rocky slopes and open sun-exposed terrain. Wild tomatoes such as *Solanum pimpinellifolium* and its relatives are documented in regions ranging from sea level up to altitudes of 3000 m, being in dry slopes, plains, and coastal deserts subject to seasonal fog (Ramírez-Ojeda et al., 2021).On the other hand, some related species may appear in humid montane forests or cloud-forest edges, yet even there they often grow in disturbed open habitats (such as roadcuts, riverbanks, or forest edges where light intensity is high. The cultivated tomato, by comparison, is more frequently found in subtropical to tropical zones and tends to thrive in disturbed sites such as field margins and anthropogenic habitats rather than pristine forests. So, although the group can live in montane and even forest fringe habitats, the dominant habitat for wild tomatoes tends to be open, sunny, well-drained soils in dry rocky or seasonally arid landscapes (Ramírez-Ojeda et al., 2021; The biology of Solanum lycopersicum L. (tomato), n.d).

2.4.3 Altitudinal Influence

Altitude plays a key role in tomato cultivation by influencing temperature, humidity, and solar radiation. In tropical regions, tomatoes are typically grown between 1,000 and 2,000 meters above sea level, where temperatures are moderate, and pest incidences are lower. At higher altitudes, cooler climates can extend the growing season but may also slow down ripening (Dixon, 2012).

2.4.4 Eco region/natural habitat

The wild relatives of *Solanum lycopersicum* naturally live in diverse ecosystems around western South America, such as the coastal and Andean regions of Peru, Ecuador, and northern Chile. These sites include arid coastal deserts, dry valleys, and humid montane forests (Ramírez-Ojeda et al., 2021). However, most wild tomato populations grow in regions with a subtropical to tropical climate with moderate temperature, seasonal rainfall, and well-drained soils derived from volcanic or alluvial materials. The plants usually are in open, sunny habitats, often growing on rocky slopes, riverbanks, or disturbed areas, when they receive full sunlight throughout the day, showing the species' high ecological adaptability (Ramírez-Ojeda et al., 2021).

Within these ecosystems, *S. lycopersicum* and its relatives, such as *S. pimpinellifolium and S. lycopersicum var. cerasiforme,* play an important ecological role as pioneer species, colonizing disturbed sites and contributing to early-stage vegetation regeneration. This ability to survive in marginal soils and fluctuating moisture regimes has been one of the key traits selected during domestication and breeding (Bai & Lindhout, 2007). The wide ecological range of these species explains why modern cultivated tomatoes are successfully cultivated under varied environmental conditions around the world (Ramírez-Ojeda et al., 2021).

2.5 Climate

2.5.1 Precipitation

Tomatoes prefer moderate and evenly distributed rainfall, ideally between 600 and 1,200 mm annually. Excessive precipitation can lead to root diseases and fruit cracking, whereas drought conditions can stress plants and lower productivity. Adequate water management through irrigation is crucial, especially during flowering and fruiting stages (Rodríguez, M., & Jiménez, D., 2019).

2.6 Geology and Soil Requirements

2.6.1 Geology and soils

Tomatoes adapt well to a big range of soils formed from sedimentary, volcanic, or clayish materials (alluvial), as long as they are well-drained and rich in organic matter. The geological composition of a region affects soil depth, structure, and mineral content, which in turn influence root development and nutrient availability. Soils that come from volcanic ash often provide excellent fertility and moisture retention, while limestone-based soils may require pH adjustment to optimize nutrient uptake. Proper soil preparation, like using compost and lime where needed, helps fight natural geological limitations and enhances tomato plant strength (Sadiq, 2025).

2.6.2 Soil type and texture

Tomatoes grow best in deep, well-aerated loamy soils that have neutral to slightly acidic pH levels (6.0-6.8) and moderate to high organic matter content (Lerner, 2001). These soils combine balanced proportions of sand, silt, and clay, ensuring both good drainage and sufficient moisture retention for healthy root development. It also has a porous soil structure that allows proper oxygen flow, preventing root diseases, while moderate salinity levels are tolerated only if drainage is adequate, and on the other hand, volcanic soils are rich in potassium and phosphorus, essential for fruit growth and ripening. Managing soil fertility through organic composts and regular pH adjustments helps maintain the ideal physical and chemical environment for tomato cultivation (Gurney's Seed and Nursery, 2024).

2.7.1 Soil depth and drainage

Solanum lycopersicum grows best in well-drained soil, a soil type that needs good drainage but also maintains moisture. (Manfredi,2019) Excess moisture can lead to root rot (clay-like soils aren't the most ideal, as they capture moisture). (Manfredi,2019) For optimal growth, it's crucial to have a mixture of predominantly loamy soil, sand, and very small amounts of clay and silt. (Manfredi,2019)

2.7.2 Geological Influence

The geological characteristics of the growth of tomatoes play a crucial role. (Earle and Earle,2015) It's important to plant tomatoes with rich mineral rocks like volcanic rock and not sandstone, because even though they both serve the same purpose of draining, sandstone doesn't provide any nutritional value. (Earle and Earle,2015) By understanding the geological factors, farmers can optimally grow healthy tomatoes. (Earle and Earle,2015)

2.7.3 Soil management practices

Soil is a crucial part of the optimal growth of *(Solanum lycopersicum)* (Kaiser, 2019). Using compost improves soil fertility. Planting different types of crops in the same area in a planned sequence over a number of seasons is also an effective tool for reducing pests. Covering the soil with a layer of organic material to improve plant health and soil quality is necessary for good drainage and protects roots from temperature changes, plus the soil also needs to be slightly acidic (Kaiser, 2019).

2.7.4 Tipo Sequences

2.7.4.1 Vegetation and growth patterns

The tomato *(Solanum lycopersicum*) has two most noticeable growth patterns: Determinate & indeterminate. Determinate plants grow to a fixed height and develop all their fruit at once, and then stop growing (Vallecillo Godoy A. J, 2022). These plants are perfect for uniform and short harvests. Indeterminate harvest continues to flower and grow after fruiting. They usually die because of frost or disease. Indeterminate plants develop roots, stems, and leaves made to withhold growth time and promote later flowering and fruiting (Vallecillo Godoy A. J, 2022).

2.7.4.2 Altitude and fruit quality

Altitude and fruit quality are related. Higher elevations typically bring lower temperatures, higher solar UV radiation, and a delayed fruiting period. Higher elevations have been associated with higher concentrations of sugar compounds, more vibrant coloration, and a greater amount of antioxidants. But if the elevation exceeds the amount for optimal growth, the quality starts to decline. (Fischer, 2022)lower fruit firmness (more squishy), fruiting is slowed down drastically, and sunburns may occur (Fischer, 2022).

2.7.5 Evapotranspiration

2.7.5.1 ET Factors

Evapotranspiration is the process of water loss from soil and the tomato itself, through evaporation or transpiration. (Allen,1998) It determines the amount of water the tomato needs for healthy growth. When ET is too high, plants lose excessive moisture, which may result in smaller fruit and bitterness. A stable ET guarantees the fruit will flourish to its fullest potential. (Allen,1998)

2.7.6.1 ET Factors

Tomato evapotranspiration depends on the tomato's weather, plant stage, and soil conditions. (Allen,1998) High temperatures, excessive sunlight, wind, and low humidity are directly correlated to higher ETs, even though young plants use less water than mature plants. Mulching can be a great practice to promote stability in moisture. (Allen,1998)

2.7.6.2 Modeling ET

By modeling, growers can decide when and how much tomato crops need to be irrigated. The FAO penman equation is the most used. (Allen,1998) This method estimates reference ET using a formula that estimates the irrigation needed by gathering earlier ETs from the past. (Allen,1998) Newer technology uses sensors and satellites to update ET by the minute and improve the use of water. (Allen,1998) Balancing rainfall with evapotranspiration is essential for tomato productivity, as water directly affects physiological processes such as nutrient transport, photosynthesis, and fruit expansion. Tomatoes require between 600 and 1,200 mm of evenly distributed rainfall per year for optimal growth and fruiting (Cherrybel, 2015). When annual precipitation drops below 400 mm, evapotranspiration exceeds available moisture, creating water deficits that limit root activity, nutrient uptake, and yield. Extended drought periods may also cause physiological disorders such as blossom end rot due to calcium imbalance. Conversely, rainfall exceeding 1,500 mm per year can lead to root diseases, fruit cracking, and nutrient leaching. Therefore, efficient irrigation systems, particularly drip irrigation, are recommended to maintain optimal soil moisture, minimize water loss, and ensure uniform growth even during dry periods. Continuous monitoring of climatic patterns and soil moisture is vital to adjust irrigation scheduling throughout the growing season (Campi, 2014).

2.8 Light and Temperature Regimes

2.8.1 Temperature regime

Temperature regimes determine tomato growth cycles, flowering, and fruit quality. The ideal range for most varieties lies between 21°C and 27°C during the day and 18°C to 20°C at night (FAO, 2020). Cool temperatures during the germination phase slow metabolic activity and delay emergence, while excessively high temperatures accelerate vegetative growth but reduce pollen viability and fruit set. Sustained heat stress can also lead to flower abortion. Maintaining a consistent thermal environment through greenhouse management, shade nets, or mulching ensures proper flowering, pollination, and uniform ripening, which are crucial for commercial tomato production (Koning, 1990). Temperatures below 10°C can delay germination and flowering, while those above 35°C may reduce pollen viability and fruit set. Therefore, maintaining a stable temperature range is essential for ensuring high yields and fruit quality (FAO, 2020).

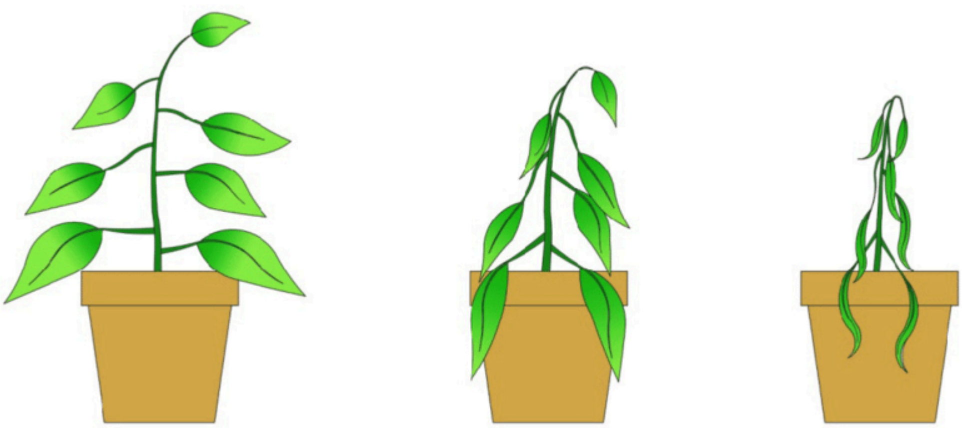
2.8.2 Light intensity and quality

Tomatoes are C3 plants, which means they rely on the Calvin cycle, which converts carbon dioxide into glucose and other organic molecules, using the energy produced during the reactions of photosynthesis. It is a process most efficient under moderate light and temperature conditions. Studies show that balanced red and blue wavelengths maximize photosynthetic efficiency, while partial inclusion of green light reaches lower leaves, resulting in increased biomass and yield (Kaiser et al., 2019). Light quantity and duration (photoperiod) directly regulate chlorophyll (pigment that gives fruit the color green) activity and sugar production, which drive vegetative and reproductive growth. Not enough light reduces fruit quality and size, while excessive intensity may cause dying leaves.

2.8.3 Water and transpiration

Water is essential for nutrient transportation, photosynthesis, and temperature regulation. Tomatoes require around 600-1200 mm of water annually for optimal production (FAO, 2020). Through transpiration, water absorbed by roots moves to leaves and evaporates through microscopic pores on the surfaces of plant leaves and stems that regulate gas exchange(stomata), maintaining internal cooling and facilitating nutrient movement. During water deficits, stomata close and conserve water but restrict CO_2 absorption, limiting photosynthesis and causing wilting (Hembram et al., 2020), as we can see in Figure 6. Controlled irrigation, such as drip systems, minimizes evaporation loss and keeps soil moisture within the best range possible.

Figure 6: Diagram of wilting stages: Stage 1 (Left) Initial wilt, Stage 2 (Center) Moderate wilt, Stage 3 (Right) Heavy wilt (Fonteno et al,2014)



2.8.4 Integrated Light–Temperature–Water Relationship

Tomatoes have evolved to live a healthy life in environments with moderate temperature, high light intensity, and regular but not excessive moisture (typical conditions of subtropical and tropical ecoregions). These factors work together, light drives photosynthesis, and water ensures rigidity and nutrient mobility. They allow tomatoes to have a high productivity and fruit quality even under different climatic conditions, showing an evolutionary adaptation to open sunlight areas and well-drained habitats (Ramírez-Ojeda et al., 2021; FAO, 2020).

Biology Chapter 3

3.1 Chromosome complement

Tomato plants, *Solanum lycopersicum,* are a diploid organism with a chromosome number of 2n=24; this means 24 chromosomes (12 homologous chromosome pairs). This number is consistent across most members of the Solanaceae family, including peppers and potatoes. But there have been studies of 2n=26 in 18 varieties of tomatoes. Both varieties have been fully fertile (Banks, 1984).

3.2 Life cycle and phenology

3.2.1 Life cycle

Solanum lycopersicum is an annual plant that completes its entire life cycle from seed germination to senescence within a single growing season. Their cycle with seed dormancy, which is broken when the seed encounters adequate moisture, oxygen, and warm temperatures, typically between 25°C and 30 °C. Water absorption triggers enzymatic activation and cellular expansion, allowing the radicle to emerge as the first structure to break through the seed coat. As the hypocotyl (stem) extends upwards, the cotyledons (first leaves) unfurl, marking the transition into the seedling stage. During early development, true leaves begin to appear, and the root systems expand both vertically and horizontally to support nutrient acquisition and structural stability (Spoelstra, 2002).

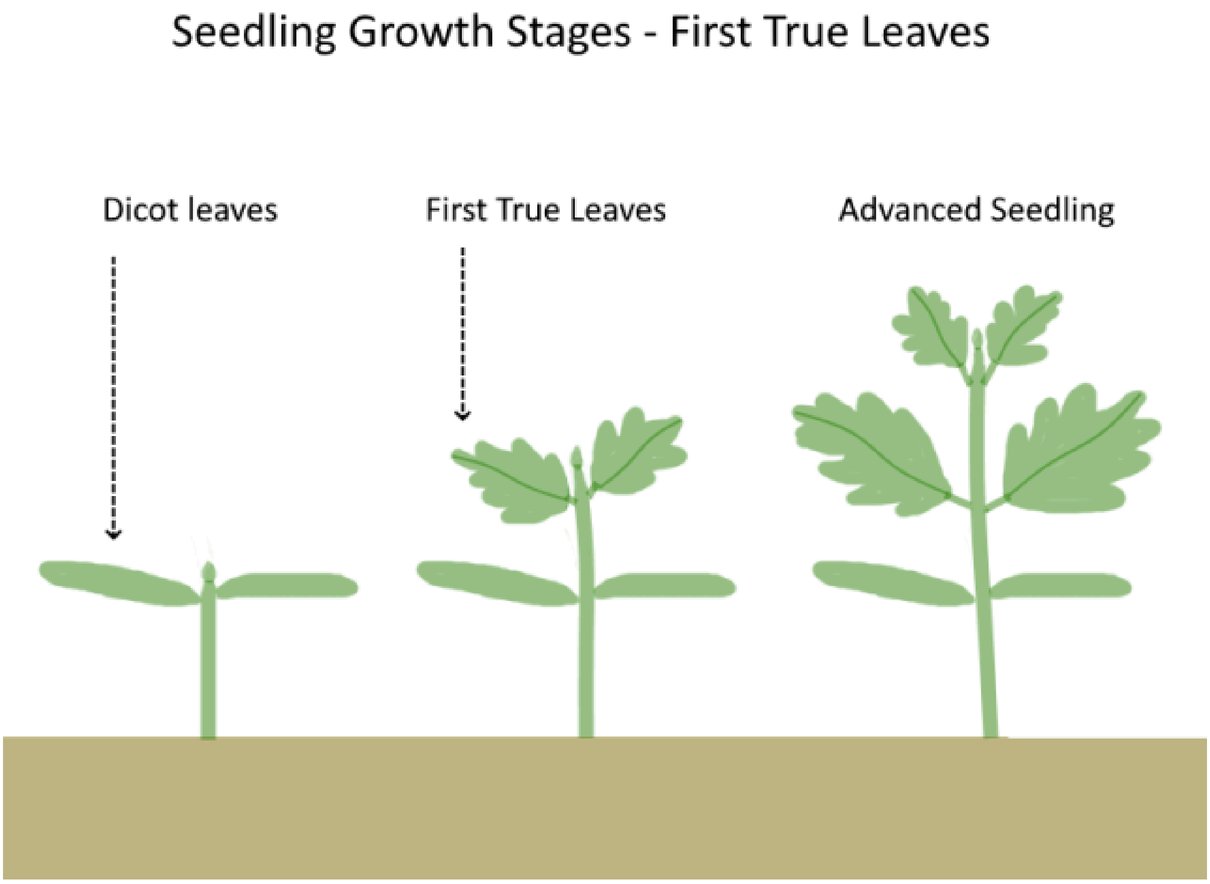
Once the plant is established, it enters a vigorous vegetative phase, during which stems, leaves, and axillary branches develop rapidly. *Solanum lycopersicum* exhibits a characteristic spiral phyllotaxy (arrangement of leaves and stem), and its leaf production follows a regular rhythm that allows the canopy to expand efficiently. Unlike many flowering plants, *Solanum lycopersicum* is day-neutral, meaning the onset of flowering is not triggered by photoperiod but by internal developmental cues. Most cultivars initiate reproductive growth once six to twelve true leaves have formed. Inflorescences emerge laterally on the stem and continue to appear at regular intervals, especially in indeterminate varieties that grow continuously throughout the season (Chomicki, 2017).

3.2.2 Seedling Development / Seedling Protection

After germination, *Solanum lycopersicum* enters the seedling stage, which extends from radicle emergence until the formation of several true leaves, as seen in **Figure 7**. During this phase, cotyledons become photosynthetically active and supply energy while the seedling establishes its root system and develops its first true leaves (Heuvelink, 2018).

Figure 7:

Seedling Growth Stages (Angelo, 2020)



Seedling growth in *Solanum lycopersicum* is strongly influenced by temperature, moisture, and light. Optimal temperatures for seedling development are between 20 and 25°C, while temperatures below 15°C inhibit metabolic processes and root development (Peet & Welles, 2005). Adequate light intensity is essential to prevent etiolation, a condition in which seedlings grow excessively elongated and weak due to insufficient photosynthesis (Genus Gardenwear, 2025).

Seedling protection is critical because tomato seedlings are highly susceptible to abiotic stress and soil-borne pathogens. Diseases such as damping off, caused by fungi including *Pythium* and *Rhizoctonia,* can lead to rapid seedling mortality, especially under excessive soil moisture and poor aeration. Preventive measures include the use of sterile or well-drained growing media, controlled irrigation, proper spacing, and adequate airflow. Protection from pests such as cutworms and aphids is also essential to ensure successful seedling establishment and survival (Jones et al., 2014).

3.2.3 Vegetative Growth / Foliage and Growth

Once established, the tomato plant enters a vigorous vegetative growth phase characterized by rapid stem elongation, expansion of foliage, and development of lateral shoots. During this stage, the plant invests most of its energy in building photosynthetic capacity and structural support necessary for future reproductive activity (Alexander, 2022). The stems thicken progressively while maintaining flexibility, and new leaves emerge in a spiral arrangement along the stem. Tomato leaves are compound and deeply lobed, providing a broad surface area for light capture and gas exchange. Their surfaces are covered with fine trichomes that help reduce herbivory, limit water loss, and release the characteristic scent associated with tomato plants (Du, 2025).

3.2.4 Flowering / Flower Production

The transition from vegetative growth to flowering represents a key developmental stage in the tomato plant's life cycle, occurring once the plant reaches sufficient maturity rather than in response to day length, since tomatoes are generally day neutral. Flowers typically emerge laterally along the stem in small clusters, and in indeterminate varieties, this process continues throughout the growing season, whereas determinate types produce flowers over shorter, more concentrated periods (Lopez, 2025). Tomato flowers are usually yellow and hermaphroditic, containing both stamens and a pistil, with the anthers fused into a cone that facilitates self-pollination, although vibration from wind or pollinating insects such as bees can improve pollen release and fertilization success. Environmental conditions strongly influence flowering; moderate temperatures, adequate sunlight, and balanced nutrient availability favor healthy flower formation, while extremes of heat and cold, water stress, or nutrient imbalances can reduce pollen viability and cause flower drop. Once pollination and fertilization occur, hormonal changes stimulate ovary enlargement and initiate fruit development, marking the plant's shift from vegetative growth to reproductive growth (Périlleux, 2014).

3.2.5 Fruit Development and Seed Set

Solanum lycopersicum is a sexual reproductive plant with bisexual flowers. Each flower possesses male reproductive organs responsible for pollen and female reproductive organs, which contain the ovary and ovules. Because both sexes are present in the flower, that means *Solanum lycopersicum* is ultimately self-pollinating. The pollen is released primarily into the stigma of the same flower. However, cross-pollination can occur, occurring from other insects, wind, or fertilizers. After fertilization, the ovary of the flower develops into a *Solanum lycopersicum* fruit, enclosing the seeds (Lambers, 2023).

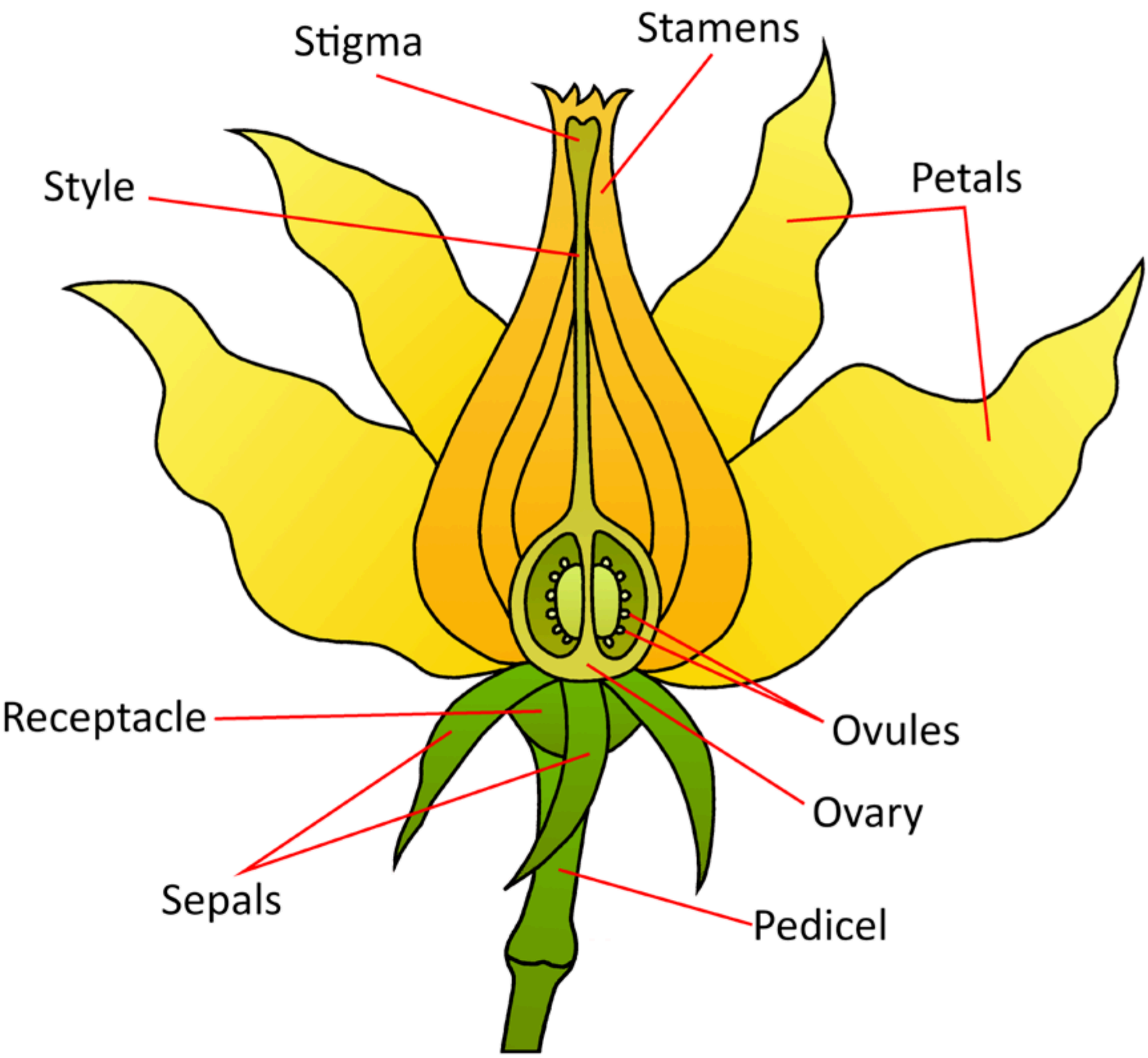
3.3 Reproductive Biology

3.3.1 Sexuality and Reproduction

Solanum lycopersicum ovule development occurs inside the flower, where multiple ovules, as seen in **Figure 8,** are attached to the placenta. Each ovule is developed through tissue in the integuments, which will later form the seed coat. The nucleus, which helps the development of the gametophyte and the embryo sac, is formed through meiosis and mitotic divisions. After pollination and double fertilization, one sperm fertilizes the egg to form a zygote. As the fruit develops, the fertilized ovules mature into seeds. A normal-sized *Solanum lycopersicum* can produce from 100 to 200 seeds (Chaban, 2022).

Figure 8:

Anatomy of the flower of the *Solanum lycopersicum* (Baranov D, 2024)



3.3.2 Pollination and Pollinators

Tomato plants are self-pollinating; pollinators play a major role in enhancing their pollination. Tomato flowers have anthers that release pollen only when shaken, which is called buzz pollination. Bees are the primary pollinators for tomato plants because they are able to vibrate flowers in search of pollen. Bees enhance pollen release, leading to increased fruit set and improved fruit quality, such as fruit size and the number of seeds. While tomatoes do not fully depend on pollinators for reproduction, the presence of bees significantly enhances the efficiency of pollination and crop productivity (Toni, 2021).

3.3.3 Anthesis

This occurs in tomatoes in the morning, usually beginning early and lasting until late in the morning, when the petals open and the flowers' reproductive organs start to work. The male and female organs of the flower are exposed during anthesis, allowing pollen to be released and pollination to take place (Toni, 2021).

3.3.4 Fruit Development

After pollination and fertilization, the tomato ovary begins to grow into the fruit. Fruit development starts with rapid cell division, which determines the final size of the tomato, and then the cell expansion, where the fruit increases in volume. When the fruit reaches full size, it goes into the ripening stage, where it changes color, softens, and develops its characteristic flavor and aroma (Liu, 2022).

3.3.5 Seed Formation

The process begins after fertilization and pollination. When pollen from the stamens reaches the ovary and fertilizes the ovules, after fertilization, each ovule develops into a seed, and the ovary grows to be a tomato fruit. The embryo keeps developing in a thin coat as the tomato matures. Just then, when the tomato is at its peak ripeness, the seeds are ready to be dispersed. (Xiao, 2022)

Propagation and Management Chapter 4

4.1 NATURAL REGENERATION

Natural regeneration in *Solanum lycopersicum* occurs primarily through seed dispersal. As a domesticated annual species, cultivated tomatoes depend mainly on human management; however, fallen fruit can release viable seeds that germinate under favorable conditions (Bergougnoux, 2014). Tomato seeds are enclosed in a fleshy berry, and once the fruit decomposes, the seeds are released into the soil. Germination occurs when the correct moisture, oxygen, and temperature (between 20℃-30℃) are present. Although natural regeneration can occur in warm climates without frost, cultivated production systems rely on controlled propagation to maintain varietal uniformity and yield stability (Heuvelink, 2018).

4.2 NURSERY PROPAGATION

Nursery propagation is the most common method used in modern tomato cultivation. Producing seedlings in controlled environments allows growers to regulate temperature, humidity, and soil conditions, improving germination rates and early plant vigor. Similar to humans, a plant's physical strength, growth speed, and ability to thrive depend on these factors (University of Florida IFAS Extension, n.d.). This stage is essential because strong seedling development directly influences later plant productivity,

4.2.1 Propagation from seed

Seed propagation is the primary method used in tomato cultivation worldwide. Tomato seeds exhibit high germination potential when exposed to appropriate environmental conditions, especially to optimal temperature, moisture, and aeration (Heuvelink, 2018)

4.2.1.1 Pre- preparation and implications for germination

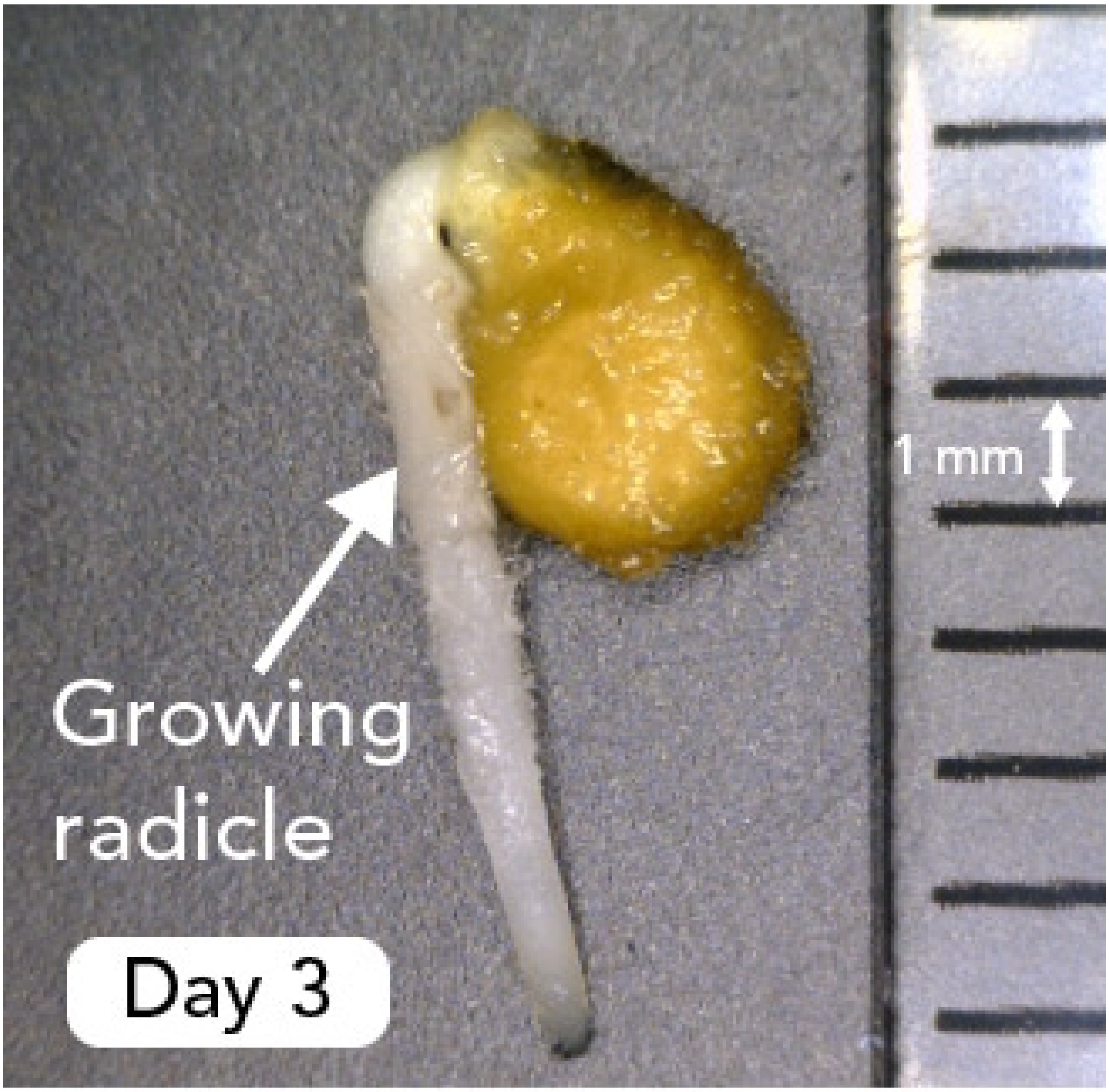
Before sowing (the process of planting seeds in or on the soil for future growth), seeds are often cleaned, dried, and sometimes treated to improve germination performance and prevent disease transmission. Removing the gelatinous coating surrounding tomato seeds during seed extraction helps reduce microbial growth and improve seed viability (University of Florida IFAS extension, n.d.)

4.2.1.2 Sowing and germination process

Tomato seeds are usually sown in seed trays or nursery beds that have sterile, well-drained growing media (soil that prevents root rot and ensures oxygen access, which are lightweight, have porous mixtures that allow excess water to escape rapidly while retaining necessary moisture. Seeds are typically placed between 0.5 and 1 centimeters below the surface to ensure enough moisture while still allowing oxygen diffusion to the developing embryo (University of Florida IFAS extension, n.d.). During germination, the radicle appears first; this radicle can be seen in **Figure 9**. It forms the primary root system that anchors the plant and absorbs water and nutrients. Shortly after, the hypocotyl stretches, and the cotyledons expand, initiating photosynthesis and supporting early plant growth (Heuvelink, 2018).

Figure 9:

Image of the radicle of a tomato seed (Let's Talk Science, n.d.)



4.2.1.3 Storage

Tomato seeds maintain viability for several years when stored under cool and dry conditions. Optimal storage environments typically include temperatures below 10 °C and low humidity to minimize metabolic activity and prevent fungal contamination (Heuvelink, 2018). Proper seed storage is particularly important in commercial agriculture because it allows producers to preserve desirable cultivars and maintain seed quality across multiple growing seasons (Bai & Lindhout, 2007).

4.2.2 Vegetative propagation

Although seed propagation remains the dominant method of tomato production, vegetative propagation techniques are increasingly used in intensive agriculture to enhance resistance to soil-borne diseases and environmental stress through the use of specialized root systems (Lee, 2003).

4.2.2.1 Grafting

Grafting is a widely used vegetative propagation method in which the shoot system (scion) of one plant is joined with the root system (rootstock) of another compatible plant. In tomato cultivation, grafting is usually used to combine high-yielding scion varieties with rootstocks that possess resistance to pathogens such as *Fusarium* or *Verticillium* (Lee, 2003).

Grafting Techniques:

Common grafting techniques include splice grafting (**Figure 10**, cleft grafting (**Figure 11**, and tube grafting (**Figure 12**. These techniques involve cutting stems of both scion and rootstock and joining them so that the vascular tissues align, allowing the formation of a functional graft union. Once the vascular tissues reconnect, the grafted plant can efficiently transport water, nutrients, and photosynthates between the rootstock and scion (Lee, 2003).

Figure 10:

Demonstration of splice grafting (Bilderback et al, 2014)

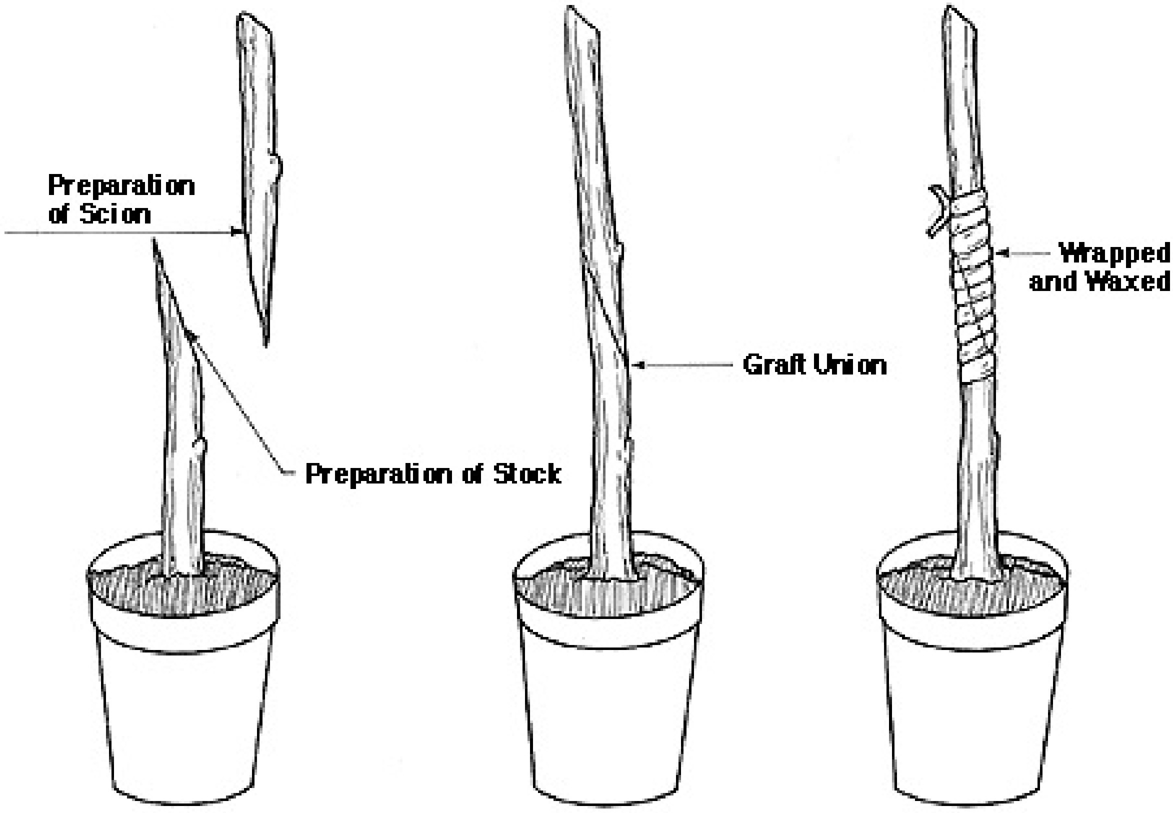


Figure 11:

The steps of grafting (Agriculture and Farming, n.d.)

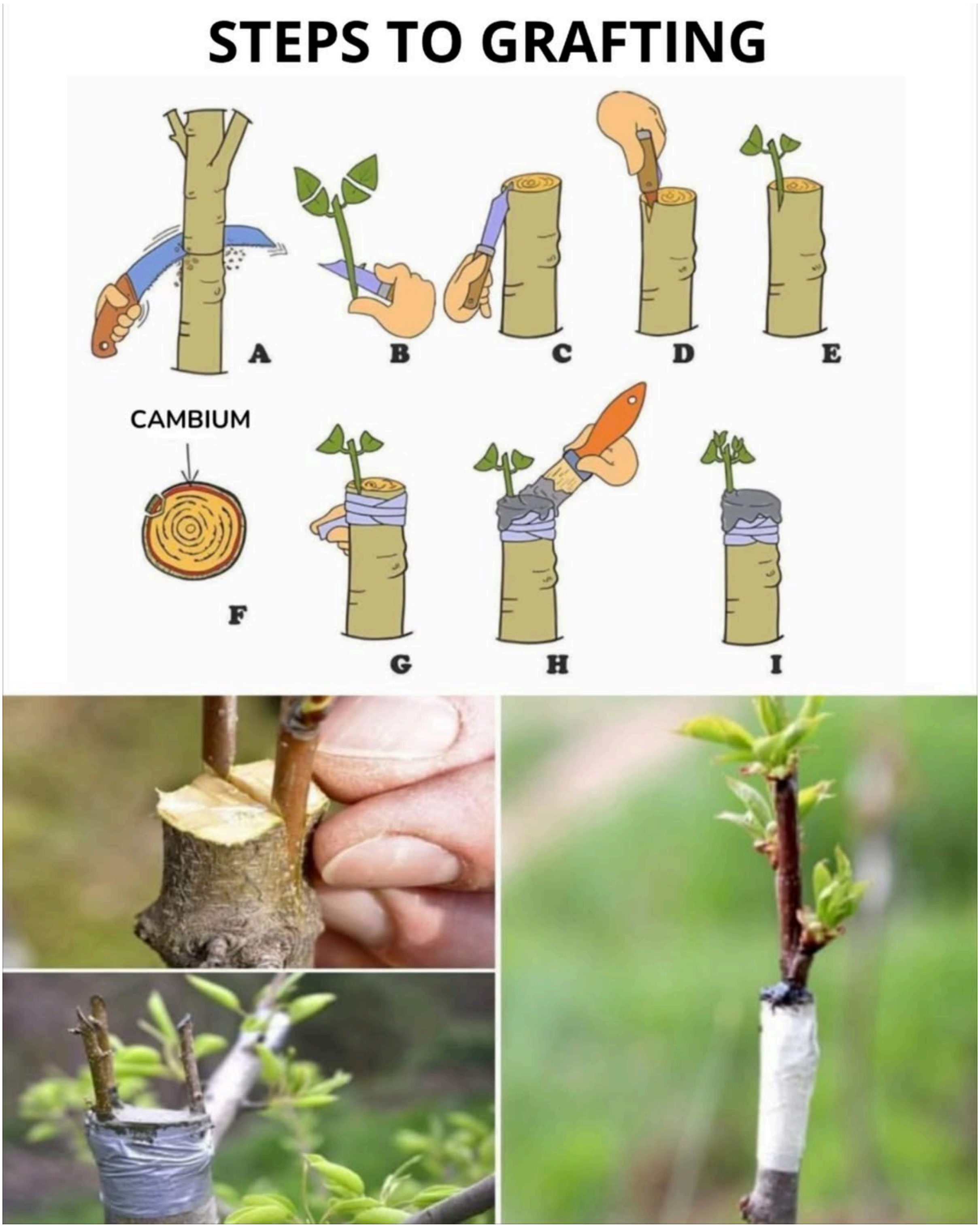
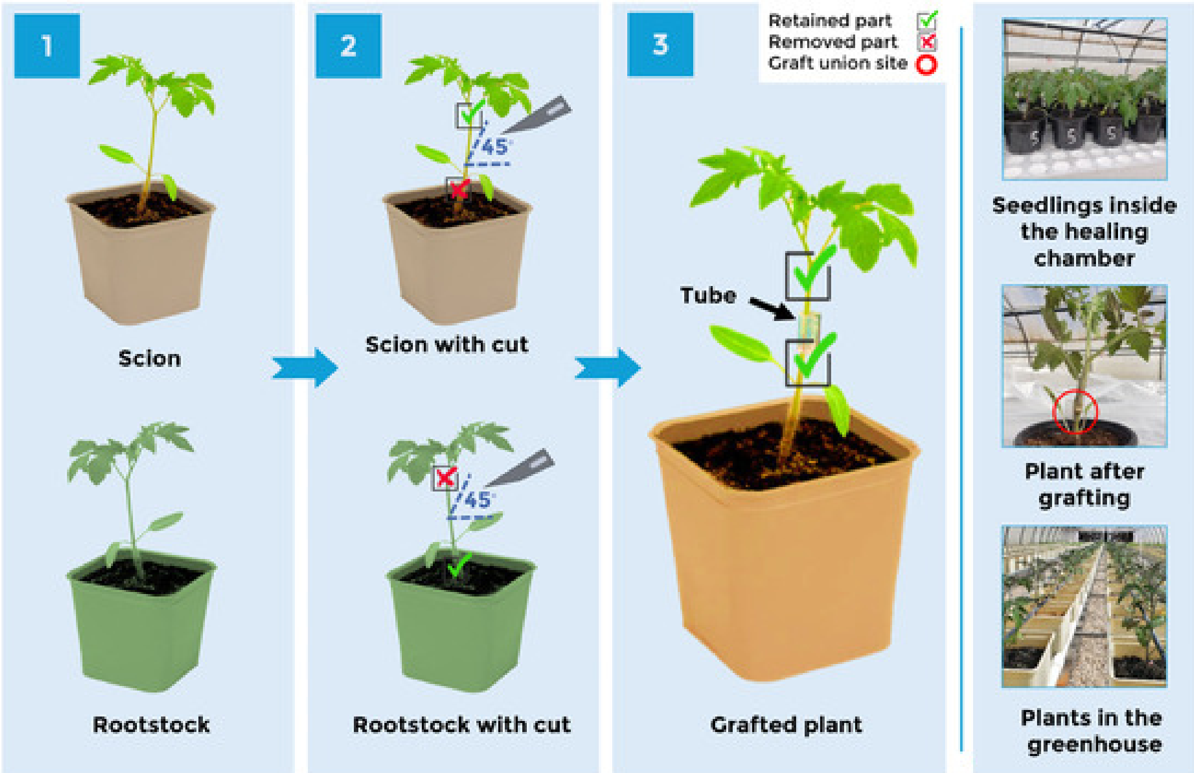


Figure 12:

illustration of the grafting process involving tomato plants, using the tube grafting technique. (Al Qaeda Ai et al., 2025)



4.2.2.2 Cuttings

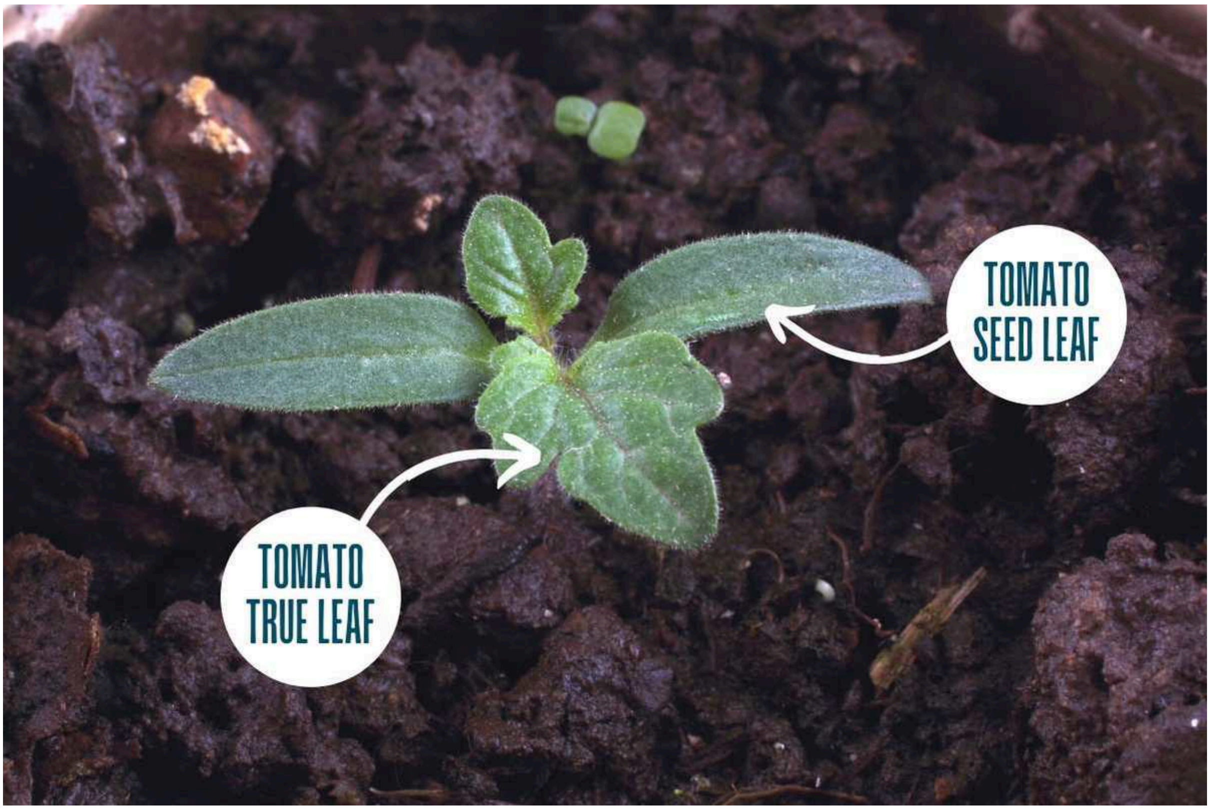
Propagation through cuttings involves removing a section of stem from an existing tomato plant and allowing it to develop roots in a moist substrate. Because tomato stems can form adventitious roots, cuttings can successfully establish new plants under appropriate environmental conditions. Although this method is less common in large-scale commercial production, it is sometimes used in experimental or small-scale cultivation systems where maintaining genetic identity is important (Heuvelink, 2018).

4.3 PLANTING

Transplanting tomato seedlings from nurseries into the field or greenhouse typically happens once plants develop several true leaves, as the ones seen in **Figure 13,** and strong root systems. At this stage, the seedlings are more resilient to environmental stress and capable of sustained vegetative growth. These plants are usually spaced between 40 centimeters and 60 centimeters apart. Proper spacing improves air circulation, reduces disease incidence, and allows sufficient sunlight penetration to support photosynthesis and fruit development (Peet & Welles, 2005)

Figure 13:

Difference between a tomato seed leaf and a true leaf (Johnston, 2022)



4.4 MANAGEMENT

Effective tomato management integrates irrigation, fertilization, structural support, and pest control to maximize yield and fruit quality (Peet & Welles, 2005).

4.4.1 Tending

Tomatoes require consistent moisture, approximately 25mm of water per week, adjusted for climate and soil type (University of Minnesota Extension, 2018). Mulching reduces evaporation and suppresses weeds, while staking (providing structural support—using stakes, poles, or cages—to plants, allowing them to grow upright rather than creeping along the ground, National Parks Board, 2023) or trellising, seen in **Figure 14,** improves air circulation and reduces disease incidence (Ohio State University Extension, 2021).

Figure 14:
Image of how trellising looks (Badgett, 2021)

4.4.2 Fruiting

Tomato fruit development begins after successful pollination and fertilization of the flower, seen in **Figure 15**. During this stage, the ovary enlarges and gradually develops into the characteristic fleshy berry of the tomato plant (Heuvelink, 2018). Fruit growth involves several physiological phases, including cell division, cell expansion, and ripening. Environmental factors such as temperature, nutrient availability, and water supply significantly influence fruit size, color, and overall quality (Peet & Welles, 2005).

Figure 15:

Image of a tomato flower (Grant, 2023)

4.4.3 Pest and disease control

Tomato plants are susceptible to numerous pests and diseases that can significantly reduce crop productivity. Effective pest management typically involves an integrated approach that mixes cultural practices, biological control, and chemical treatments when needed. Also, preventive strategies such as crop rotation, proper spacing, sanitation of plant debris, and the use of resistant varieties are commonly employed to minimize the risk of pest outbreaks and disease transmissions (University of California Integrated Pest Management Program, n.d; Jones et al., 2014)

4.4.3.1 Common tomato pests

Several insect species commonly affect tomato crops. Aphids feed on plant sap and can transmit viral disease, while whiteflies weaken plants and contribute to the spread of plant pathogens (University of California Integrated Pest Management Program, n.d.). Another frequent pest is the tomato hornworm, a large caterpillar that consumes leaves and can rapidly remove leaves from plants if it's not controlled. Early detection and biological control methods, such as natural predators or manual removal, are often used to manage these pests in the most efficient and fastest way (Jones et al., 2014).

Importance, markets, and uses chapter 5

5.1 IMPORTANCE

5.1.1 Global importance

Globally, tomatoes play a major role in food systems due to their high production and widespread consumption. They are grown in more than 170 countries and are a staple ingredient in many cuisines. Their demand in both fresh and processed form makes them an essential commodity in international trade and contributes to food in many regions (Importance of the tomato, 2021).

5.1.2 Economic importance

The global tomato industry generates billions of dollars annually, supporting millions of farmers and workers across the world. Yields can range from 20 to 100 tons per hectare (Mordor Intelligence, 2025), depending on production systems and technology. Tomatoes are economically significant due to their high demand and their role in both fresh markets and processing industries, where they are transformed into value-added products with longer shelf life (Sheard,1966).

5.1.3 Regional and local importance

Tomatoes play a vital role in regional and local food systems by supporting small farmers, contributing to food security, and sustaining local economies. Their cultivation provides income opportunities and strengthens community markets, while their daily consumption highlights their cultural importance in local diets and traditional cuisines (Growpact Kenya, 2025; USDA, 2024).

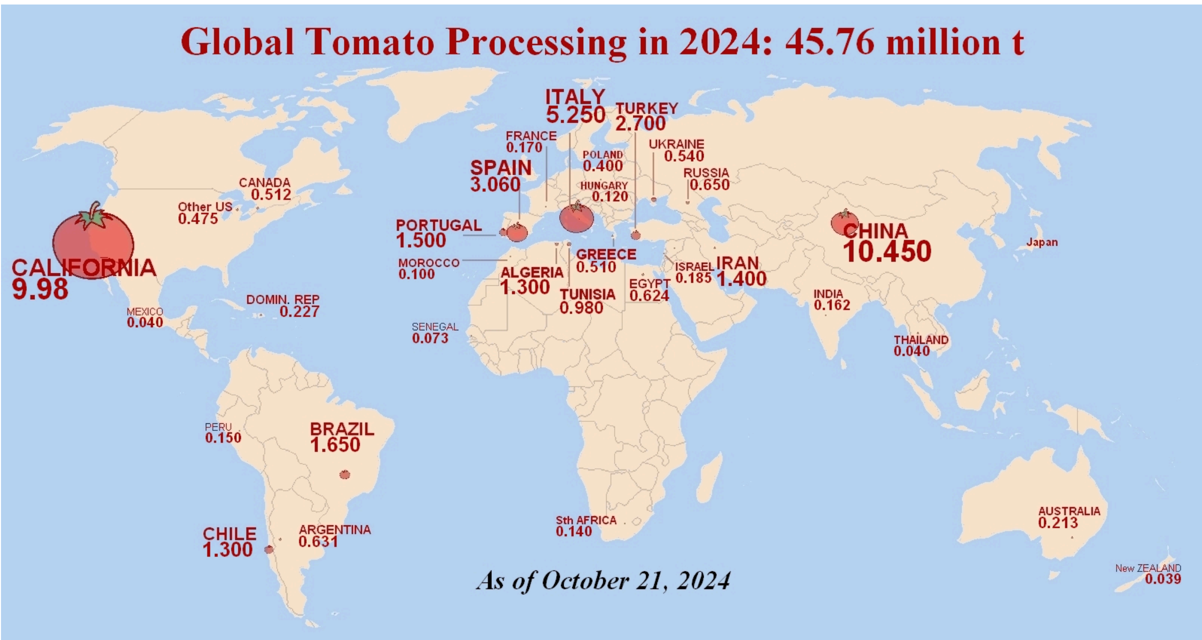
5.2 MARKETS AND PRODUCTION

5.2.1 Global production

Tomatoes, as one of the most important crops worldwide, contribute a vast importance in the agricultural sector. In recent years, tomato production has reached 190 metric tons annually. (Branthôme, 2024) Tomatoes have been growing steadily for the past few years, with an increase in demand from countries such as China, India, and the United States. China contributes to over one-third of the total output. Tomatoes are grown in over 170 nations. Processing this crop into sauces and pates makes Tomatoes a key crop in the global food system. (United Nations, 2025)

Figure 16

Global tomato processing in 2024 (Branthôme)



5.2.2 Major producing countries

The largest tomato-producing nation is China by far, followed by India, Turkey, and the USA. (Branthôme, 2024) These countries lead the world market, not only because of their favorable weather conditions but also because of their high demand for fresh and processed produce. (Branthôme, 2024)

5.2.3 Trade and distribution

Fresh tomatoes are mostly traded regionally because of their delicate nature. (Branthôme, 2024) Countries with top-of-the-line processing industries manage to industrialize this crop into pastes, sauces, and canned goods, being able to export the crop over longer distances. These imports and exports then depend on the demand for the crop in said country. (Branthôme, 2024)

5.2.4 Market structure

The tomato market is divided into two main structures: fresh and processed. Fresh includes more local and medium-sized producers, supplying the crop nationally, as it is a delicate crop. In contrast, the processed market is led by larger corporations that manage the cultivation, processing, and distribution internationally. Fresh produce relies on proximity to consumers, while processed goods rely on longer shelf life and a good system of distribution. (Branthôme,2024)

5.3 FOOD USES

5.3.1 Fresh fruit (raw consumption)

The tomato is widely consumed fresh due to its high water content, which helps it keep fresh, has a delicious flavor, and is high in nutritional content. It is frequently consumed as a snack, in the form of cherry tomatoes, and especially in salads. Because of its acidity and sweetness, it can be used in a variety of diets. Tomatoes are acknowledged as one of the most consumed fresh fruits and vegetables worldwide (Ali et al., 2020)

5.3.2 Processed products

Products, including sauces (ketchup), pastes, and canned tomatoes, are made from tomatoes through extensive processing. This process helps improve flavor and increase shelf life. Scientific studies show that tomato-based products are important dietary sources of lycopene, and processing it does not reduce or lower this compound; in fact, it will increase the stability (Agarwal et al., 2001)

5.3.3 Juice and beverages

Tomatoes are also used in beverages, especially in vegetable juice mixes and the original tomato juice. Many of the elements that tomes include are also preserved in these beverages, like lycopene. Even after processing and storage, tomatoes used in drinks retain bioactive ingredients (Agarwal et al., 2001)

5.4 INDUSTRIAL USES

5.4.1 Food industry

In the food industry, tomatoes are processed into products such as sauces, pastes, juices, canned tomatoes, and ketchup. It is estimated that about 25-30% of global tomato production is processed, reflecting its importance in industrial food supply chains. Processing not only increases product variety but also ensures year-round availability and reduces waste (FAO, 2023).

5.4.2 By-products

Tomato processing generates byproducts including skins, seeds, and pulp residues, which are valuable sources of compounds such as lycopene, oils, and fiber. These materials are increasingly used in animal feed, cosmetics, nutraceuticals, and biofuel production, contributing to sustainable resource use and waste reduction in the agricultural industry (FAO, 2023).

5.5 NUTRITIONAL AND MEDICAL USES

5.5.1 Nutritional composition

Tomatoes are low in calories and high in vital nutrients. They include minerals like potassium and vitamins like vitamin C, vitamin A, and vitamin K. Tomatoes are also a significant source of phenolic chemicals, carotenoids, and lycopene, all of which support the antioxidant qualities (Ali et al., 2020).

5.5.2 Health benefits

The antioxidant content inside the tomatoes is responsible for their health benefits. It contains. By absorbing free radicals and preserving vital macromolecules such as proteins and DNA, lycopene and other phytochemicals help lower oxidative stress. This antioxidant action improves cardiovascular health and reduces cellular damage (Ali et al., 2020)

5.5.3 Disease prevention

Consuming tomatoes has been associated in a lot of studies with a lower chance of developing any chronic illness. Lycopene has been linked to decreasing the risk of heart disease and some types of cancer, such as prostate cancer. It may also reduce the risk of cancer and many other degenerative diseases (Agarwal et al., 2001).

5.6 TRADITIONAL AND CULTURAL USES

5.6.1 Cultural significance

Tomatoes are a staple in many countries, from the rich sauces in pasta in Italy, the stew and salsas in Latin America, to butter chicken in India. Even though tomatoes originally came from the Americas, the whole world has appreciated and incorporated this rich and sweet fruit into its cuisines. (Branthôme, 2024).

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