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REVIEW ARTICLE OPEN ACCESS

ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, GENETIC DIVERSITY AND BREEDING OF TOMATO (*Solanum lycopersicum* L.)

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ABSTRACT

Family: Solanaceae, Sub-Family: Soloanoideae & Cestroideae, Tribe: Solaneae, Genera: *Solanum*, Species: *Solanum* lycopersicum L. Tomatoes, peppers, potatoes and eggplants all belong to the Solanaceae family of flowering plants. Plants in this family are also called nightshades. There are more than 3000 species of nightshades. Many of them are important to our economy. The *Solanum* lycopersicum */ S. esculentum*-complex contains seven species that are easily crossed with cultivated tomato and these have served as a source of genetic variability for the improvement of tomato varieties. The tomato is native to Central, South, and southern North America from Mexico to Peru. Wild tomato plants come from the Andean region of South America. This area includes the countries of Peru, Bolivia, Chile and Ecuador. The characteristics of this wild fruit were different from the cultivated fruit: small size (1-2 cm diameter), bilocular and acid taste. Tomato plants are generally much branched, spreading 60–180 cm and somewhat trailing when fruiting, but a few forms are compact and upright. Leaves are more or less hairy, strongly odorous, pinnately compound, and up to 45 cm long. The five-petaled flowers are yellow, 2 cm across, pendant, and clustered. Fruits are berries that vary in diameter from 1.5 to 7.5 cm or more. They are usually red, scarlet, or yellow, though green and purple varieties do exist, and they vary in shape from almost spherical to oval and elongate to pear-shaped. Each fruit contains at least two cells of small seeds surrounded by jellylike pulp. The tomato seed matures 35-50 days after pollination, during which seeds become germinable, desiccation tolerance is induced and water content decreases. Fruit is red and ripe by 60 days after pollination. Tomato varieties can be divided into three major categories based on their growth viz., Indeterminate, Determinate and Semi-Determinate. Tomato varieties can be divided into ten types based on shape viz., Beefsteak Tomatoes, Plum Tomatoes, Cherry Tomatoes, Grape Tomatoes, Campari Tomatoes, Tomberry Tomatoes, Oxheart Tomatoes, Pear Tomatoes, Slicing / globe Tomatoes, and Salad / Standard Tomatoes. Tomato varieties can be divided into nine types based on color viz., Red tomato varieties, Pink tomato varieties, Orange Tomato Varieties, Yellow Tomato Varieties, White Tomato Varieties, Green Tomato Varieties, Purple Tomato Varieties, Blue/black/indigo Tomato Varieties and Stripes, blushing and swirls. Wild tomato varieties were small and mostly yellow, not red. We could say that they were similar to what we know today as cherry tomatoes. Nowadays, apart from different sizes, we can also find different colors of tomatoes varying from our familiar red, to pink, yellow, orange, purple, white and black. Conventional breeding has based on standard methods which are Mass selection, Pedigree, and Hybridization. These are all conventional methods for breeding. Conventional breeding has developed the cultivars and also dominant resistance genes to control pest and disease. Tomatoes have been bred by humans for many characteristics such as yield, shelf-life, pest resistance, taste, fruit size and shape, colour, seed size and weight, and nutritional quality. By the end of the 19th century, tomatoes were bred by many farmers and gardeners. Tomatoes are now eaten freely throughout the world, and their consumption is believed to benefit the heart among other things. Lycopene, one of nature's most powerful antioxidants, is present in tomatoes, and, especially when tomatoes are cooked, has been found beneficial in preventing prostate cancer. However, other research contradicts this claim. Tomato extract branded as Lycomato is now also being promoted for treatment of high blood pressure. In this review article Origin, Distribution, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Tomato (*Solanum lycopersicum* L.) are discussed.

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INTRODUCTION

Tomato belongs to the Family

Solanaceae, Sub-Family: Soloanoideae, Tribe: Solaneae, Genus: *Solanum*, Species: *Solanum lycopersicum* (Tanuja Buckseth, 2023).

Tomatoes, peppers, potatoes and eggplants all belong to the Solanaceae family of flowering plants. Plants in this family are also called nightshades. There are more than 3000 species of nightshades. Many of them are important to our economy. There are more than 7000 varietiesvarieties of tomatoes alone (Letstalk science, 2021).

The *Solanum lycopersicum /S. esculentum*-complex contains seven species that are easily crossed with cultivated tomato and these have served as a source of genetic variability for the improvement of tomato varieties (Rick, 1979). Tomatoes are considered a fruit or vegetable depending on context. According to *Encyclopedia Britannica*, tomatoes are a fruit labeled in grocery stores as a vegetable due to their taste and culinary purposes. Botanically, a tomato is a fruit—a berry, consisting of the ovary, together with its seeds, of a flowering plant. However, the tomato is considered a "culinary vegetable" because it has a much lower sugar content than culinary fruits; because it is more savoury (umami) than sweet, it is typically served as part of a salad or main course of a meal, rather than as a dessert. Tomatoes are not the only food source with this ambiguity; bell peppers, cucumbers, green beans, aubergines/eggplants, avocados, and squashes of all kinds (such as courgettes/zucchini and pumpkins) are all botanically fruit, yet cooked as vegetables (Wikipedia, 2023). The Italians called the tomato pomodoro ("golden apple"), which has given rise to speculation that the first tomatoes known to Europeans were yellow. It has been suggested that the French called it pomme d'amour ("love apple") because it was thought to have aphrodisiacal properties. Some scholars assert, however, that the tomato was at first taken to be a kind of eggplant, of which it is a close relative. The eggplant was called pomme des Mours ("apple of the Moors") because it was a favourite vegetable of the Arabs, and pomodoro and pomme d'amour may be corruptions of that name (EEB, 2023).

The tomato is native to Central, South, and southern North America from Mexico to Peru (Bionity, 2023). Wild tomato plants come from the Andean region of South America. This area includes the countries of Peru, Bolivia, Chile and Ecuador. Scientists think that Aztec and Inca people grew tomatoes as early as 700BCE. The tomatoes they grew were a very different size from the tomatoes we have today. They also tasted different (Letstalkscience, 2021). During prehispanic times, various useful plants were introduced and domesticated in Mesoamerica from South America. The original South American tomato fruit became a synanthrophyte, a plant species brought indirectly to Mexico through trade between prehispanic cultures. The characteristics of this wild fruit were different from the cultivated fruit: small size (1-2 cm diameter), bilocular and acid taste (Jenkins, 1948). Upon its arrival in Mesoamerica, its similar morphology with the green tomato (*Physalis*) facilitated its adoption and adaptation by Mexican cultures. Since those times, the use and diversification in morphotypes, dimensions, forms and colours of the fruits used as food by Mexican indigenous cultures were extraordinary. As such, Mexico, together with the Andes zone, houses the largest morphological variability in tomato (Rick, 1978; Jenkins, 1948) and is considered the centre of diversity and domestication of *S. lycopersicum* (Jenkins, 1948).

Tomato plants belong to the plant group known as flowering plants or angiosperms. The tomato plant reproduces sexually, meaning that it requires both female and male organs to produce seeds. Every tomato seed has a tiny tomato plant inside. When the conditions are just right, tomato seeds will germinate. As the seed germinates, the radicle or young root first appears and grows down into the ground. The cotyledons or seed leaves then appear and grow up towards the Sun and the young plant develops true leaves. As the plant matures, more leaves develop and flower buds form. On mature tomato plants, flowers develop and this is where sexual reproduction occurs (Tomatosphere, 2023). Tomato plants are generally much branched, spreading 60–180 cm and somewhat trailing when fruiting, but a few1) forms are compact and upright. Leaves are more or less hairy, strongly odorous, pinnately compound, and up to 45 cm long. The five-petaled flowers are yellow, 2 cm across, pendant, and clustered.2) Fruits are berries that vary in diameter from 1.5 to 7.5 cm or more. They are usually red, scarlet, or yellow, though green and purple3) varieties do exist, and they vary in shape from almost spherical to oval and elongate to pear-shaped. Each fruit contains at least two cells of small seeds surrounded by jellylike pulp (EEB, 2023). The tomato4) seed matures 35-50 days after pollination, during which seeds become germinable, desiccation tolerance is induced and water content decreases. Fruit is red and ripe by 60 days after pollination (OECD, 2008). Tomato varieties can be divided into three major categories based on their growth viz., 1) **Indeterminate** – In this category, there are varieties with continuous growth. The plants have a relatively constant number of leaves between their inflorescences. We cultivate these varieties mainly indoors. If they grow outdoors, they need support through staking. 2) **Semi-Determinate** – In this category, there are varieties whose shoots stop growing when they are at an advanced stage. This category is particularly preferred for outdoor cultivation. And 3) **Determinate** – In this category, there are varieties whose shoots interrupt their lateral growth after they give a certain number of flowers (depending on the variety) (Wikifarmer, 2023). Tomato varieties can be divided into ten major categories based on their fruit shape (VF, 2023) viz.,

Beefsteak Tomatoes: Beefsteak - these tomatoes are large (around 10 cm in diameter) and meaty with thinner skin. This type is often used for sandwiches. Their color may be red, yellow or sometimes pink. Usually, they are indeterminate.

Plum Tomatoes: Plum tomatoes (also called Roma (Paste) tomatoes, including some pear tomatoes) - they don't have much juice, but they're high in solids, so it is usually used for tomato sauces or (like name sais) Italian recipes. They are 7–9 cm long and typically determinate.

Cherry Tomatoes: Cherry tomatoes - they have the same size as wild tomatoes (1-2cm). They are round and have a sweet taste. It grow in large clusters, even when the summer is cool. Most of them are indeterminate. Cherry tomatoes are ideal for growing in pots.

Grape Tomatoes: Grape tomatoes - this type similar to plum tomatoes, but smaller than that kind. They grow in large clusters, like Cherry tomatoes. Most of them are indeterminate.

Campari Tomatoes: Campari tomatoes - they are specific because of their sweetness. Their size is between cherry and plum tomatoes. They are juicy with low acidity and high sugar level.

Tomberry Tomatoes: Tomberries - this is the small type with only 5 mm in diameter. It is marked as " *the smallest tomatoes in the world*".

Oxheart Tomatoes: Oxheart tomatoes - their fruit is about 10-15cm in shape of a heart, so in size, they are similar to beefsteaks. The fruit is in pale pink color.

Pear Tomatoes: Pear tomatoes - they got their name because of their shape (pear). They belong to smaller tomatoes.

Slicing Tomatoes: "Slicing" (sometimes called "globe") tomatoes - it's mostly commercial type. They can even be in the diameter 5–6 cm.

Salad Tomatoes: Salad tomatoes (also called Standard tomatoes) - they are 5-7.5cm in diameter. Because they are ideal for sandwiches, they have more varieties than other types.

Tomato varieties can be divided into nine major categories based on their fruit color (VF, 2023) viz.,

Red tomato varieties - they have usual, rich tomato flavor.

Pink tomato varieties - varieties with a similar flavor to red tomatoes.

Orange Tomato Varieties - they are sweet.

Yellow Tomato Varieties - have a less marked flavor than the red tomatoes.

White Tomato Varieties - their flavor isn't rich, because they are low acid, like yellow types.

Green Tomato Varieties - strong flavor but not strong as the flavor of red type.

Purple and Brown Tomato Varieties - this is tomato with strong, but, some say, smoky flavor.

Blue/black/indigo- These tomatoes started with Indigo Rose, which gets its indigo/black/ blue colour from anthocyanin in the skin.

Stripes, blushing and swirls- Some tomatoes feature combinations of colours. Stripes generally occur only on the skin, while blushing and swirls can be seen both on the skin and in the flesh.

Wild tomato varieties were small and mostly yellow, not red. We could say that they were similar to what we know today as cherry tomatoes. Nowadays, apart from different sizes, we can also find different colors of tomatoes varying from our familiar red, to pink, yellow, orange, purple, white and black (Wikifarmer, 2023). An international consortium of researchers from 10 countries, began sequencing the tomato genome in 2004. A pre-release version of the genome was made available in December 2009. The latest reference genome published in 2021 had 799 MB and encodes 34,384 (predicted) proteins, spread over 12 chromosomes (Wikipedia, 2023).

Conventional breeding has based on standard methods which are Mass selection, Pedigree, and Hybridization. These are all conventional methods for breeding. Conventional breeding has developed the cultivars and also dominant resistance genes to control pest and disease. The replacement of inbred lines with hybrids increases the yield and other beneficial traits of tomato (Iqbal *et al.,* 2019). Variation in tomatoes has resulted from natural means and with the help of humans, through artificial selection (also known as selective breeding). Tomatoes have been bred by humans for many characteristics such as yield, shelf-life, pest resistance, taste, fruit size and shape, colour, seed size and weight, and nutritional quality. By the end of the 19th century, tomatoes were bred by many farmers and gardeners. Scientists are finding out more about which tomato genes are linked to characteristics like colour and size. This is because of progress in the study of genetics. They have also been able to create new tomato varieties using genetic engineering**.** This can be done in many ways. Usually scientists change genes so that the characteristics they want appear in the plant. In 1994, the 'FlavrSavr' tomato was the first genetically engineered tomato sold in stores. This tomato cultivar did not ripen as fast or soften as quickly as conventional tomatoes. This made it easier to pick and ship these tomatoes without damaging them. The 'FlavrSavr' did not make enough money in the end. It cost too much to grow and ship. There were also negative stories about it in the media, so it was no longer sold (Letstalkscience, 2021).

Important hybrids available in tomato in Public Sector are: IARI (New Delhi) KT-4, Pusa Hybrid-1, Pusa Hybrid-2, Pusa Hybrid-4, Pusa Divya IIHR (Bangalore) Arka Vardhan, Arka Vishal, Arka Shreshtha, Arka Abhijit GBPUAT (Pantnagar) Pant Hybrid-1, Pant Hybrid-2 NDUAT (Faizabad) NDTH-1, NDTH-2, NDTH-6 UHF (Solan) Solan Shagun, Solan Garima, Solan Sindhur. Important hybrids available in tomato in Private Sector are; Ankur ARTH-3, ARTH-4 Century Century-12, Maitri, Rishi**,** Indo American Karnataka, Mangla, Vaishali, Rupali, Naveen, Rashmi, Sheetal Mahyco MTH-1, MTH-2, MTH-6, MTH-15, MTH-16, S-28, Sonali Namdhari NS-386, NS-815, Summerset, Cross B, Gotya Nath NA-501, NA-601 Nijjar NH-15, NH-25, NH-38 Pioneer LIHB-230 Sandoz Learika, Rasika, Avinash 11 Sungrow Arjuna, Krishna, Bhim Sutton Sutton Grom, Prolific Beejo Sheetal BSS-39, BSS-20, BSS-40, BSS-90. Disease resistant varieties are: Early Selection,KT-10, KT-15, Flat Large Red, Red Cherry, Pant Bahar, BSS-20, Roma, Meenakshi, Roza, HS-110, H-24, H-36, Hissar Gaurav, Hissar Anmol, Pearl Harbour, Red Currant, H-22, H-25, Solan Vajar, Kalyanpur No.1, Ottawa 30, Ottawa 31, Red Cherry, Early Market (Tanuja Buckseth, 2023). Tomatoes are a significant source of umami flavor. They are consumed in diverse ways: raw or cooked, and in many dishes, sauces, salads, and drinks. While tomatoes are fruits—botanically classified as berries—they are commonly used culinarily as a vegetable ingredient or side dish (Wikipedia, 2023). Tomatoes are commonly used in a variety of dishes, including sauces, soups, and salads, and can also be eaten raw or cooked. They are a popular ingredient in many cuisines, including Italian, Mexican, and American. (Priyanka, 2022). The fruit contains a large quantity of water, vitamins and minerals, low amounts of proteins and fats, and some carbohydrates. It also contains carotenes, such as lycopene (which gives the fruit its predominantly red colour) and *beta*-Carotene (which gives the fruit its orange colour). Modern tomato cultivars produce fruits that contain up to 3% sugar of fresh fruit weight. It also contains tomatine, an alkaloid with fungicidal properties. The concentration of tomatine decreases as the fruit matures and tomatine concentration contributes to determining the taxonomy of the species. (OECD, 2008). Tomatoes are now eaten freely throughout the world, and their consumption is believed to benefit the heart among other things. Lycopene, one of nature's most powerful antioxidants, is present in tomatoes, and, especially when tomatoes are cooked, has been found beneficial in preventing prostate cancer. However, other research contradicts this claim. Tomato extract branded as Lycomato is now also being promoted for treatment of high blood pressure (Bionity, 2023). Tomato is widely consumed worldwide. It is a popular species preferred in gastronomy for its characteristic flavour. It is used in several traditional dishes because of its compatibility with other food ingredients and high nutritional value (OECD, 2008). The town of Buñol, Spain, annually celebrates La Tomatina, a festival centered on an enormous tomato fight. Tomatoes are also a popular "non-lethal" throwing weapon in mass protests; and there is a common tradition of throwing rotten tomatoes at bad performers on a stage, although this tradition is more symbolic today (Bionity, 2023). In this review article Origin, Distribution, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Tomato (*Solanum lycopersicum* L.) are discussed.

ORIGIN AND DISTRIBUTION

Mexico is presumed to be the most probable region of domestication, with Peru as the centre of diversity for wild relatives. *Solanum lycopersicum cerasiforme* is thought to be the ancestor of cultivated tomato, based on its wide presence in Central America and the presence of a shorter style length in the flower (Cox, 2000). Cultivated tomato is related to wild tomatoes originating from Peru, Ecuador and other parts of South America including the Galapagos Islands. The centre of its domestication and diversification is Mexico (Rick, 1978; Peralta et al., 2008). Wild relatives of tomato and intermediate forms (landraces or creoles) harbour a wealth of genetic diversity and are important sources of genetic material in crop improvement and conservation programmes (Sánchez-Peña *et al*., 2004). Tomato belongs to the large and diverse *Solanaceae* family also called Nightshades which includes more than three thousand species. Among them, major crops arose from Old world(Eggplant from Asia) and New world (pepper, potato, tobacco, tomato from South America). The *Lycopersicon* clade contains the domesticated tomato (*Solanum lycopersicum*) and its 12 closest wild relatives (Peralta and Spooner 2005).

Tomato clade species are originated from the Andean region, including Peru, Bolivia, Ecuador, Colombia and Chile (Fig. 1). Their growing environments range from near sea level to 3,300 m altitude, from arid to rainy climate and from Andeans Highlands to the coast of Galapagos Islands (*S. cheesmaniae;S. galapagense*). Their habitats are often narrow and isolated valleys where they were adapted to particular microclimates and various soil types. Their very large range of ecological conditions contributed to the diversity of the wild species. This broad variation is also expressed at the morphological, physiological, sexual and molecular levels (Peralta and Spooner 2005). Over times, several phylogenetic classifications have been proposed and several adjustments occurred. Being first classified in the *Solanum* genus, the group turned to a specific genus, *Lycopersicum* (Miller, 1731). It recently got renamed *Solanum* within an updated classification

(Peralta and Spooner 2001). The natural geographic distribution or centre of origin of *Solanum lycopersicum*, (*S.* section *Lycopersicon*) has been localised in the narrow band between the Andes mountain ranges and the Pacific coast of western South America. This extends from southern Ecuador to northern Chile, including the Galapagos Islands (Peralta et al., 2008). Wild tomato plants come from the Andean region of South America. This area includes the countries of Peru, Bolivia, Chile and Ecuador. Scientists think that Aztec and Inca people grew tomatoes as early as 700BCE. The tomatoes they grew were a very different size from the tomatoes we have today. The wild ancestor of the tomato, *Solanum pimpinellifolium*, is native to western South America. These wild versions were the size of peas. They also tasted different (Letstalkscience, 2021) (Fig. 2).

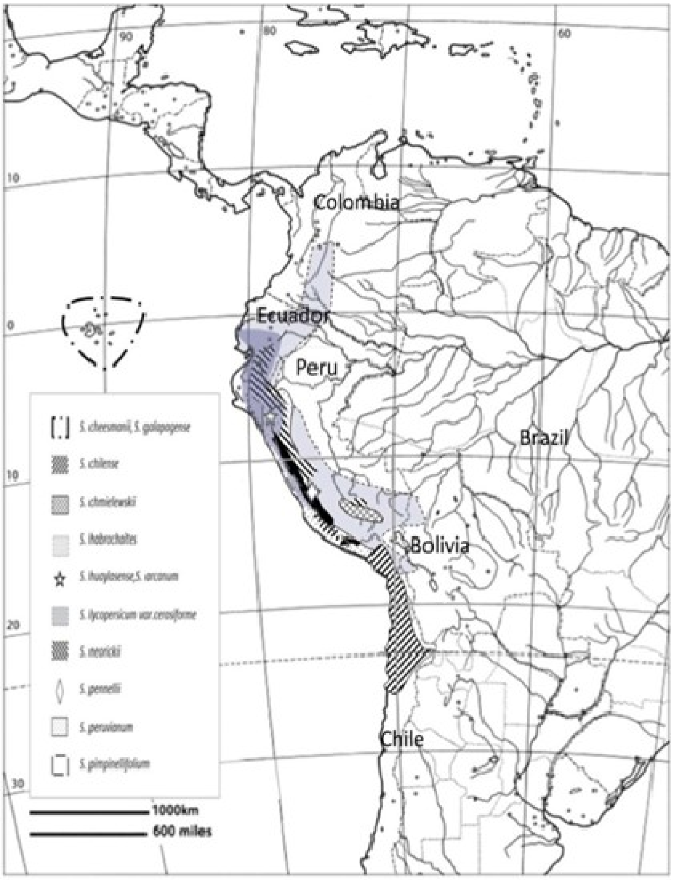


Fig. 1. Tomato species are originated from the Andean region, including Peru, Bolivia, Ecuador, Colombia and Chile

Fig. 2. Right: Tiny wild relative; Left: Tomato fruits of today

We don't know who first brought tomato seeds to Europe, but descriptions of tomatoes appeared in some of the earliest European books about botany. These were written in the 16th century. More domestication of the tomato plant happened in Europe in the 18th and 19th centuries. There is no clear evidence of how tomatoes came to North America. Scientists think it happened sometime in the 16th or 17th century. People were growing tomatoes in the United States by the middle of the 18th century. They weren't popular, though. Many people thought they were poisonous because they belonged to the nightshade family. There are stories that in the early 1800s, famous Americans would eat tomatoes in front of audiences just to prove they were not poisonous. No one knows whether or not these stories are true. Eventually Americans realized tomatoes were not poisonous. But they were still unpopular because many people thought they tasted too acidic (Letstalkscience, 2021). The tomato is native to Central, South, and southern North America from Mexico to Peru (Bionity, 2023). Wild tomato plants originated in the Andean region of South America, which is today known as Peru, Bolivia, Chile, and Ecuador. It is believed that tomatoes were first grown by the Aztecs and Incas as early as 700 A.D. The tomatoes that were grown at that time were very different in size and taste from the tomatoes that we know today. It is not known exactly how or who brought tomato seeds to Europe, but in the 16th century, references to tomatoes began to appear. Further domestication occurred throughout Europe in the 18th and 19th centuries. There is no clear evidence for how the tomato was introduced to North America, but it is believed to have occurred sometime in the 16th or 17th century. By the middle of the 18th century, tomatoes were cultivated, but not widely consumed in the United States. This was because people believed that tomatoes were poisonous since they belonged to the nightshade family. It has been reported that in the early 1800, an American publicly consumed tomatoes showing the audiences that they were not poisonous. After it was established that tomatoes were not poisonous, tomatoes were still slow to gain popularity because many people found them too acidic for their taste (Tomatosphere, 2023). The tomato is the edible berry of the plant *Solanum lycopersicum*, commonly known as the tomato plant**.** The species originated in western South America, Mexico, and Central America. The Mexican Nahuatl word *tomatl* gave rise to the Spanish word *tomate*, from which the English word *tomato* derived. Its domestication and use as a cultivated food may have originated with the indigenous peoples of Mexico. The Aztecs used tomatoes in their cooking at the time of the Spanish conquest of the Aztec Empire, and after the Spanish encountered the tomato for the first time after their contact with the Aztecs, they brought the plant to Europe, in a widespread transfer of plants known as the Columbian exchange. From there, the tomato was introduced to other parts of the European-colonized world during the 16th century (Wikipedia, 2023).

The wild ancestor of the tomato (*Solanum lycopersicum var. lycopersicum*), *Solanum pimpinellifolium*, is native to western South America. These wild versions were the size of peas. The first evidence of domestication points to the Aztecs and other peoples in Mesoamerica, who used the fruit fresh and in their cooking. The Spanish first introduced tomatoes to Europe, where they became used in Spanish food. In France, Italy and northern Europe, the tomato was initially grown as an ornamental plant. It was regarded with suspicion as a food because botanists recognized it as a nightshade, a relative of the poisonous belladonna. This was exacerbated by the interaction of the tomato's acidic juice with pewter plates. The leaves and fruit contain tomatine, which in large quantities would be toxic. However, the ripe fruit contains a much lower amount of tomatine than the immature fruit. The term Mesoamerica is derived from the Greek and means "Middle America." It refers to a. geographical and cultural area which extends from central Mexico down through Central America, including the territory which is now made up of the countries of Guatemala, Belize, Honduras, and El. Salvador. The exact date of domestication is unknown; by 500 BC, it was already being cultivated in southern Mexico and probably other areas. The Pueblo people are thought to have believed that those who witnessed the ingestion of tomato seeds were blessed with powers of divination. The large, lumpy variety of tomato, a mutation from a smoother, smaller fruit, originated in Mesoamerica, and may be the direct ancestor of some modern cultivated tomatoes. Tomatoes were not grown in England until the 1590s. However, by the mid-18th century, tomatoes were widely eaten in Britain. The tomato arrived in India by the way of Portuguese explorers, in the 16th century. It was grown from the 18th century onwards for the British; even today, in Bengal, the alternative name is *biliti begun*, meaning 'foreign eggplant'. It was then adopted widely as it is well suited to India's climate, with Uttarakhand as one of the main producers (Wikipedia, 2023). After the 15th century, Europe and Asia heard about tomato, thanks to Mexicans who first ate it. In Mexico, it existed since 500 BC. It's unclear how did it reach Europe, maybe by Christopher Columbus or Hernán Cortés, who captured the Aztec city of Tenochtitlan. Since Spanish colonization of the Americas, tomato reached Spanish Philippines and then Asia as well as Europe. It is known that it was in use in Italy by 1548. In Britain, although existed for long time, it was believed that it was unfit for eating, even poisonous. The Same case was in North America. The 19th century brought the tomato to the Middle East, but today tomato is the main ingredient of their cuisine (VF, 2023).

Tomatoes come in many different shapes, colours, and sizes. During pre-hispanic times, various useful plants were introduced and domesticated in Mesoamerica from South America. The original South American tomato fruit became a synanthrophyte, a plant species brought indirectly to Mexico through trade between prehispanic cultures. The characteristics of this wild fruit were different from the cultivated fruit: small size (1-2 cm diameter), bilocular and acid taste (Jenkins, 1948). Upon its arrival in Mesoamerica, its similar morphology with the green tomato (*Physalis*) facilitated its adoption and adaptation by Mexican cultures. Since those times, the use and diversification in morphotypes, dimensions, forms and colours of the fruits used as food by Mexican indigenous cultures were extraordinary. As such, Mexico, together with the Andes zone, houses the largest morphological variability in tomato (Rick, 1978; Jenkins, 1948) and is considered the centre of diversity and domestication of *S. lycopersicum* (Jenkins, 1948). In the case of cultivated plants, in addition to the centre of biological origin, other areas exist where wild ancestors and other related forms in an incipient stage of domestication (e.g. weed forms and local landraces) co-exist. This area, known as the centre of genetic diversity, contains an extraordinary diversity of forms. Harlan, de Wet and Price (1973) defined geographic areas different from the natural centre of distribution of the crop as secondary centres or centres of trans-domestication. These are the zones where the species is domesticated. Occasionally, both areas coincide. In the case of tomato, its centre of origin and its centre of diversity are different (Harlan, 1971). The first mention of tomato in England was by the botanist Gerard in 1597. Besler in 1613, a German naturalist, first showed engravings of tomato plants present at the Eichstätt Garden in Germany. Considering the size of the fruit shown in the engravings, it is assumed that they depict plants already domesticated as ornamentals. In 1760, tomato was represented as an ornamental in the Andrieux-Vilmorin catalogue in France. Tomato returned to the Americas in the 18th century, according to reports of its cultivation in the West Indies and the Caribbean. Tomato was also transported to North America in the 18th century by European colonists arriving at commercial harbours in New Jersey, the United States. The first written account dates from 1710, when it was registered as an ornamental plant by William Salmon. However, it was not trusted as a foodstuff in the United States until the beginning of the 20th century because of its similarity to certain poisonous fruits (Rick, 1978). The first improved tomatoes were developed by Italian breeders in the 17th or early 18th century, who converted the small, wrinkled and hard tomato into the red coloured, smooth and juicy varieties known today. Tomato is now a cosmopolitan crop with major production in temperate regions, even though its origins lay in tropical regions.

The domestication time of tomato is unclear. It is supposed to be due to a recent divergence from S. *pimpinellifolium.* The first hypothesis supports Peru as the center of origin and domestication (de Candolle 1882). This hypothesis gives emphasis on botanical evidences and has been complemented by botanical, linguistic and historical aspects. The second hypothesis supports that domestication occurred primarily in Mexico in the Vera Cruz Puebla area (Jenkins 1948), as there is no evidence for pre-Colombian cultivation of tomato in South America but good evidences in Mexico. Referring to Guilandini (1572), Jenkins (1 9 4 8) also argued that tomato name comes most probably from the Mexican Nahua people word "Tomatl" that described "plants bearing globous and juicy fruit" (Sahagún 1988). Historical records allow the reconstruction of the arrival of tomatoes in the Old World, following European contact. The Spanish navigators brought seeds to Europe in the 16th century and friars sent some of these to their brothers. The tomato first arrived in Andalusia (via the Canary Islands) and was dispersed throughout Spain. The Spanish and the Italians were the first to accept this "exotic" fruit. In other European countries acceptance was slow and the tomato long remained an ornamental plant because of the fear of poisoning or "the curse of the dulcamara" (Long Towell, 2001). Domestication is a special type of species diversification, distinct from species divergence through natural selection in the wild. Domesticated species differ from wild and relative species for a set of traits known as the domestication syndrome (Doebley *et al*., 2006). This belief was associated with the toxic, hallucinogenic and aphrodisiac properties of other members of the Solanaceae, such as Belladona (*Belladona*) and Mandragora (*Mandragora*), which have detrimental effects on health caused by some alkaloids (OECD, 2008). Domestication is often controlled by a limited number of chromosomal regions with major phenotypic effect (Purugganan and Fuller, 2009). In tomato, edible fruits, attractive red color and fruit size increase are characterizing this process. Tomatoes come in many different shapes, colours and sizes. People create this variety through artificial selection or selective breeding. They breed tomato plants in order to choose the characteristics they want. Some characteristics include producing more fruit per plant, better shelf life (fruit will last longer before it rots), more resistance to pests, better taste, different size, shape, colour or weight, and more nutritional value. By the end of the 19th century, many farmers and gardeners were breeding tomatoes. They kept the seeds from the tomatoes they grew and planted them again the next year. This is called seed saving. It has led to what we now call heirloom varieties. Heirloom tomato plants produce fruit in many different shapes, sizes and colours. They are true-breeding. This means that new plants have the same characteristics as their parent plants.

Large-scale breeding of tomatoes for commercial sale began in the early 20th century. This produced hybrid varieties. Hybrid tomatoes are the offspring of two different tomato varieties. Hybrids often have the best characteristics of each of their parent plants. This makes them highly desired. Commercial farmers who grow hybrid tomatoes are discouraged from using their own seeds from previous years. They are required to purchase seeds from a seed company. This is to make sure that all the tomatoes they grow are of the same quality. This way they can be sold to grocery stores and food processors (Letstalkscience, 2021). The wild species originated in the Andes Mountains of South America, probably mainly in Peru and Ecuador, and is thought to have been domesticated in pre-Columbian Mexico; its name is derived from the Náhuatl (Aztec) word tomatl**.** The tomato was introduced to Europe by the Spanish in the early 16th century, and the Spanish and Italians seem to have been the first Europeans to adopt it as a food. In France and northern Europe the tomato was initially grown as an ornamental plant and was regarded with suspicion as a food because botanists recognized it as a relative of the poisonous belladonna and deadly nightshade. Indeed, the roots and leaves of the tomato plant are poisonous and contain the neurotoxin solanine (EEB, 2023). Tomatoes were introduced to North America from Europe. Thomas Jefferson is known to have raised them at Monticello in 1781. The tomato was used for food in Louisiana as early as 1812, but not in the northeastern states until about 1835. It did not attain widespread popularity in the United States until the early 20th century. The plant is now grown commercially throughout the world (EEB, 2023). According to Andrew F Smith's *The Tomato in America*, the tomato probably originated in the highlands of the west coast of South America. Smith notes there is no evidence the tomato was cultivated or even eaten before the Spanish arrived. Other researchers, however, have pointed out that this is not conclusive, as many other fruits in continuous cultivation in Peru are not present in the very limited historical record. Much horticultural knowledge was lost after the arrival of Europeans. There is a competing hypothesis that says the tomato, like the word "tomato", originated in Mexico, where one of the two apparently oldest "wild" types grows. It is entirely possible that domestication even arose in both regions independently. In any case, by some means the tomato migrated to Central America. Maya and other peoples in the region used the fruit in their cooking, and it was being cultivated in southern Mexico and probably other areas, by the 16th century. It is thought that the Pueblo people believed those who witnessed the ingestion of tomato seeds were blessed with powers of divination. The large, lumpy tomato, a mutation from a smoother, smaller fruit, originated and was encouraged in Central America. Smith states this variant is the direct ancestor of some modern cultivated tomatoes. Two modern tomato cultivar groups, one represented by the Matt's Wild Cherry tomato, the other by currant tomatoes, both originate by recent domestication of the wild tomato plants apparently native to eastern Mexico. After the Spanish colonization of the Americas, the Spanish distributed the tomato throughout their colonies in the Caribbean. They also took it to the Philippines, whence it moved to Southeast Asia and then the entire Asian continent. The Spanish also brought the tomato to Europe. It grew easily in Mediterranean climates, and cultivation began in the 1540s. It was probably eaten shortly after it was introduced, though it was certainly being used as food by the early 1600s in Spain. Nonetheless, he believed that it was poisonous (tomato leaves and stems contain poisonous glycoalkaloids, but the fruit is safe). Gerard's views were influential, and the tomato was considered unfit for eating (though not necessarily poisonous) for many years in Britain and its North American colonies. By the mid-1700s, however, tomatoes were widely eaten in Britain; and before the end of that century, the *Encyclopædia Britannica* stated that the tomato was "in daily use" in soups, broths, and as a garnish. The earliest reference to tomatoes being grown in British North America is from 1710, when herbalist William Salmon reported seeing them in what is today South Carolina. The tomato was introduced to France through Provence from Italy during the late 18th century and became a culinary symbol of the French Revolution due to its red color (Bionity, 2023).

TAXONOMY

The scientific name of the tomato is *Solanum lycopersicum*. It is a member of the Solanaceae family, which includes a number of other plants that are important for human consumption, such as potatoes, peppers, and eggplants. The genus name, *Solanum,* comes from the Latin word for “nightshade,” and the species name, *lycopersicum*, means “wolf peach” in Latin. Nightshades include more than 3000 species including many that are economically important (Letstalkscience, 2021; Noracallo, 2021; Priyanka, 2022; Tomatosphere, 2023; ITIS, 2023; Wikipedia, 2023; Bionity, 2023). Family: Solanaceae, Sub-Family: Soloanoideae, Cestroideae, Tribe: Solaneae, Genera: *Solanum*, *Lycopersicon,* Species: *Solanum lycopersicum* (Tanuja Buckseth, 2023). Tomatoes have had a few different scientific names over the years. Names like Solanum lycopersicum and Lycopersicon esculentum. The names have changed because scientists have changed how they thought tomatoes are related to other plants. In the early 1700s, a botanist named Carl Linnaeus put tomatoes into the genusgenus Solanum. He made this decision based on what he could see about the plants. In the mid-1700s, another botanist, Philip Miller, did not agree with Linnaeus's biological classification. He placed tomatoes into the genus Lycopersicon instead. He thought that tomatoes belonged in a different genus from poisonous nightshade species. Recently, taxonomists reclassified tomatoes again. They put them back into the genus Solanum. They made this decision based on information they learned about tomato genes, using genetic research methods. This story shows that scientific knowledge doesn’t stay the same forever. It changes all the time, as scientists learn new information (Letstalkscience, 2021). The Italians called the tomato pomodoro (“golden apple”), which has given rise to speculation that the first tomatoes known to Europeans were yellow. It has been suggested that the French called it pomme d’amour (“love apple”) because it was thought to have aphrodisiacal properties. Some scholars assert, however, that the tomato was at first taken to be a kind of eggplant, of which it is a close relative. The eggplant was called pomme des Mours (“apple of the Moors”) because it was a favourite vegetable of the Arabs, and pomodoro and pomme d’amour may be corruptions of that name (EEB, 2023). The name is from Aztec language *tomatl*, which Spanish made into *tomate*, and English into a tomato. Italian name is *Pomodoro*, which is taken by Polish and Russian. Germans called it *Paradeisapfel*, or "apple of paradise", which was transferred into Hungarian, Slovenian, and Serbian. In Iran it was called "Armenian eggplant", and now *gojeh farangi* , which means "foreign plum".(VF, 2023). The common name known all over the world, tomato, originates from a Spanish usage assigned to the Mexican word in Náhuatl “*xictomatl*” (“*xictli*”: navel and “*tomatl*”: tomato), meaning the tomato with a navel. This refers to the scar left on the fruit by the peduncle. In Mexico the plant is frequently called “*jitomate*” (OECD, 2008). The word *tomato* derives from a word in the Nahuatl language, *tomatl*. The specific name, *lycopersicum*, means "wolf-peach" (compare the related species *S. lycocarpum*, whose scientific name means "wolf-fruit", common name "wolf-apple") (Bionity, 2023). The word *tomato* comes from the Spanish *tomate*, which in turn comes from the Nahuatl word *tomatl* [ˈtomat͡ɬ] pronunciation (help·info), meaning 'swelling fruit'; also 'fat water' or 'fat thing'. The native Mexican tomatillo is *tomate*. When Aztecs started to cultivate the fruit to be larger, sweeter and red, they called the new variety *xitomatl* (or *jitomates*) (pronounced [ʃiːˈtomatɬ]), ('plump with navel' or 'fat water with navel'). The specific name *lycopersicum* (from the 1753 book *Species Plantarum*) is of Greek origin (λύκοπερσικων, *lykopersikon*), meaning 'wolf peach' (Wikipedia, 2023).

Synonyms: Heuzé et al. (2015) have listed ten synonyms for *Solanum lycopersicum:*

1) Lycopersicon esculentum f. pyriforme (Dunal) C. H. Müll.,
2) Lycopersicon esculentum var. commune L. H. Bailey,
3) Lycopersicon esculentum var. grandifolium L. H. Bailey,
4) Lycopersicon esculentum var. pyriforme (Dunal) L. H. Bailey,
5) Lycopersicon esculentum var. validum L. H. Bailey,
6) Lycopersicon lycopersicum (L.) H. Karst.,
7) Lycopersicon lycopersicum var. cerasiforme auct.,
8) Lycopersicon lycopersicum var. pyriforme auct.,
9) Lycopersicon pyriforme Dunal, Solanum lycopersicum L.
10) *Solanum lycopersicum* L.

Eight Synonyms have been reported by NIH (2023) for *Solanum lycopersicum*

1) *Lycopersicon esculentum* Mill.
2) *Lycopersicon esculentum*
3) *Lycopersicon esculentum* var. *esculentum*
4) *Solanum esculentum* Dunal
5) *Solanum esculentum*
6) *Solanum lycopersicum*
7) *Solanum lycopersicum* var. *humboldtii*
8) Lycopersicon esculentum Mill. [Solanaceae]

IT IS (2023) has listed 14 synonyms for *Solanum lycopersicum*:

1) Lycopersicon esculentum Mill.
2) Lycopersicon lycopersicum (L.) Karst.
3) Lycopersicon cerasiforme Dunal
4) Lycopersicon pyriforme Dunal
5) Lycopersicon esculentum ssp. galenii (Mill.) Luckwill
6) Lycopersicon esculentum var. cerasiforme (Dunal) Alef.
7) Lycopersicon esculentum var. esculentum Mill.
8) Lycopersicon esculentum var. cerasiforme (Dunal) A. Gray
9) Lycopersicon esculentum var. leptophyllum (Dunal) D'Arcy
10) Lycopersicon esculentum var. pyriforme (Dunal) L.H. Bailey
11) Lycopersicon lycopersicum var. cerasiforme (Dunal) Alef.
12) Solanum lycopersicum var. cerasiforme (Dunal) Spooner, G.J. Anderson & R.K. Jansen
13) Solanum lycopersicum var. lycopersicum L.
14) Lycopersicon esculentum var. pyriforme (Dunal) Alef.

Botanical classification

In 1753 the tomato was placed in the genus *Solanum* by Linnaeus as *Solanum lycopersicum* L. (derivation, 'lyco', wolf, plus 'persicum', peach, i.e., "wolf-peach"). However, in 1768 Philip Miller placed it in its own genus, and he named it *Lycopersicon esculentum*. This name came into wide use but was in breach of the plant naming rules. Technically, the combination *Lycopersicon lycopersicum* (L.) H.Karst. would be more correct, but this name (published in 1881) has hardly ever been used. Therefore, it was decided to conserve the well-known *Lycopersicon esculentum*, making this the correct name for the tomato when it is placed in the genus *Lycopersicon*. However, genetic evidence has now shown that Linnaeus was correct in the placement of the tomato in the genus *Solanum*, making the Linnaean name correct; if *Lycopersicon* is excluded from *Solanum*, *Solanum* is left as a paraphyletic taxon. Despite this, it is likely that the exact taxonomic placement of the tomato will be controversial for some time to come, with both names found in the literature (Wikidoc**,** 2011).

In 1753, Linnaeus placed the tomato in the genus Solanum (alongside the potato) as *Solanum lycopersicum*. In 1768, Philip Miller moved it to its own genus, naming it *Lycopersicon esculentum*. The name came into wide use, but was technically in breach of the plant naming rules because Linnaeus's species name *lycopersicum* still had priority. Although the name *Lycopersicum lycopersicum* was suggested by Karsten (1888), it is not used because it violates the International Code of Nomenclature barring the use of tautonyms in botanical nomenclature. The corrected name *Lycopersicon lycopersicum* (Nicolson 1974) was technically valid, because Miller's genus name and Linnaeus's species name differ in exact spelling, but since *Lycopersicon esculentum* has become so well known, it was officially listed as a *nomen conservandum* in 1983, and would be the correct name for the tomato in classifications which do not place the tomato in the genus *Solanum*. Genetic evidence has now shown that Linnaeus was correct to put the tomato in the genus *Solanum*, making *Solanum lycopersicum* the correct name. Both names, however, will probably be found in the literature for some time. Two of the major reasons for considering the genera separate are the leaf structure (tomato leaves are markedly different from any other *Solanum*), and the biochemistry (many of the alkaloids common to other *Solanum* species are conspicuously absent from the tomato). On the other hand, hybrids of tomato and diploid potato can be created in the lab by somatic fusion, and are partially fertile, providing evidence of the close relationship between these species (Wikipedia, 2023).

This small genus is currently thought to consist of the cultivated tomato*, L.esculentum, a*nd seven closely related wild *Lycopersicon* species (Rick, 1976). Earlier taxonomic treatments (Muller, 1940; Luckwill, 1943) have become inadequate as the number of species and races collected from South America have increased. Muller (1940) originally subdivided the genus into two groups: (i) Eulycopersicon - coloured-fruited species. And (ii) Eriopersicon- green-fruited species. This split, based on fruit colour is arbitrary and does not correspond to more fundamental differences between the species (Tanuja Buckseth, 2023). *Lycopersicon* is a relatively small genus within the extremely large and diverse family Solanaceae. The family is currently considered to consist of around 90 genera. These are mainly divided between two sub-families, the Solanoideae and the Cestroideae. This division between the major sub-families is based on different patterns of embryo development. Solanoideae have a coiled embryo of more or less uniform diameter. In the Cestroideae the embryo is typically straight or only slightly curved. A large number of morphological, chemical and cytogenetic differences accompany this basic division. The Solanoideae show remarkable cytogenetic uniformity in that all members have a chromosome base number of $x = 12$. Cestroideae have a more variable chromosome number which is rarely based on 12. All species in the genus Lycopersicon are typical of the Solanoideae sub-family, each having an identical genome formula ($2n = 2x = 24$). Sub-family Solanoideae is further subdivided into tribes. *Lycopersicon* belongs to the largest tribe in the family, Tribe Solaneae. This tribe consists of around 18 genera, ranging from *Lycopersicon* which is one of the smallest to the closely related genus *Solanum*, which is the largest in the family. *Solanum* includes around 1500 species and is one of the most diverse genera of vascular plants. The vast size and complexity of the genus *Solanum* creates problems for taxonomists and distorts the independent generic status of *Lycopersicon*. The two genera are separated on the basis of the unique anther morphology typically found in *Lycopersicon* species. The flower of *Lycopersicon* normally has five anthers, although some varieties of the crop species *L. esculentum* have six. The stamens are joined together to form a flask-shaped anther cone which is characteristic of the genus. The 'neck' of the cone is made up of the elongated sterile tip of each anther. This is the key characteristic which has traditionally been used to separate *Lycopersicon* from *Solanum*. Associated with this characteristic is the unusual pattern of anther dehiscence found in *Lycopersicon* species. The anthers split laterally; contrasting with the terminally dehiscent anthers typically found in *Solanum*. Pollen is therefore liberated inside the anther cone and emerges through the communal channel formed by the junction of each elongated anther. The use of this key character clearly delineates the closely related group of species belonging to the genus *Lycopersicon* (Tanuja Buckseth, 2023).

The commercial tomato belongs to a species most frequently referred to as *Lycopersicon esculentum* Miller. The correct Latin name for this species has been the subject of much discussion which has not been fully resolved. The alternative names *Solanum lycopersicum* L., or *Lycopersicon lycopersicum* (L.) Karsten have appeared in the literature. *Lycopersicon esculentum* was first proposed for the tomato by Miller in 1768, replacing the earlier Linnean name *Solanum lycopersicum*. However, Karsten in 1900 suggested that *Lycopersicon lycopersicum* should be adopted. Under the rules of the International Code of Botanical Nomenclature the original specific name '*lycopersicum*' should have been retained following the creation of the new genus *Lycopersicon*. The arguments on either side have been most recently summarized by Broome *et al*. (1983). Broome et al. (1983) conclude that because of its long and popular usage, the scientific name of the tomato *Lycopersicon esculentum* Mill. Should be used (Taylor, 1986). Tomatoes have had several scientific names over the years including Solanum lycopersicum and Lycopersicon esculentum. In the early 1700s, Linnaeus put tomatoes in the genus Solanum based on their visible characteristics. In the mid-1700s, Philip Miller, another botanist, did not agree with Linnaeus' classification and instead placed tomatoes into the genus Lycopersicon. He thought that tomatoes belonged in a different genus from other poisonous nightshade species. More recently, taxonomists reclassified the species again, putting them back into the genus Solanum based genetic information. What this story about the classification of tomatoes goes to show is that scientific knowledge is not static, and that scientific knowledge constantly changes based on new information (Tomatosphere, 2023). Tomatoes, peppers, potatoes and eggplants all belong to the Solanaceae family of flowering plants. Plants in this family are also called nightshades. There are more than 3000 species of nightshades. Many of them are important to our economy. There are more than 7000 varietiesvarieties of tomatoes alone. But all of these make up only one speciesspecies of tomato. This species is called *S. lycopersicum* (Letstalkscience, 2021).

This is a list of species in the plant genus *Solanum*. There may be as many as 1,500 species worldwide. With some 1240 accepted specific and infra-specific taxa of the more than 4,000 described, the genus *Solanum* contains more species than any other genus in the family Solanaceae and it is one of the largest among the angiosperms. Phylogenetic analysis of molecular data has established or confirmed that the genera *Lycopersicon, Cyphomandra, Normania,* and *Triguera*, which were previously classified independently, should in reality be included within the *Solanum*. In fact, all the species from these four genera have been formally transferred to *Solanum*. On the other hand, the genus *Lycianthes*, which is sometimes included within the *Solanum*, has been shown to be a separate genus (Wikipedia, 2023a). Nightshade, (genus Solanum), genus of about 2,300 species of flowering plants in the nightshade family (Solanaceae). The term nightshade is often associated with poisonous species, though the genus also contains a number of economically important food crops, including tomato (Solanum lycopersicum), potato (S. tuberosum), and eggplant (S. melongena) (Britanica, 2023). The tomato clade (*Solanum* section *Lycopersicon*) offers a powerful experimental system in which both prezygotic and postzygotic isolating mechanisms may be revealed. This clade is comprised of 13 species, per the most recent taxonomic treatments (Peralta *et al.* 2008; Rodriguez *et al.* 2009). Four other *Solanum* species (*S. ochranthum*, *S. jugandifolium*, *S. lycopersicoides* and *S. sitiens*) are closely affiliated with the tomato group (Fig.3). In Fig. 4 subsections and species are given.

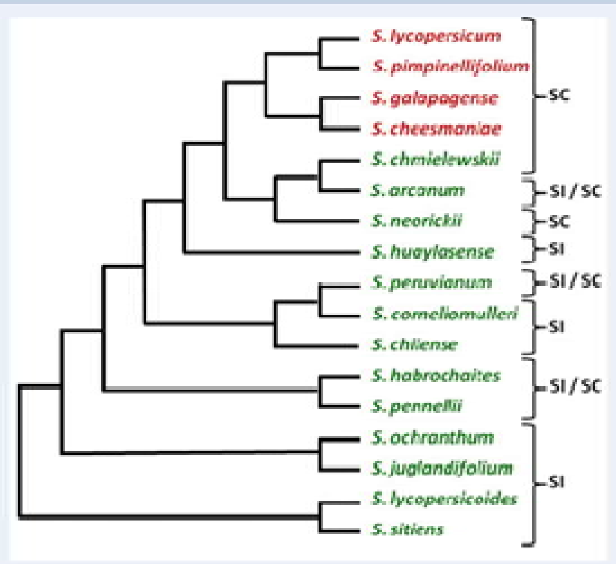


Fig. 3. Phylogenetic tree of allied *Solanum* species in the tomato clade. *S. lycopersicum, S. pimpinellifolium, S. galapagense and S. cheesmaniae* bear red/orange fruits, and all others bear green/purple fruits. Tree is based on Rodriguez et al. (2009), with the addition of mating systems. SC self-compatible, SI self-incompatible

Subsection	Species New Nomenclature [previous nomenclature]
Arcanum	*S. arcanum* [*L. peruvianum*]
	S. chmielewskii [*L. chmielewskii*]
	S. neorickii [*L. parviflorum*]
Neolycopersicon	*S. pennellii* [*L. pennellii*]
Eriopersicon	*S. habrochaites* [*L. hirsutum*]
	S. chilense [*L.chilense*]
	S. huaylasense [partly *L. peruvianum*]
	S. peruvianum [*L. peruvianum*]
	S. corneliomulleri [partly *L. peruvianum*, known as *L. glandulosum*]
Lycopersicon	*S. cheesmaniae* [*L. cheesmaniae*]
	S. galapagense [partly *L. cheesmanieae*]
	S. pimpinelifolium [*L. pimpinellifolium*]
	S. lycopersicum var. *cerasiforme** [*L. esculentum* var. *cerasifome*]
	S. lycopersicum [*L. esculentum*]

Fig. 4. Features of the *Lycopersicon* subsection (*Solanum* sect. *Lycopersicon*)

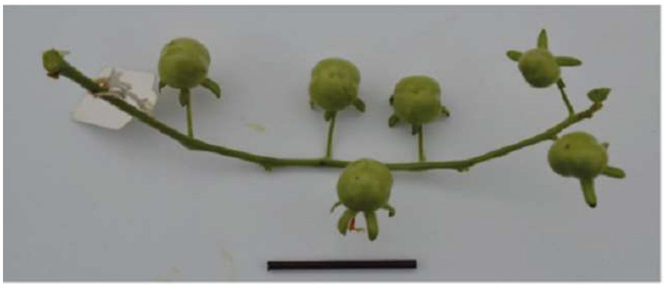
The first classification was morphology based (Luckwill 1943). Later molecular data confirmed tomato membership of Linnaeus classification, but also improved subtaxa classification. The tomato clade is an interesting example for research on plant biodiversity, notably, on evolution, adaptation, human domestication and nutrition perspectives (Peralta and Spooner 2007). Nowadays, across South America, populations of wild tomatoes are being severely reduced. Their natural habitats are shrinking due to urban development and intensive agriculture as well as goat herding in the highlands, as recently documented by a botanical expedition in Peru (Grandillo *et al.,* 2011).

Many studies were conducted on evolutionary aspects of the *Lycopersicon* clade. The mating system was extensively studied, using the clade as a model to study its effects on species variation. Mating system has played a key role in evolution of wild tomatoes, varying from allogamous self-incompatible, to facultative allogamous, to autogamous and self-compatible. Flower stigma exertion and gametophytic incompatibility system contribute in greater outcrossing and genetic diversity. All the species of the clade are intercrossable, but with a variable success rate (Rick *et al*., 1979). Fruit color discriminate the wild relative species. Most of the latter carry green fruits, with the exception of the two species from the Galapagos (with yellow and orange fruits) and *S. pimpinellifolium*, which is the only wild relative species with red fruits. *S. pimpinellifolium* fruits are round, small, weighing only few grams. These fruits are edible and the species referred as the today's tomato. The plant presents a reduced apical dominance and prostrate growth habit resulting in a large shrub with inflorescence carrying many flowers and fruits. Five wild species related to the cultivated tomato were *Solanum pimpinellifollium* L., *Solanum peruvianum* L., *Solanum habrochaites* S., *Solanum pennellii* L., and *Solanum chilense* R. (Paran and van der Knaap 2007; Flores-Hernández et al., 2017) (Fig. 5).

***S. pimpinellifollium* L.**

***S. peruvianum* L.**

***S. habrochaites* S.**



S. pennellii **L.**

S. chilense **R.**

Fig. 5. Five wild species related to the cultivated tomato

S. lycopersicum var *cerasiforme* fruit is larger than *S. pimpinellifolium* and is commonly round and red. This subspecies of tomato is referred to as the "cherry tomato". It has been proposed as the direct ancestor of cultivated tomato because of its diversity, its wide spread occurrence in Central America and its close genetic relationship with cultivated tomato (Rick and Chetelat 1995). The modern cultivated tomato, *S. lycopersicum*, is cosmopolite. It has spread all around the world and is now cultivated under a broad range of environments and conditions. The plant group *Solanum* sect. *Lycopersicon* – a clade of 13 species, including the domesticated tomato (*Solanum lycopersicum* L.) and its wild relatives – along with four allied species in the immediate out groups *Solanum* sects. *Juglandifolia* and *Lycopersicoides* were examined (Silvana Grandillo *et al.,* 2011). We summarize the geographic distribution and morphological characters of these plant groups, describing their evolutionary relationships in the context of a new taxonomic revision at the species level of all these groups. We provide an overview of the role that wild tomato species have played in the development of cytogenetic stocks, in classical and molecular genetic studies as well as in crop improvement through traditional and advanced tools. We discuss how the very narrow genetic basis of cultivated tomato germplasm has forced tomato geneticists and breeders to rely on the wealth of genetic variation present in the wild relatives to address the many breeding challenges. The numerous molecular mapping studies conducted using interspecific crosses have clearly demonstrated that the breeding value of exotic (wild) tomato germplasm goes far beyond its phenotype (Silvana Grandillo *et al.,* 2011). The genus *Solanum* consists of approximately 1 500 species. The tomato clade (section *Lycopersicon*, formerly recognised as the genus *Lycopersicon*) includes the cultivated tomato (*Solanum lycopersicum*) and 12 wild relatives, all natives to western South America (Peralta *et al*., 2008) (Table 1). Tomato (*Solanum lycopersicum*) is derived from two wild ancestor species, *Solanum pimpinellifolium* and *Solanum cerasiforme*. The 12 wild members of the *Lycopersicum* clade demonstrate a high level of phenotypic and genetic variation, including a great diversity in mating systems and reproductive biology. Peralta *et al*. (2008) recognised 12 species of wild tomato; Within these 12 species, informal species groupings were made: 4 closely related green-fruited species – *S. arcanum*, *S. huaylasense*, *S. peruvianum* and *S. corneliomulleri* – were grouped in the *S. peruvianum sensu lato* (*sensu lato* refers to a broad concept of a species). Another group of yellow to orange-fruited species contains two species endemic to the Galapagos Islands: *S. galapagense* and *S. cheesmaniae*. Table 2 lists tomato species for the genus *Solanum,* subsect. *Lycopersicon* (USDA-ARS, 2009).

Table 1. Taxonomy of the genus Solanum sect. Lycopersicoides, sect. Juglandifolia, sect. Lycopersicon

Species	Synonyms
S. lycopersicoides Dunal	*L. lycopersicoides (*Dunal) A. Child ex J.M.H. Shaw
S. sitiens I.M.Johnst	*L. sitiens* (I.M.Johnst) J.M.H. Shaw
S. juglandifolium Dunal	*L. juglandifolium* (Dunal) J.M.H. Shaw
S. ocharanthum Dunal	*L. ocharanthum* (Dunal) J.M.H. Shaw
S. pennellii Correl	*L. pennellii* (Correl) D'Arcy
S. habrochaites S.Knapp & D.M.Spooner	*L. hirsutum* Dunal
S. chilense (Dunal) Reiche	*L. chilense* Dunal
S. huaylasense Peralta	partly *L. peruvianum* (L.) Miller
S. peruvianum L.	*L. peruvianum* (L.) Miller
S. corneliomulleri J.F.Macbr. (1 geographic race Misti near Arequipa)	partly *L. peruvianum* (L.) Miller also known as *L. glandulosum* C.F.Müll
S. arcanum Peralta(4 geographic races humifusum, lomas, Marañon, Chotano-Yamaluc)	partly *L. peruvianum* (L.) Miller
S. chmielewskii (C.M.Rich et al.)	*L. chmielewskii* C.M.Rich et al. D.M.Spooner et al.
S. neorickii D.M.Spooner et al.	*L. parviflorum* C.M.Rich et al.
S. pimpinellifolium L.	*L. pimpinellifolium* (L.) Miller
S. lycopersicon L.	*L. esculentum* Miller
S. cheesmaniae (L. Riley) Fosberg	*L. cheesmaniae* L. Riley
S. galapagense S.C. Darwin & Peralta	Partly *L. chesmaniae* L. Riley

Table 2. Taxonomy of the genus *Solanum* sect. *Lycopersicoides*

1 Solanum agrimoniifolium (Dunal) J. F. Macbr. (subgroup. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon)
2 Solanum arcanum Peralta (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: = Solanum habrochaites S. Knapp & D. M. Spooner
3 Solanum caldasii Dunal (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Juglandifolia)
4 Solanum cheesmaniae (L. Riley) Fosberg (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: = Solanum ochranthum Dunal
5 Solanum chilense (Dunal) Reiche (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms:
6 Solanum chmielewskii (C.M. Rick et al.) D.M. Spooner et al. (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: (≡) Lycopersicon chilense Dunal
7 Solanum corneliomulleri J.F. Macbr. (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms:
8 Solanum galapagense S.C. Darwin & Peralta (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: (=) Lycopersicon cheesmaniae var. minor (Hook. f.) D.M. Porter (≡) Lycopersicon glandulosum C.H. Müll.
9 Solanum habrochaites S. Knapp & D.M. Spooner (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: (=) Lycopersicon agrimoniifolium Dunal (≡) Lycopersicon hirsutum Dunal (=) Lycopersicon hirsutum f. glabratum C.H. Müll. (=) Solanum agrimoniifolium (Dunal) J.F. Macbr.
10 Solanum huaylasense Peralta (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon)
11 Solanum juglandifolium Dunal (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Juglandifolia)
12 Solanum lycopersicoides Dunal (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Lycopersicoides)
13 Solanum lycopersicum L. (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon)
14 Solanum lycopersicum var. cerasiforme (Alef.) Fosberg (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms:

Solanum lycopersicum var. lycopersicum (subg. Potatoe sect. Petota subsect. Lycopersicon ser. Neolycopersicon) Synonyms: (≡) Lycopersicon esculentum Mill. (=) Lycopersicon esculentum var. commune L.H. Bailey (≡) Lycopersicon esculentum var. esculentum (=) Lycopersicon esculentum var. grandifolium L.H. Bailey (=) Lycopersicon esculentum f. pyriforme (Dunal) C.H. Müll. (=) Lycopersicon esculentum var. pyriforme (Dunal) Alef. (=) Lycopersicon esculentum var. validum L.H. Bailey (≡) Lycopersicon lycopersicum (L.) H. Karst (=) Lycopersicon lycopersicum var. pyriforme auct. (=) Lycopersicon pyriforme Dunal
16 *Solanum neorickii* D.M. Spooner et al. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (=) *Lycopersicon parviflorum* C.M. Rick et al.
17 *Solanum ochranthum* Dunal (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Juglandifolia*) Synonyms: (=) *Solanum caldasii* Dunal
18 *Solanum pennellii* Correll (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (≡) *Lycopersicon pennellii* (Correll) D'Arcy (≡) *Lycopersicon pennellii* var. *pennellii* (≡) *Lycopersicon pennellii* var. *puberulum* (Correll) D'Arcy (=) *Solanum pennellii* var. *elachistus* Martic. & Quezada (=) *Solanum pennellii* var. *pennellii* (=) *Solanum pennellii* var. *puberulum* Correll
19 *Solanum pennellii* var. *elachistus* Martic. & Quezada (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) = *Solanum pennellii* Correll
20 *Solanum pennellii* var. *pennellii* (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) = *Solanum pennellii* Correll
21 *Solanum pennellii* var. *puberulum* Correll (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) = *Solanum pennellii* Correll
22 *Solanum peruvianum* L. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (=) *Lycopersicon dentatum* Dunal (≡) *Lycopersicon peruvianum* (L.) Mill. (=) *Lycopersicon peruvianum* var. *dentatum* (Dunal) Dunal (≡) *Lycopersicon peruvianum* var. *peruvianum*
23 *Solanum pimpinellifolium* L. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (≡) *Lycopersicon esculentum* subsp. *pimpinellifolium* (L.) Brezhnev (≡) *Lycopersicon esculentum* var. *racemigerum* (Lange) Brezhnev (≡) *Lycopersicon pimpinellifolium* (L.) Mill. (=) *Lycopersicon racemigerum* Lange
24 *Solanum rickii* Correll (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Lycopersicoides*) = *Solanum sitiens* I.M. Johnst.
25 *Solanum* sect. *lycopersicon* hybr. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (=) *Lycopersicon* hybr. *Solanum* sect. *lycopersicon* spp. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Neolycopersicon*) Synonyms: (=) *Lycopersicon* spp
26 *Solanum sitiens* I.M. Johnst. (subg. *Potatoe* sect. *Petota* subsect. *Lycopersicon* ser. *Lycopersicoides* Synonyms: (=) *Solanum rickii* Correll

Sections of *Solanum*: *Solanum* section *Lycopersicon* (Solanaceae) includes the cultivated tomato (*S. lycopersicum*) and 12 additional wild relatives, endemic to western South America from Ecuador to Northern Bolivia and Chile, and with two endemic species in the Galápagos Islands; weedy escaped forms of *S. lycopersicum* are distributed worldwide. Two species in *Solanum*, section *Juglandifolia*, distributed in Colombia, Ecuador, and Peru, are sister to section *Lycopersicon*, and two species of *Solanum*, section *Lycopersicoides*, distributed in Southern Peru and Northern Chile, are sister to sections *Lycopersicon* and *Juglandifolia* (Peralta *et al.,* 2008). The *S. esculentum*-complex contains seven species that are easily crossed with cultivated tomato and these have served as a source of genetic variability for the improvement of tomato varieties (Rick, 1979).

BOTANICAL DESCRIPTION

Tomato is a perennial herbaceous plant but it is often grown as an annual crop even if biennial and perennial forms exist. The growth habit of the plant varies from indeterminate to determinate and may reach up to 3 metres (m) in height. The primary root may grow several metres in length. The stem is angular and covered by hairy and glandular trichomes that confer a characteristic smell. Leaves are alternately arranged on the stem with a 137.5° phyllotaxy. Leaves range in shape from lobed to compound, with segments arranged pinnately. Compound leaves are typically comprised of five to nine leaflets. Leaflets are petiolated and dentated. All leaves are covered by glandular, hairy trichomes. The tomato fruit is globular or ovoid. Botanically, the fruit exhibits all of the common characteristics of berries; a simple fleshy fruit that encloses its seed in the pulp. The outer skin is a thin and fleshy tissue that comprises the remainder of the fruit wall as well as the placenta. The colour of the fruit is derived from the cells within the fleshy tissue. Tomato fruits can be either bilocular or multilocular. Between 50 and 200 seeds are located inside the locular cavities and are enclosed in gelatinous membranes. On average, the seeds are small (5 x 4 x 2 mm) and lentil shaped.

The seed contains the embryo and the endosperm and is covered by a strong seed coat, called the testa. The development of the fruit takes seven to nine weeks after fertilisation (OECD, 2008). Tomato plants are generally much branched, spreading 60–180 cm and somewhat trailing when fruiting, but a few forms are compact and upright. Leaves are more or less hairy, strongly odorous, pinnately compound, and up to 45 cm long. The five-petaled flowers are yellow, 2 cm across, pendant, and clustered. Fruits are berries that vary in diameter from 1.5 to 7.5 cm or more. They are usually red, scarlet, or yellow, though green and purple varieties do exist, and they vary in shape from almost spherical to oval and elongate to pear-shaped. Each fruit contains at least two cells of small seeds surrounded by jellylike pulp (EEB, 2023). Tomato plants are vines, initially decumbent, typically growing 180 cm or more above the ground if supported, although erect bush varieties have been bred, generally 100 cm tall or shorter. Indeterminate types are "tender" perennials, dying annually in temperate climates (they are originally native to tropical highlands), although they can live up to three years in a greenhouse in some cases. Determinate types are annual in all climates. Tomato plants are dicots, and grow as a series of branching stems, with a terminal bud at the tip that does the actual growing. When the tip eventually stops growing, whether because of pruning or flowering, lateral buds take over and grow into other, fully functional, vines. Tomato vines are typically pubescent, meaning covered with fine short hairs. The hairs facilitate the vining process, turning into roots wherever the plant is in contact with the ground and moisture, especially if the vine's connection to its original root has been damaged or severed. Most tomato plants have compound leaves, and are called regular leaf (RL) plants, but some cultivars have simple leaves known as potato leaf (PL) style because of their resemblance to that particular relative. Of RL plants, there are variations, such as rugose leaves, which are deeply grooved, and variegated, angora leaves, which have additional colors where a genetic mutation causes chlorophyll to be excluded from some portions of the leaves. The leaves are 10–25 cm long, odd pinnate, with five to nine leaflets on petioles, each leaflet up to 8 cm long, with a serrated margin; both the stem and leaves are densely glandular-hairy. Their flowers, appearing on the apical meristem, have the anthers fused along the edges, forming a column surrounding the pistil's style. Flowers in domestic cultivars can be self-fertilizing. The flowers are 1–2 cm across, yellow, with five pointed lobes on the corolla; they are borne in a cyme of three to 12 together. Although in culinary terms, tomato is regarded as a vegetable, its fruit is classified botanically as a berry. As a true fruit, it develops from the ovary of the plant after fertilization, its flesh comprising the pericarp walls.


Plants

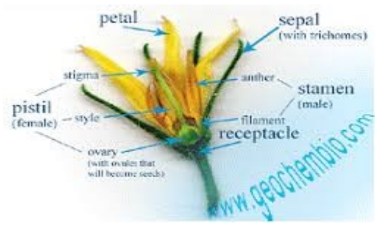

Plant with flowers


Inserted stigma, which is enclosed by the flower cone

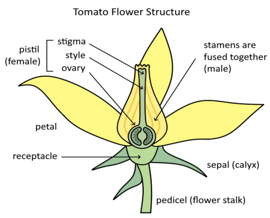

Protruding stigma (also called exserted stigma)


Inflorescence

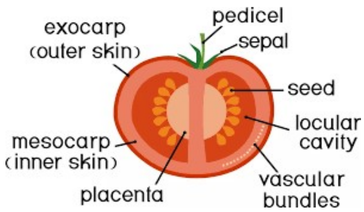

Tomato flower in full bloom, next to a young, green developing fruit



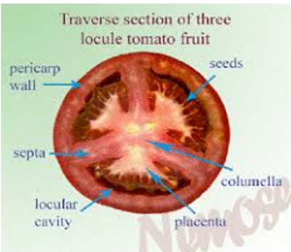
Parts of flower



Parts of flower



Parts of fruit



Parts of fruiit


Flowers and ripe fruit


Seeds

Fig. 6. Botanical Description of tomato

The fruit contains hollow spaces full of seeds and moisture, called locular cavities. These vary, among cultivated species, according to type. Some smaller varieties have two cavities, globe-shaped varieties typically have three to five, beefsteak tomatoes have a great number of smaller cavities, while paste tomatoes have very few, very small cavities (Wikipedia, 2023). Tomato's scientific name is *Solanum lycopersicum* and is a member of the *Solanaceae* family. This family also includes other commonly used vegetables like potatoes, peppers, and many others. It is a perennial plant, although most producers grow it as an annual. Tomato plant is a dicot and herbaceous plant. The plant forms a pile root that grows to a depth of up to 2 m. It develops vines that grow as branching stems. At the top, there is a terminal bud. When this bud stops developing further, the plant takes the sign to start growing peripheral buds and consequently new vines. Tomato leaves are usually compound; however, some varieties have simple leaves 10-25 cm long, pinnate with 5-7 leaflets. Both the vines and the leaves are covered with tiny hairs. Flowers are yellow with five lobes on the corolla. They are 1-2 cm diameter and grow on the apical meristem. Fruits are berries with small oval to round-shaped, flat, ochre-colored seeds (Wikifarmer, 2023). Tomato plants are vines, initially decumbent, typically growing six feet or more above the ground if supported, although erect bush varieties have been bred, generally three feet tall or shorter. It is a "tender" perennial, dying annually in temperate climates (to which it is not native). Tomato plants are dicots, and grow as a series of branching stems, with a terminal bud at the tip that does the actual growing. When that tip eventually stops growing, whether because of pruning or flowering, lateral buds take over and grow into other, fully functional, vines. Tomato plant vines are typically pubescent, covered with tiny hairs. These hairs facilitate the vining process, turning into roots wherever the plant is in contact with the ground and moisture, especially if there is some issue with the vine's contact to its original root. Tomato plants generally have compound leaves, known as Regular Leaf (RL) plants. Some cultivars, though, have simple leaves known as potato leaf style because of their resemblance to that close cousin. Of regular leaf varieties, there are variations, such as rugose leaves, which are deeply grooved, angora leaves, which are pubescent (hairy), and variegated, which have additional colors where a genetic flaw excludes chlorophyll from the leaves. Their flowers, appearing on the apical meristem, have the anthers fused along the edges, forming a column surrounded by the pistil's style. These tend to be self-fertilizing. This is because they are native to the Americas; *all* plants from the New World evolved without honeybees (which are native to the old world, only), and have other specific means of fertilization. Its fruit is classified, botanically, as a berry. As a true fruit, it develops from the ovary of the plant after fertilization, its flesh comprising the pericarp walls. The fruit contains hollow spaces full of seeds and moisture, called locular cavities. These vary, among cultivated species, according to type. Some smaller tomatoes have two cavities, globe-shaped typically have three to five, and beefsteak having a great number of smaller ones, while paste tomatoes have very few, very small cavities. The seeds need to come from a mature fruit, and be dried/fermented before germination (Fig. 6) (Bionity, 2023).

Flower Structure: Flowers are important for reproduction and the production of seeds. A tomato flower is sometimes referred to as a perfect flower because both male and female organs are located within the same flower (Fig. 7). The tomato flower consists of four main parts (Tomatosphere, 2023):

Sepal: This part of the flower, which is green in colour, is first visible when the bud forms. It protects the flower bud before it opens.

Petal: This is the part of the flower that attracts bumble bees. In tomato flowers, the petals are usually yellow in colour.

Stamen: This is the male part of the flower. It usually consists of the filament and an anther with pollen which is found at the top of the filament. The pollen contains the male genetic information. In tomato flowers, the stamens are fused into a tube-shaped structure. They are also yellow like the petals.

Pistil: This is the female part of the flower. It consists of the stigma, style, and ovary and is located at the centre of the flower, surrounded by the stamens. The female reproductive organ, the ovary, is located at the base of the pistil. The ovary contains the ovules. Once the ovules are fertilized, an embryo can develop and form seeds that will be found inside the tomato fruit

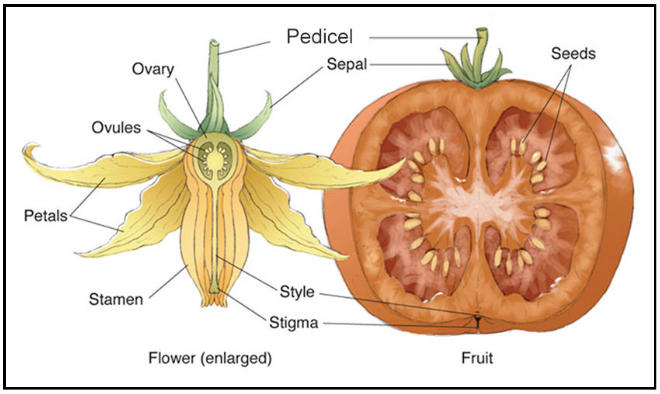


Fig. 7. Diagram of a tomato flower and its fruit. The ovary within the flower develops into a tomato fruit that we eat. The petals, stamens, and stigma dry up and fall off as the fruit matures

Floral biology: Although some tomato wild species of the genus *Solanum* are allogamous, all commercial tomato cultivars are considered to be mainly self-compatible and inbreeding, i.e. autogamous. Tomato flowers are perfect, regular and hypogynous and are borne on inflorescences that may be either determinate (cymose) or indeterminate (racemose), depending on the species. The flower is connected to the axis by a pedicel that includes the abscission point. The first flower appears when the plant has three leaves and, frequently, the first and the last bud of an inflorescence are aborted. The number of flowers produced by an inflorescence is dependent upon environmental factors. As flowers form sequentially, buds, flowers and fruits can co-exist in an inflorescence. The flowers are yellow and generally less than 2.5 cm in diameter when in full bloom. They possess four helically arranged whorls of organs; green sepals form the outer whorl or calyx, at least five yellow petals are present in the corolla, stamens alternate with petal position and are fused to form an anther cone and a whorl of two or more fused carpels form the pistil at the centre of the flower. The number of carpels found in the pistil varies between species and relates to the number of locules present in the resulting fruit (OECD, 2008).

Pollination: In the wild, original state, tomatoes required cross-pollination; they were much more self-incompatible than domestic cultivars. As a floral device to reduce selfing, the pistils of wild tomatoes extended farther out of the flower than today's cultivars. The stamens were, and remain, entirely within the closed corolla. As tomatoes were moved from their native areas, their traditional pollinators, (probably a species of halictid bee) did not move with them. The trait of self-fertility (or self-pollenizing) became an advantage and domestic cultivars of tomato have been selected to maximize this trait. That tomatoes pollinate themselves poorly without outside aid is clearly shown in greenhouse situations where pollination must be aided by artificial wind, vibration of the plants (one brand of vibrator is a wand called an "electric bee" that is used manually), or more often today, by cultured bumblebees. The anther of a tomato flower is shaped like a hollow tube, with the pollen produced within the structure rather than on the surface, as with most species. The pollen moves through pores in the anther, but very little pollen is shed without some kind of outside motion. The best source of outside motion is a sonicating bee such as a bumblebee or the original wild halictid pollinator. In an outside setting, wind or biological agents provide sufficient motion to produce commercially viable crops (Bionity, 2023). For some varieties, flowers have the style shorter than the tip of the anther cone, while for other varieties the style is longer than the anther cone. The stigma is receptive from one to two days before to four to eight days after its own flower releases pollen, thus cross-pollination is possible. The first meiosis during pollen production occurs when the anthers reach one-third of their final length. Anther dehiscence delivers thousands of pollen grains into the channel formed by the hairs. However, as anthers release pollen inwardly towards the style, vibration- assisted self-pollination is usual, especially in short-style varieties. In long-style varieties, the downward posture of the flower allows self-pollination by gravity. The anther cone releases pollen around the stigma at the slightest vibration. Wind and insects provide the vibrating action necessary for self-pollination under field conditions. Under greenhouse conditions, mechanical vibrating devices or insects are used (OECD, 2008). As is the case for most self-pollinating plants, the viability of exposed tomato pollen is limited. Pollen viability and the number of pollen grains are reduced by high temperatures above 32/26°C day/night. Natural cross-pollination rates among commercial varieties range from 0.07% to 12%. Accotto *et al*., 2005). The rate of crossing quickly decreases as the distance from the pollen source increases and little viable pollen is transferred beyond 30 m (~95 feet) from its source. Male sterility exists in tomato and, as this condition precludes self-fertilisation, such plants can be used to produce hybrid seed. Cross-pollination of male-sterile flowers is achieved by insect activity, rather than by wind or mechanical vibrators as employed for self-fertilisation (McGregor, 1976).

Fruit Development: For flowers to develop into the tomato fruit, two things need to happen in the flowers: pollination and fertilization.

Pollination: This is a process where the pollen, from anthers, is deposited onto the stigma. This can be done by the wind (wind pollination) or by bumble bees through buzz pollination. Buzz pollination occurs when a bee lands on a flower and vibrates its flight muscles. This movement can shake loose pollen from the flower. Some of these pollen grains may land in other flowers, resulting in pollination.

Fertilization: During this process, the male and the female gametes, from the pollen and ovule, combine. This is similar to when sperm and egg cells combine in animals. The two gametes come together in the ovary and develop into a seed, which contains the embryo, endosperm, and seed coat. Once the seeds are formed, the tomato life cycle can begin all over again (Tomatosphere, 2023). The tomato seed matures 35-50 days after pollination, during which seeds become germinable, desiccation tolerance is induced and water content decreases. Fruit is red and ripe by 60 days after pollination (OECD, 2008).

Reproduction: Tomato plants belong to the plant group known as flowering plants or angiosperms. The tomato plant reproduces sexually, meaning that it requires both female and male organs to produce seeds. Every tomato seed has a tiny tomato plant inside. When the conditions are just right, tomato seeds will germinate**.** As the seed germinates, the radicle or young root first appears and grows down into the ground. The cotyledons or seed leaves then appear and grow up towards the Sun and the young plant develops true leaves. As the plant matures, more leaves develop and flower buds form (Fig. 8).

On mature tomato plants, flowers develop and this is where sexual reproduction occurs (Tomatosphere, 2023).

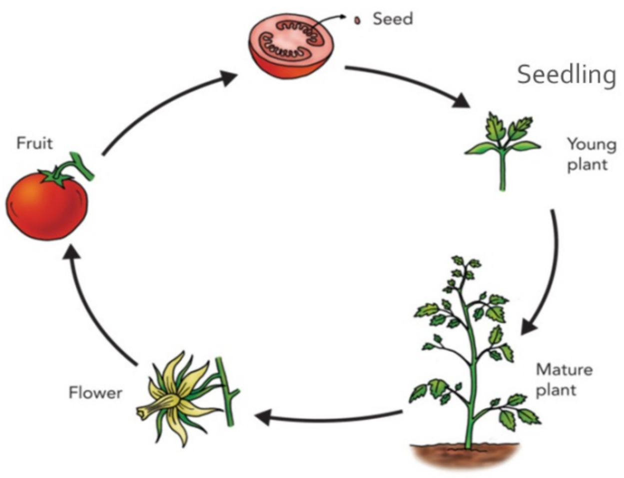


Fig. 8. Diagram of the tomato life cycle. The life cycle starts from seeds and as the plant grows and matures, flowers develop. After pollination and fertilization, fruits develop which contain seeds, allowing for the life cycle to start again

GENETICS AND CYTOGENETICS

Scientists are finding out more about which tomato genes are linked to characteristics like colour and size. This is because of progress in the study of genetics. They have also been able to create new tomato varieties using genetic engineering**.** This can be done in many ways. Usually scientists change genes so that the characteristics they want appear in the plant. In 1994, the 'FlavrSavr' tomato was the first genetically engineered tomato sold in stores. This tomato cultivar did not ripen as fast or soften as quickly as conventional tomatoes. This made it easier to pick and ship these tomatoes without damaging them. The 'FlavrSavr' did not make enough money in the end. It cost too much to grow and ship. There were also negative stories about it in the media, so it was no longer sold. Plant breeders are always working on ways to improve tomatoes. For instance, heirloom tomatoes often taste better than store-bought ones. In 2012, researchers identified a gene responsible for the taste of heirloom tomatoes. This gene was missing from tomatoes that were artificially selected to last longer. Hopefully, we will soon be able to create a long-lasting and super tasty tomato thanks to this discovery (Letstalkscience, 2021). More recently, due to advances in genomics, scientists are finding out more about which genes are responsible for a certain characteristics, such as the colour and size. Scientists have also been able to create new tomato varieties through genetic engineering. This can be done in many ways. But generally, the genes are changed so that the trait or characteristic that the scientists are looking for can be observed in the plant. One famous example of a genetically engineered tomato is the 'FlavrSavr', which became the first commercially available genetically engineered tomato in 1994. With genetic engineering this tomato cultivar did not ripen as fast or soften as quickly as a conventional tomato, making it easier to harvest and transport without damage. The 'FlavrSavr' tomato was ultimately not profitable because it was costly to produce and distribute. It also received negative media attention because it was a genetically engineered organism, which resulted in its removal from the market (Tomatosphere, 2023). Based on research from the Tomato Genome Consortium 2012, the three wild species most closely related to cultivated tomato include the red-fruited species *S. pimpinellifolium* and the orange-fruited species found on the Galapagos Islands, *S. galapagense* and *S. cheesmaniae* (Menda *et al*., 2013). Tomato and its wild relatives have 12 chromosomes (2n=2x=24). The 12 tomato chromosomes were first identified by Barton (1950). For all species: 2n = 2x = 24 *Solanum lycopersicum* L. *Solanum lycopersicum* L. can be hybridized with all other species of *Lycopersicon.* Hybridization leads to recombination, hence a source of genetic variability (Tanuja Buckseth, 2023). Tomato has a relatively small genome size (around 950 Mb). About 30% of the genome is composed of repetitive sequences which are mainly located in heterochromatin regions (Van der Hoeven *et al.,* 2002). An international consortium of researchers from 10 countries began sequencing the tomato genome in 2004. A pre-release version of the genome was made available in December 2009. The latest reference genome published in 2021 had 799 MB and encodes 34,384 (predicted) proteins, spread over 12 chromosomes (Wikipedia, 2023).

GENETIC DIVRSITY

Wild tomato varieties were small and mostly yellow, not red. We could say that they were similar to what we know today as cherry tomatoes. Nowadays, apart from different sizes, we can also find different colors of tomatoes varying from our familiar red, to pink, yellow, orange, purple, white and black (Wikifarmer, 2023) (Fig.9,10, 11, 12, 13). The majority of the known improved varieties are related to the original fruit domesticated in Mesoamerica more than 500 years ago. The most important changes introduced by the domestication process are: reduction of the gene pool, modification of the reproductive system and increase of fruit size. The gene pool characterising *Solanum lycopersicum* as a species has constantly been under human management. If this selection process diminishing genetic diversity continues, there is a risk of losing the genetic diversity that once gave rise to the original fruit (OECD, 2008). As such, the breeding possibilities offered by using the knowledge of wild relatives of cultivated tomato are very diverse. At present, some characteristics of agricultural importance of tomato have been adapted based on the gene diversity present in wild relatives (Sánchez-Peña *et al.,* 2004). As a result, diagnostic investigations and distribution studies of wild and weedy relatives present at the moment are a priority because of the high levels of genetic diversity they still preserve (Sim *et al*., 2012).

Two closely related, wild tomato-like nightshade species, *Solanum lycopersicoides* and *Solanum sitiens*, inhabit a small area within the Atacama Desert region of Peru and Chile. Each species possesses unique traits, including abiotic and biotic stress tolerances, and can be hybridized with cultivated tomato. Conservation and utilization of these tomato relatives would benefit from an understanding of genetic diversity and relationships within and between populations. As expected for self-incompatible species, populations of *S. lycopersicoides* and *S. sitiens* were relatively diverse, but contained less diversity than the wild tomato *Solanum chilense*, a related allogamous species native to this region. Populations of *S. lycopersicoides* were slightly more diverse than populations of *S. sitiens* according to SSRs, but the opposite trend was found with allozymes. A higher coefficient of inbreeding was noted in *S. sitiens*. A pattern of isolation by distance was evident in both species, consistent with the highly fragmented nature of the populations *in situ*. The populations of each taxon showed strong geographical structure, with evidence for three major groups, corresponding to the northern, central and southern elements of their respective distributions (Albrecht *et al*., 2010). We explored genetic variation by sequencing a selection of 84 tomato accessions and related wild species representative of the *Lycopersicon*, *Arcanum*, *Eriopersicon* and *Neolycopersicon* groups, which has yielded a huge amount of precious data on sequence diversity in the tomato clade. Three new reference genomes were reconstructed to support our comparative genome analyses.

Fig. 9. Genetic Variabilty for shape, size and color of tomato fruits

Fig. 10. Genetic Variabilty for shape, size and color of tomato fruits

Fig. 11. Genetic Variabilty for shape, size and color of tomato fruits

Fig. 12. A group of tomatoes with differing shapes, sizes and colours

Fig. 13. Genetic variability for flesh color

Comparative sequence alignment revealed group-, species- and accession-specific polymorphisms, explaining characteristic fruit traits and growth habits in the various cultivars. Using gene models from the annotated Heinz 1706 reference genome, we observed differences in the ratio between non-synonymous and synonymous SNPs (dN/dS) in fruit diversification and plant growth genes compared to a random set of genes, indicating positive selection and differences in selection pressure between crop accessions and wild species. In wild species, the number of single-nucleotide polymorphisms (SNPs) exceeds 10 million, i.e. 20-fold higher than found in most of the crop accessions, indicating dramatic genetic erosion of crop and heirloom tomatoes. In addition, the highest levels of heterozygosity were found for allogamous self-incompatible wild species, while facultative and autogamous self-compatible species display a lower heterozygosity level. Using whole-genome SNP information for maximum-likelihood analysis, we achieved complete tree resolution, whereas maximum-likelihood trees based on SNPs from ten fruit and growth genes show incomplete resolution for the crop accessions, partly due to the effect of heterozygous SNPs. Finally, results suggest that phylogenetic relationships are correlated with habitat, indicating the occurrence of geographical races within these groups, which is of practical importance for *Solanum* genome evolution studies (Aflitos *et al*., 2014).

Twenty five tomato (*Solanum lycopersicum* L.) genotypes were subjected to genetic diversity analysis using twenty SSR markers. Out of 20 markers used, 14 SSRs were polymorphic and a total numbers of 22 SSR alleles were generated by 14 SSR markers, out of which 19 were polymorphic and 3 were monomorphic, with an average of 1.57 alleles per locus. The range of amplified products was 100-400bp approximately. Jaccard's similarity coefficient varied from 0.65 between germplasm EC519821 and CO-3 to a maximum of 1.0 between genotypes EC519769 and DARL-66, with an average value of 0.83. Cluster analysis based on Jaccard's similarity coefficient using the unweighted pair-group method with arithmetic mean (UPGMA) revealed 2 distinct clusters, A and B, comprising 1 and 24 genotypes respectively and at 75 and 78 per cent similarity, respectively. The genotypes which showed similar morphological and genetic trends were grouped more or less together in both these cases were a few. Cluster A comprised most diverse germplasm (EC519821) belongs to *pimpinellifolium* wild species with similari- ty coefficient 0.65% and differentiated with other cultivated species. Cherry Tomato and Cherry-2 were trends in simi- lar cluster similar with approximately 96% similarity.SSR markers were able in in differentiating the genotypes based on morphologically and genotypically. However, the grouping of 25 genotypes were independently of geographic distribution.The genetic distance information found in this study might be helpful to breeder for planning among these genotypes (Ashish Kaushal *et al*., 2017). Cultivated tomato (*Solanum lycopersicum* L.) has undergone a reduction in its genetic base as a result of the processes of modern domestication and breeding, which has been extensively documented by molecular markers in different genotypes, both nationally and internationally. The aim of this study was to characterize agronomically, under greenhouse conditions, accessions of five wild relatives of the cultivated tomato for their incorporation into breeding programs of this vegetable. In addition, it is expected to reduce its vulnerability to climate change and adverse biotic and abiotic factors.

The species described were *Solanum pennellii* L., *Solanum pimpinellifollium* L., *Solanum peruvianum* L., *Solanum chilense* R. and *Solanum habrochaites* S. The accessions were evaluated under greenhouse conditions under a completely randomized experimental design with four replications. welve traits of agronomic interest were evaluated to describe the variation between the accessions of each one of the evaluated species, which were studied by analysis of variance and comparison of means. The results showed high significance among the accessions of each one of the evaluated species for all the traits. The above shows that there is a high potential in each of the accessions of the species studied to exploit them genetically in the improvement of the cultivated tomato (Flores-Hernández *et al*., 2017). The wild relatives of the cultivated tomato provide a great diversity in mating systems and reproductive biology (Rick 1988). Several species, including cultivated tomato, *S. lycopersicum* (formerly *Lycopersicon esculentum*), are autogamous, *i.e.* self-compatible (SC) and normally self- pollinating (Table 3). They bear small- to modest-sized flowers, on mostly simple and short inflorescences; their corolla segments are relatively pale colored, the anthers short, and the stigma surface does not protrude (exsert) far beyond the tip of the anther cone, all traits that promote self-pollination and discourage outcrossing.

Table 3. Mating systems in cultivated tomto and its wild relatives

Mating system	Compatibility	Species	Synonyms
Autogamous	All SC	*S. lycopersicum*	*L. esculentum*
		S. cheesmaniae	*L. cheesmanii*
		S. galapagense	*L. cheesmanii* f. *minor*
		S. neorickii	*L. parviflorum*
Facultative	All SC	*S. pimpinellifolium*	*L. pimpinellifolium*
		S. chmielewskii	*L. chmielewskii*
Facultative	Mostly SI, some SC populations	*S. peruvianum*	*L. peruvianum*
		S. arcanum	*L. peruvianum*
		S. habrochaites	*L. hirsutum*
		S. pennellii	*L. pennellii*
Allogamous	All SI	*S. chilense*	*L. chilense*
		S. corneliomulleri	*L. peruvianum*
		S. huaylasense	*L. peruvianum*
		S. juglandifolium	–
		S. lycopersicoides	–
		S. ochranthum	–
		S. sitiens	*S. rickii*

SC self-compatible, SI self-incompatible

Sixty tomato genotypes were evaluated to study the genetic diversity. Multivariate analysis following D2 statistics revealed that considerable genetic diversity exists within and among the eight clusters. Genetic diversity studies for twenty attributes with respect to growth, earliness, yield and ToLCV resistance for sixty genotypes of tomato revealed that average fruit weight contributed maximum towards divergence followed by number of fruits per plant and number of locules per fruit. The sixty genotypes were grouped into eight clusters, among which cluster VII was the largest group comprising of 20 genotypes, followed by cluster II with thirteen genotypes, cluster I with ten genotypes, cluster V with eight genotypes, cluster VIII with six genotypes and cluster III, IV and VI were monotypic or solitary. The intra cluster distance varied from 0 to 382.80 and cluster VIII recorded highest intra cluster distance (382.80) followed by cluster V (271.17), cluster VII (215.88), cluster II (154.35) and cluster I (98.04).. Highest inter cluster distance (1296.49) was between cluster V and VIII, while the lowest (130.38) was between cluster I and VI. The inter cluster distance was minimum between cluster I and VI indicating narrow genetic diversity, where as the inter cluster distance was maximum between V and VIII followed by II and VIII (852.84) indicating wider genetic diversity between these groups. Selection of parents from these diverse clusters for hybridization would help in achieving novel recombinants (Ravindra Babu *et al.,* 2018). A wide selection of tomato (*Solanum lycopersicum* L.) genotypes with diverse origin and breeding history (14 modern varieties, 71 landraces and 22 commercial hybrids) has been initially genotyped with a selection of highly informative simple sequence repeat (SSR) markers and two SCAR markers originally developed for resistance against two main fungal tomato diseases. Our data revealed a high level of genetic diversity across the selection, with an average number of alleles per locus (NA) equal to 9.6, and the average polymorphism information content (PIC) equal to 0.74. Further, the selected SSRs have been verified as highly polymorphic and able to discriminate different patterns within our collection, amplifying a total of 56 alleles (Gonias *et al.,* 2019).

It is generally believed that domestication and breeding of plants has led to genetic erosion, including loss of nutritional value and resistances to diseases, especially in tomato. We studied the diversity dynamics of greenhouse tomato varieties in NW Europe, especially The Netherlands, over the last seven decades. According to the used SNP array, the genetic diversity was indeed very low during the

1960s, but is now eight times higher when compared to that dip. The pressure since the 1970s to apply less pesticides led to the introgression of many disease resistances from wild relatives, representing the first boost of genetic diversity. In Europe a second boost ensued, largely driven by German popular media who named poor tasting tomatoes *Wasserbomben* (water bombs). The subsequent collapse of Dutch tomato exports to Germany fueled breeding for fruit flavor, further increasing diversity since the 1990s. The increased diversity in composition of aroma volatiles observed starting from 1990s may reflect the efforts of breeders to improve fruit quality. Specific groups of aroma compounds showed different quantitative trend over the decades studied. Our study provides compelling evidence that breeding has increased the diversity of tomato varieties considerably since the 1970s (Schouten *et al*., 2019). In this study, 55 tomato genotypes from different geographical regions were evaluated with ISSR markers (Inter Simple Sequence Repeats). The seven ISSR primers originated 63 amplified bands, of which 90.48% were polymorphic. The cluster analysis based on the Nei-Li similarity coefficient using the average genetic clustering method (UPGMA) revealed the conformation of five clusters at a level of similarity of 72%. The ISSR technique did not discriminate tomato genotypes according to the species or region of provenance. The STRUCTURE analysis and the dendrogram did not reveal a genetic structure in the population evaluated. The genotypes of the species of *S. pimpinellifolium*, *S. l. cerasiforme*, *S. lycopersicum* and *S. peruvianum* were found consistently grouped, showing a close genetic relationship among them. A high genetic variation among the individuals within each of the groups formed was suggested by the AMOVA. The ISSR markers were effective in assessing the genetic diversity and structure of populations of tomato genotypes. The high genetic variability found in this study indicates the valuable genetic potential present in tomato germplasm, especially of wild species, which could be used for future breeding programs of the species (Vargas *et al*., 2020). In the present study, 22 tomato (Solanum lycopersicum L.) genotypes were evaluated to study the extent of genetic diversity through 20 quantitative traits. The genotypes were categorized into 5 distinct clusters using D2 statistics. Cluster I had the maximum number of genotypes (8), followed by clusters IV and V (4 genotypes each) and clusters II and III (3 genotypes each). Highest intra cluster was recorded in cluster III, while the inter cluster distance was maximum between cluster V and cluster IV (53,348.13) indicating the presence of wide range of variability among genotypes of the cluster. Fruit yield per plant contributed the maximum (64.50 %) to the genetic diversity, followed by fruit volume, number of fruits per plant, average fruit weight, number of locules per fruit, fruit diameter and fruit length. The cluster III recorded highest mean for the characters like fruit length (4.28 cm), fruit diameter (5.12 cm), fruit volume (115.58 cc), average fruit weight (114.20 g), pericarp thickness (6.70 mm) and fruit yield per plant (1.64 kg) (Kiran et al., 2020). A collection of 163 accessions, including *Solanum pimpinellifolium*, *Solanum lycopersicum* var. *cerasiforme* and *Solanum lycopersicum* var. *lycopersicum*, was selected to represent the genetic and morphological variability of tomato at its centers of origin and domestication: Andean regions of Peru and Ecuador and Mesoamerica. The collection has been morphologically characterized showing diversity for fruit, flower and vegetative traits. We have not only identified known QTLs and genes, but also new regions associated with traits such as fruit color, number of flowers per inflorescence or inflorescence architecture. To speed up and facilitate the use of this information, F2 populations were constructed by crossing the whole collection with three different parents. This F2 collection is useful for testing SNPs identified by GWAs, selection sweeps or any other candidate gene. All these resources together make this collection a good candidate for genetic studies (Mata-Nicolás *et al.,* 2020). In this study morphological characterization was carried out on 55 different tomato accessions collected from provinces in the Aegean Region. Morphological data was analyzed by cluster and principal component analyses. The first six components with co-efficient values greater than 1.0 together explained 79.59% of the total variance present in the data set. Scores of the first three components which accounted for 57.12% of the total variation were highly correlated to characters related fruit shoulder shape, width of pedicel scar, shape of pistil scar, ribbing at calyx end, fruit width, number of locules, intensity of greenback (green shoulder), exterior color of mature fruit, flesh color of perikarp, fruit length, fruit weight, plant growth type, presence of green (shoulder) trips on the fruit and blossom end shape. A wide variation was observed among the populations. As a result of the clustering analysis, 2 main groups and 6 subgroups were formed. There were 2 subgroups in the first main group and 4 subgroups in the second main group and tomato accessions were identified according to this analysis (Binbir *et al*., 2020).

Tomato flavor is largely determined by the balance of sugars, acids and volatile compounds. Several genes controlling the levels of these metabolites in tomato fruit have been cloned, including LIN5, ALMT9, AAT1, CXE1, and LoxC. The aim of this study was to identify any association of these genes with trait variation and to describe the genetic diversity at these loci in the red-fruited tomato clade comprised of the wild ancestor *Solanum pimpinellifolium*, the semi-domesticated species *Solanum lycopersicum cerasiforme* and early domesticated *Solanum lycopersicum*. High genetic diversity was observed at these five loci, including novel haplotypes that could be incorporated into breeding programs to improve fruit quality of modern tomatoes (Lara Pereira *et al*., 2021). The present study was conducted for the phenotypic characterization of twenty exotic tomato genotypes along with two locally grown cultivars in semi-arid subtropical climate. Data were collected for morphological, fruit quality and fruit yield traits. A significant ($p<0.05$) phenotypic variation was observed for all the studied traits. Maximum yield was obtained from "Rober" i.e., 1508.31 g per plant. The maximum shelf life was observed in the Cromco, with the least weight loss (2.45%) and loss in the firmness of fruit (22.61%) in 4 days. Correlation analyses revealed a strong genetic association among morphological and yield related traits. High estimates of the heritability (ranged from 79.77% to 95.01% for different traits), along with a high genetic advance (up to 34%) showed the potential usefulness of these traits and genotypes to develop breeding programs to improve the tomato yield and fruit quality (Zeshan Hassan *et al.,* 2021). Fruit flavor is defined as the perception of the food by the olfactory and gustatory systems, and is one of the main determinants of fruit quality. Tomato flavor is largely determined by the balance of sugars, acids and volatile compounds. Several genes controlling the levels of these metabolites in tomato fruit have been cloned, including *LIN5*, *ALMT9*, *AAT1*, *CXE1*, and *LoxC*. The aim of this study was to identify any association of these genes with trait variation and to describe the genetic diversity at these loci in the red-fruited tomato clade comprised of the wild ancestor *Solanum pimpinellifolium*, the semi-domesticated species *Solanum lycopersicum cerasiforme* and early domesticated *Solanum lycopersicum*. High genetic diversity was observed at these five loci, including novel haplotypes that could be incorporated into breeding programs to improve fruit quality of modern tomatoes. Using newly available high-quality genome assemblies, we assayed each gene for potential functional causative polymorphisms and resolved a duplication at the *LoxC* locus found in several wild and semi-domesticated accessions which caused lower accumulation of lipid derived volatiles. In addition, we explored gene expression of the five genes in nine phylogenetically diverse tomato accessions. In general, the expression patterns of these genes increased during fruit ripening but diverged between accessions without clear relationship between expression and metabolite levels (Lara Pereira *et al.,* 2021).

Germplasm characterization is an effective way to unravel morphological diversity in vegetative and fruit characters. This study was conducted to determine diversity in tomato (*Solanum* spp.) fruits using eight conventional descriptors (CD) and 47 Tomato Analyzer (TA) software descriptors related to fruit morphometry. Phenotyping was carried out on 50 accessions selected for morphological variation from the National Genetic Resources Bank. Variability was detected for fruit characteristics with CD and quantified by TA. Fruit shape was the main character used for visual grouping of accessions into ten different varietal groupings of shape: Circular (26 %), Flattened (20 %), Oboval (20 %), Pyriform (12 %), Elliptical (6 %), Chordate (6

%), Cylindrical (4 %), Oblong (2 %), Oval (2 %) and Flattened (2 %) and from very small to large size. Significant variation was observed for fruit weight (3.75-217.44 g), equatorial diameter (17.85-75.55 mm), polar diameter (17.57-96.76 mm), circumference (61.86-312.64 mm) and area (249.56-6367.57 mm). Principal component analysis contributed to the total variation and the first two explained 30.02 % of the variation where fruit shape index and proximal/distal end shape of the fruit showed high contribution in the variation of the first component. There was a strong positive correlation between fruit shape and fruit size, while negative correlations were between fruit shape index, internal eccentricity and proximal end shape (Quispe-Choque *et al*., 2022).

BREEDING

Germplasm: Bai and Lindhout (2007) reported on the genetic diversity collections in the Germplasm banks viz., Germplasm Resources Information Network, Tomato Genetics Resource Center, Davis, California, Botanical and Experimental Garden and Solanaceae Genome Network. The contribution of Mesoamerica and the Andes area to the world not only apply to the domesticated fruit, but also include the amount of genetic information sheltered in the country's rural zones where domesticated crops, landraces and wild relatives co-exist.

Breeding: Variation in tomatoes has resulted from natural means and with the help of humans, through artificial selection (also known as selective breeding). Tomatoes have been bred by humans for many characteristics such as yield, shelf-life, pest resistance, taste, fruit size and shape, colour, seed size and weight, and nutritional quality. By the end of the 19th century, tomatoes were bred by many farmers and gardeners. They were able to keep the seeds from the tomatoes they produced and plant them from year to year to grow more plants. This practice of seed saving has led to what we now call Heirloom tomato varieties**.** These plants produce tomatoes with amazing variations in shape, size, and colour. Heirloom varieties are true breeding and therefore keep the same traits as the parent plants. With the start of commercial breeding in the beginning of the 20th century, hybrid tomato varieties appeared. Hybrid tomatoes are the offspring from the cross-breeding of two different tomato varieties. Hybrids often have the best traits from each of the parent plants, which make them highly desired. Commercial farmers, growing hybrid tomatoes, are discouraged from using their own seeds and are required to purchase seeds from a seed company. This is to make sure that the tomato quality is consistent for grocery stores and food processors (Tomatosphere, 2023). The Tomato Genetic Resource Center, Germplasm Resources Information Network, AVRDC, and numerous seed banks around the world store seed representing genetic variations of value to modern agriculture. These seed stocks are available for legitimate breeding and research efforts. While individual breeding efforts can produce useful results, the bulk of tomato breeding work is at universities and major agriculture-related corporations. These efforts have resulted in significant regionally adapted breeding lines and hybrids, such as the Mountain series from North Carolina. Corporations including Heinz, Monsanto, BHNSeed, and Bejoseed have breeding programs that attempt to improve production, size, shape, color, flavor, disease tolerance, pest tolerance, nutritional value, and numerous other traits (Wikipedia, 2023).

Tomato (*Solanum lycopersicon*) has undergone intensive breeding for decades. Breeding and selection have been based on traits desirable for the processing or the fresh market. The processed market often involves growing tomatoes in open fields requiring simultaneous fruit ripening and machinery harvesting. In addition, traits such as high sugar and total soluble solids content are required for the processed market. In the case of fresh market tomatoes, traits such as large fruit size, uniform fruit shape, uniform colour, long shelf life and fruit firmness are important (Rick, 1978). Over the last century, breeding and selection of tomatoes have resulted in numerous hybrids and cultivars. During the 1950s, hybrid tomatoes were developed to obtain higher yields and improve fruit quality and disease resistance. Hybrids accounted for more than 50% of production both in protected cultivation and in the open area. The production of hybrid tomatoes requires emasculation of flowers prior to cross-pollination. However, 40 male-sterile mutants have been identified in tomato (Stevens and Rick, 1986) that can facilitate hybrid seed production. Marker-assisted selection is now a major instrument in conventional breeding. Markers linked to characteristics/traits of interest for breeding have been identified and developed for tomato. *In vitro* culture and somatic hybridisation were also used in tomato breeding. Although all forms of *S. esculentum* var. *esculentum* are self-compatible and mainly inbreeding, the wild cherry tomato types have a tendency to outcross due to exsertion of the stigma beyond the anther cone at anthesis (Rick, 1950).

High fruit total soluble solids (TSS) in tomatoes is a key component of fruit quality. TSS is a proxy for sugar content. Higher TSS increases consumer fruit likeability. Genetic, molecular and biochemical characterisation of wild tomato species with high fruit TSS (10-15% compared with 4-6% in cultivars) can be exploited in breeding programmes (Beckles et al., 2012). Nevertheless, wild species with high TSS have low yield. An example of breeding a variety with both high TSS and yield is *Solara*. Decades of breeding have resulted in a loss in genetic diversity. The challenges for breeders today include reintroducing the complex trait of flavour and breeding for novel disease resistance genes, that on average are effective for five years until the pathogen overcomes resistance (Menda *et al.,* 2013). The wild species are the most valuable source of such traits.

Breeding methods

Introduction: Seeds of improved varieties are introduced from one ecological area into another and evaluated Either used directly for large scale cultivation or crossed with indigenous cultivars to develop better varieties Several introductions like Sioux, Roma, Marglobe, Best of All and La Bonita became popular with farmers for large scale cultivation (Tanuja Buckseth, 2023).

Mass selection: Mass selection is basically a breeding method. Through this method, tomato fruit quality and yield can be increased. In this method, phenotypically better plants are selected and they grow in bulk. And again, phenotypically better plants are grown, and this is repeated again and again till the desired characters are developed. In this way, quality and fruit yield are increased. In this way, desire characters are combined and developed new varieties (Iqbal et al., 2019). Mainly Individual Plant Selection is used where chance variants, superior types from a mixed homozygous population in tomato is selected Effective method to make maximum use of germplasm (Tanuja Buckseth, 2023).

Hybridization: Hybridization mostly done in the cross-pollinated crops. But it is also done in some cross-pollinated crops just like tomato. And introduce many other tomato varieties. But it needs some hard work and pollination is done by human intervention in tomato. Tomato is self-pollinated crop while tomato varieties can be developed through hybridization. First of all, inbred lives are produced by self-crossing. And then cross the inbred lives of different varieties and grow plants and the plants are selected which have traits which are required. Sometimes undesirable traits are also transfer with the desirable traits then these undesirable traits are eliminated by backcrossing method although this is time-consuming (Iqbal *et al.,* 2019).

Varieties Developed:	Parents Used
Pusa Ruby:	Sioux X Improved Meeruti,
Pusa Early Dwarf:	Improved Meeruti X Red Cloud,
HS -101:	Selection 2-3 X Exotic Cultivar,
HS-102:	S 12 X Pusa Early Dwarf
Punjab Chhuhara:	Punjab Tropic X EC 55055
Marglobe :	Marvel X Globe
Sel.1:	Pusa Early Dwarf X HS 101
Sel.2:	(HS 101 X Punjab Tropic) X (H-14 X Punjab Tropic)
H-24 (Hisar Anmol):	*L. esculentum* X *L. hirsutum* f. *glabratum* and
Pusa Red Plum:	*L. esculentum* X *L. pimpinellifolium*

(Tanuja Buckseth, 2023).

Back Cross Method: Successfully used in breeding varieties resistant to diseases such as Fusarium, Verticilium, Stemphylium and Root Knot Nematode. Transgression of the desired genes from the wild related *Lycopersicon* species into the cultivated species (*S.lycopersicum*). Transfer leaf curl virus resistance from *Lycopersicon hirsutum* f. *glabratum* to cultivated tomato (Tanuja Buckseth, 2023).

Pedigree method: In the pedigree method, the controlled cross between the plants is carried. And by individual plant selection, the desirable trait is obtained, and inbred lines are prepared by growing them in lines and rows through successive generations. This method is beneficial and reliable to develop new varieties of the tomato crop. This method develops new cultivars faster than mass selection. This is done by selecting individual plants in the early generation (Iqbal *et al.,* 2019). Most common breeding method in tomato**.** Single plant selection is initiated in F2 and continued through successive generations till pure lines are obtained (generally till F6) Selection pressure is on heritable characters (Tanuja Buckseth, 2023).

Single Seed Descent Method**:** Modified pedigree method. Now encouraged to be used by tomato breeder as generation can be advanced in the off-season. Allows the maintenance of broad genetic base in advanced generation (Tanuja Buckseth, 2023).

Genetic mutation**:** Mutation has played an important role in tomato genetics. Spontaneous mutation is an important source of genetic variation. One spontaneous mutation, providing plants with determinate growth habit, has revolutionised tomato production. Other mutations have been identified that confer male sterility or cause aneuploidy. In addition, the use of artificial mutagenesis has led to the production of around 1 200 mutant lines that can be used for scientific research. Around 1 000 mutant loci have been characterised, 400 of which have been assigned to specific chromosomes. Monogenic mutants, markers, disease resistance genes and other types of stocks are maintained by the Tomato Genetic Resources Center. The Solanaceae Genome network (SGN) maintains 13 000 M2 characterised families derived from tomato mutagenesis (OECD, 2008).

Introgression lines**:** Introgression lines that contain chromosome segments from alien relatives in the background of the cultivated tomato greatly increase the genetic diversity available for improvement. They can also be advantageous for QTL mapping and gene identification studies (Gur and Zamir, 2004) and have been used to develop numerous high-density molecular linkage maps, genomic databases and DNA libraries.

Molecular breeding: There are some methods that used to modify our crop plants are: Molecular markers, Quantitative traits locus, Genetic engineering, polymerase chain reaction. These methods have been for many purposes such as estimation of genetic variability, identification of genotype and determination of the sequences of useful genes. These techniques are also helpful for the estimation of genetic distances between population and breeding materials. Molecular markers technique is one of the important methods to modify our crop plant. It is widely used for breeding tomato. Many genes used that confer resistance to crucial categories of tomato pathogens and these are very perfectly mapped and cloned. Maps are developed that allowed for "pyramiding" resistance genes in tomato through the mass assisted selection. This method is need to the capacity for high-throughput analyses at low quality and low cost. For practical uses, it is most crucial method. This technique is also helpful and available to handle the efficiently large amounts of material at very low costs. If we want to get the specific needs for modification the molecular applications in practical plant breeding. Molecular marker techniques for plant breeding are useful in order to increase their availability to breeding programs. Isozyme molecular maker is one of the best marker types to breeding of tomato. It is helpful for study the genetic variation between cultivated and wild species of tomatoes. Isozyme used for molecular linkage mapping and breeding purposes. Rare Isozyme alleles provide more perfect results for resistance purposes. Specific region of the tomato genome and uni-gene sequence are needed to association of the Isozyme marker (Iqbal *et al*., 2019).

Marker-assisted selection: The relationship between phenotype and the markers is only possible through the development of markers/ linkage maps. The using of marker-assisted selection is one of the known methodsof finding the chromosomal segment which having marker and the identification of the traits. CAPS (cleaved amplified polymorphic sequence) is the other form of the simple PCR marker. Here another marker named SCAR (sequence characterized amplified region) which is used as the DNA marker in case of breeding of crop plants. This is very efficient to enhance breeding programmes. One of the best examples of plant breeding that may change from the selection of phenotype towards the selection of genes with the help of marker-assisted selection (Iqbal *et al*., 2019).

Important hybrids available in tomato in Public Sector: IARI (New Delhi) KT-4, Pusa Hybrid-1, Pusa Hybrid-2, Pusa Hybrid-4, Pusa Divya IIHR (Bangalore) Arka Vardhan, Arka Vishal, Arka Shreshtha, Arka Abhijit GBPUAT (Pantnagar) Pant Hybrid-1, Pant Hybrid-2 NDUAT (Faizabad) NDTH-1, NDTH-2, NDTH-6 UHF (Solan) Solan Shagun, Solan Garima, Solan Sindhur (Tanuja Buckseth, 2023).

Important hybrids available in tomato in Private Sector: Ankur ARTH-3, ARTH-4 Century Century-12, Maitri, Rishi**,** Indo American Karnataka, Mangla, Vaishali, Rupali, Naveen, Rashmi, Sheetal Mahyco MTH-1, MTH-2, MTH-6, MTH-15, MTH-16, S-28, Sonali Namdhari NS-386, NS-815, Summerset, Cross B, Gotya Nath NA-501, NA-601 Nijjar NH-15, NH-25, NH-38 Pioneer LIHB-230 Sandoz Learika, Rasika, Avinash 11 Sungrow Arjuna, Krishna, Bhim Sutton Sutton Grom, Prolific Beejo Sheetal BSS-39, BSS-20, BSS-40, BSS-90 (Tanuja Buckseth, 2023).

Disease resistant varieties: Early Selection,KT-10, KT-15, Flat Large Red, Red Cherry, Pant Bahar, BSS-20, Roma, Meenakshi, Roza, HS-110, H-24, H-36, Hissar Gaurav, Hissar Anmol, Pearl Harbour, Red Currant, H-22, H-25, Solan Vajar, Kalyanpur No.1, Ottawa 30, Ottawa 31, Red Cherry, Early Market (Tanuja Buckseth, 2023).

Genetically modified tomato: The first commercially available genetically modified food was a tomato called Flavr Savr, which was engineered to have a longer shelf life. However, it is no longer commercially available. Scientists are continuing to develop tomatoes with new traits not found in natural crops, such as increased resistance to pests or environmental stresses or better flavour (Wikipedia, 2023). The reasons for creating genetically modified tomatoes were because of the potential advantages of genetically modified foods. In the present age, vegetables and fruits are not commercially cultivated merely for the local market, but are intended for shipping over long distances to nation-wide and international markets. Ripe fruits and vegetables have soft skins and can easily be damaged during handling and processing. They can also rot in the time taken to ship and get them to the shops. In order to ensure easier handling and longer shelf life, vegetables and fruits are harvested when still green, and then artificially ripened with ethylene gas. The drawback in this is that the artificially ripened fruit and vegetables do not have the tasty flavor of their naturally ripened counterparts (Tanuja Buckseth, 2023).

Bt genes transgenic tomato – first developed and tested by Monsanto in 1989: Transgenics with insecticidal properties, like delta- endotoxin of *Bacillus thuringiensis* (Bt) protienase inhibitors etc. In India, gene cry AC was introduced into tomato to produce transgenic resistant to *Helicoverpa armigera*. In India, Parker, Bonus, VFN-8 possesses resistance against *H. armigera.* Bt genes (Gui ai, G42Aa (cry AB)) are being utilized to develop transgenics with resistance to fruit borer Coat protein(cp) from the viral genome TMV(Tomato mosaic virus) and CMV(cucumber mosaic virus) (Tanuja Buckseth, 2023).

Classficatins of tomato varieties based on types of plants (Bonnie Plants, 2023; VF, 2023; Wikifarmer, 2023):

Tomato varieties can be divided into three major categories based on their growth:

- **Determinate** varieties (including bush varieties) reach a certain plant height and then stop growing i.e., there are varieties whose shoots interrupt their lateral growth after they give a certain number of flowers (depending on the variety). The majority of their fruit matures within a month or two and appears at the ends of the branches. These are popular with gardeners who like to can, make sauce, or have another reason for wanting most of their tomatoes at once. It might even be that you'd prefer to harvest early and leave late summer for a long vacation. Determinate Tomatoes grow in bushes and usually have 60-90cm in height. Determinate types flower and give fruits all at once.
- **Indeterminate** varieties continue to grow and produce tomatoes all along the stems throughout the growing season. Indeterminate plants need extra-tall supports of at least 5 feet. Because indeterminate varieties throw out so many shoots, gardeners often prune them for optimum-sized fruit or train them on a very tall trellis. However, if you don't prune, no harm done! You may have seen photos of 10- or 15-foot tomato vines. These are definitely indeterminate types. Indeterminate varieties are vining varieties and are 1.5-3m tall., Indeterminate varieties continue to grow and give fruits at a different time, but produce larger crops over a longer period.
- **Semi-Determinate** varieties whose shoots stop growing when they are at an advanced stage. This category is particularly preferred for outdoor cultivation.

Most gardeners grow both types, determinate for large harvests for canning and freezing and indeterminate to get fruit for salads and sandwiches throughout the growing season.

Classficatins of tomato varieties based on fruit shape (VF, 2023):

- **Beefsteak Tomatoes:** Beefsteak - these tomatoes are large (around 10 cm in diameter) and meaty with thinner skin. This type is often used for sandwiches. Their color may be red, yellow or sometimes pink. Usually, they are indeterminate.
- **Plum Tomatoes:** Plum tomatoes (also called Roma (Paste) tomatoes, including some pear tomatoes) - they don't have much juice, but they're high in solids, so it is usually used for tomato sauces or (like name sais) Italian recipes. They are 7–9 cm long and typically determinate.
- **Cherry Tomatoes:** Cherry tomatoes - they have the same size as wild tomatoes (1-2cm). They are round and have a sweet taste. It grow in large clusters, even when the summer is cool. Most of them are indeterminate. Cherry tomatoes are ideal for growing in pots.
- **Grape Tomatoes:** Grape tomatoes - this type similar to plum tomatoes, but smaller than that kind. They grow in large clusters, like Cherry tomatoes. Most of them are indeterminate.
- **Campari Tomatoes:** Campari tomatoes - they are specific because of their sweetness. Their size is between cherry and plum tomatoes. They are juicy with low acidity and high sugar level.
- **Tomberry Tomatoes:** Tomberries - this is the small type with only 5 mm in diameter. It is marked as " *the smallest tomatoes in the world*".
- **Oxheart Tomatoes:** Oxheart tomatoes - their fruit is about 10-15cm in shape of a heart, so in size, they are similar to beefsteaks. The fruit is in pale pink color.
- **Pear Tomatoes:** Pear tomatoes - they got their name because of their shape (pear). They belong to smaller tomatoes.
- **Slicing Tomatoes:** "Slicing" (sometimes called "globe") tomatoes - it's mostly commercial type. They can even be in the diameter 5–6 cm.
- **Salad Tomatoes:** Salad tomatoes (also called Standard tomatoes) - they are 5-7.5cm in diameter. Because they are ideal for sandwiches, they have more varieties than other types.

Classficatins of tomato varieties based on the color of fruit (Woodward, 2021; VF, 2023):

Tomatoes are not just red, they can be almost white or green, maroon, indigo, purple, brown, yellow, orange and red (or combinations of these). Their colour is determined by a combination of skin colour and flesh colour. Skins can be yellow or colourless, while the flesh can be all the colours:

- **Red:** The classic scarlet red tomatoes have red flesh with yellow skin over the top. The red pigment is derived from the phytochemical antioxidant lycopene, and during ripening there is a 500-fold increase may be paler in hot weather. Red tomatoes contain large amounts of lycopene and lesser amounts of beta-carotene. They have usual, rich tomato flavor.
- **Pink:** These tomatoes have red flesh with white skin. There are fewer pink tomatoes because white skin is a recessive characteristic. Although pink is the description used, the colour often ranges through different shades of pink to crimson. These tomatoes are high in the antioxidant lycopene when ripe, and they also contain beta-carotene. These varieties are with a similar flavor to red tomatoes.
- **Orange:** These vary from pale yellow-orange to butternut pumpkin orange. They have less lycopene than other tomatoes but are high in beta-carotene and also contain prolycopene. There are also some orange tomatoes that are orange because of a different form of lycopene, known as cis-lycopene. This lycopene is 8 times more absorbable than the lycopene (it's a trans-lycopene) that makes red tomatoes red. They are sweet.
- **Yellow:** Tomatoes with clear skins range from bright lemon yellow all the way through to pale ivory, while yellow tomatoes with yellow skins can be soft to butter yellow. When cut, the flesh is often paler in colour than the skin. Many yellow tomatoes with either colourless or yellow skin become more orange as they ripen. Yellow tomatoes have less lycopene than red varieties, but they have other carotenoids such as delta-carotene and lutein. Yellow Tomato Varieties have a less marked flavor than the red tomatoes.
- **White:** Some tomatoes are so pale that they seem to be white, especially when not fully ripe. The flesh is almost white, and the skin is clear. They turn pale yellow when completely ripe. These tomatoes are generally delicate and mild in flavour. Their flavor is not rich, because they are low in acid, like yellow types.
- **Green:** Tomatoes with green flesh when ripe can have either yellow or clear skin. Green tomatoes with yellow skin will usually turn a rich yellow when ripe, but when cut the flesh is disconcertingly bright green. Those with clear skins will remain green when ripe; as the colour change indicating ripeness is very subtle, the fruits need to be gently squeezed in order to detect the slight 'give' of a ripe fruit. Green in tomatoes comes from chlorophyll. Green Tomato Varieties have strong flavor but not strong as the flavor of red type.
- **Purple and Brown:** These tomatoes have a green flesh gene, which prevents the chlorophyll breakdown that would usually happen in ripening tomatoes. This results in the formation of a brown compound known as pheophytin. When this compound combines with the pink or red of lycopene, you get a brown- or purple-coloured tomato, depending on the skin colour. The combination of lycopene, pheophytin, less beta-carotene and some chlorophyll provides a range of colours. When these tomatoes have clear skin, the colour looks purple; when the skin is yellow, the colour is perceived as maroon/brown. Flesh colour is substantially purple/brown with a greenish pigment, especially in the gel that surrounds the seeds. Many of these tomatoes confusingly have 'black' in their names, when they are really not at all black, either in the skin or flesh. Purple Tomato Varieties have strong, but, some say, smoky flavor.

- **Blue/black/indigo**: These tomatoes started with Indigo Rose, which gets its indigo/black/ blue colour from anthocyanin in the skin. Since the development of this tomato in 2011, many other blue/black tomatoes have been bred by crossing with either this tomato or varieties that were derived from the first cross. The area of blue/indigo skin is determined by how much sunlight hits the tomato as it develops. Usually the anthocyanin is only in the skin, but sometimes it can occur in the flesh just below the skin. The flesh can be green, yellow, pink, orange or red. Anthocyanin is essentially tasteless, so it doesn't add to the flavour profile.
- **Stripes, blushing and swirls:** Some tomatoes feature combinations of colours. Stripes generally occur only on the skin, while blushing and swirls can be seen both on the skin and in the flesh. The classic Tigerella and Green Zebra are two of the first striped varieties. Tomatoes with yellow flesh and red blushing and swirls have been around for a while, but modern breeding programs have seen many more combinations of all colours becoming available in the level of lycopene within fruits.

Other tomato varieties:

- ***Heirloom tomato type*:** Now is the most popular Heirloom tomato type (especially in organic gardening) which can be found in different colors - from common red to white and purple. Besides productivity, it is resistant to many diseases and self-pollinator, as well. This type is not a regular hybrid but have been developed over many years through open-pollination. (Hybrids are produced by force cross-pollination between two different types.) (VF, 2023).
- ***Hybrid types*:** Hybrid types are tougher, but Heirloom tomatoes have more flavor. When gardeners save their own seeds for the next year, they usually plant heirloom, because the next year it will be an identical plant like year before; Hybrid's seeds will not give the same plant every year, but plant with some random combination of traits or even plant could be more likely to one parent used for combining when hybrid was made. (Hybrids are produced by force cross-pollination between two different types) (VF, 2023).

USES

Tomatoes are considered a fruit or vegetable depending on context. According to *Encyclopedia Britannica*, tomatoes are a fruit labeled in grocery stores as a vegetable due to their taste and culinary purposes. Botanically, a tomato is a fruit—a berry, consisting of the ovary, together with its seeds, of a flowering plant. However, the tomato is considered a "culinary vegetable" because it has a much lower sugar content than culinary fruits; because it is more savoury (umami) than sweet, it is typically served as part of a salad or main course of a meal, rather than as a dessert. Tomatoes are not the only food source with this ambiguity; bell peppers, cucumbers, green beans, aubergines/eggplants, avocados, and squashes of all kinds (such as courgettes/zucchini and pumpkins) are all botanically fruit, yet cooked as vegetables (Wikipedia, 2023). Tomatoes are a significant source of umami flavor. They are consumed in diverse ways: raw or cooked, and in many dishes, sauces, salads, and drinks. While tomatoes are fruits—botanically classified as berries—they are commonly used culinarily as a vegetable ingredient or side dish (Wikipedia, 2023; Tomatosphere, 2023). The Aztecs raised several varieties of tomato, with red tomatoes called *xictomatl* and green tomatoes called *tomatl* (tomatillo). Bernardino de Sahagún reported seeing a great variety of tomatoes in the Aztec market at Tenochtitlán (Mexico City): "large tomatoes, small tomatoes, leaf tomatoes, sweet tomatoes, large serpent tomatoes, nipple-shaped tomatoes", and tomatoes of all colors from the brightest red to the deepest yellow. Bernardino de Sahagún mentioned Aztecs cooking various sauces, some with and without tomatoes of different sizes, serving them in city markets: "foods sauces, hot sauces; fried [food], olla-cooked [food], juices, sauces of juices, shredded [food] with chile, with tomatoes, with smoked chile, with hot chile, with yellow chile, with mild red chile sauce, yellow chile sauce, hot chile sauce, with "bird excrement" sauce, sauce of smoked chile, heated [sauces], bean sauce; [he sells] toasted beans, cooked beans, mushroom sauce, sauce of small squash, sauce of large tomatoes, sauce of ordinary tomatoes, sauce of various kinds of sour herbs, avocado sauce" (Wikipedia, 2023). Uses of tomatoes include (Bionity, 2023) Tomato paste, Tomato purée, Tomato pie, Gazpacho (Andalusian cuisine), Ketchup, Pa amb tomàquet (Catalan cuisine), Pizza and Tomato sauce (common in Italian cuisine). Tomato juice is often canned and sold as a beverage. Unripe green tomatoes can also be used to make salsa, be breaded and fried, or pickled. Tomatoes are commonly used in a variety of dishes, including sauces, soups, and salads, and can also be eaten raw or cooked. They are a popular ingredient in many cuisines, including Italian, Mexican, and American (Priyanka, 2022). Tomato, *Solanum lycopersicum*, plants which give red fruit. In use is also name *Lycopersicon esculentum.* Although it's botanically a fruit, culinary it is vegetable, because it is not sweet. Tomato is used in many different ways in the kitchen, raw or cooked. It is probably derived in Central and South America. The plant is annual and usually is 1-3m high. Fruit is a berry which develops from the ovary of the plant. Thanks to greenhouses, we eat it during the whole year (VF, 2023).

NUTRITIONAL VALUE

The fruit contains a large quantity of water, vitamins and minerals, low amounts of proteins and fats, and some carbohydrates. It also contains carotenes, such as lycopene (which gives the fruit its predominantly red colour) and *beta*-Carotene (which gives the fruit its orange colour). Modern tomato cultivars produce fruits that contain up to 3% sugar of fresh fruit weight. It also contains tomatine, an alkaloid with fungicidal properties. The concentration of tomatine decreases as the fruit matures and tomatine concentration contributes to determining the taxonomy of the species. (OECD, 2008). Tomato fruits are high in vitamins and minerals, including vitamin C, potassium, and lycopene, a powerful antioxidant (Priyanka, 2022). Tomatoes are the major dietary source of the antioxidant lycopene, which has been linked to many health benefits, including reduced risk of heart disease and cancer. They are a great source of vitamin C, potassium, folate, and vitamin K. The water content of tomatoes is around 95%. The other 5% consists mainly of carbohydrates and fiber. Here are the nutrients in a small (100-gram) raw tomato. Calories: 18, Water**:** 95%, Protein**:** 0.9 g, Carbs**:** 3.9 g, Sugar: 2.6 g, Fiber**:** 1.2 g, and Fat: 0.2 g. Tomatoes are a good source of several vitamins and minerals (Bjarnadottir, 2023).

Tomatoes are a good source of several important nutrients (Priyanka, 2022) including:

- **Vitamin C:** Tomatoes are a good source of vitamin C, which is an important nutrient that helps to support the immune system and protect against free radicals. One medium tomato contains about 17.6 milligrams of vitamin C, which is about 20% of the recommended daily intake.
- **Potassium:** Tomatoes are a good source of potassium, a mineral that helps to regulate heart function and maintain proper electrolyte balance. One medium tomato contains about 237 milligrams of potassium, which is about 5% of the recommended daily intake.
- **Lycopene:** Tomatoes are an excellent source of lycopene, a powerful antioxidant that gives tomatoes their bright red color. Lycopene has been linked to a number of potential health benefits, including a reduced risk of heart disease and certain types of cancer.
- **Vitamin E:** Tomatoes are a good source of vitamin E, an important nutrient that helps to protect against free radicals and support the immune system. One medium tomato contains about 0.6 milligrams of vitamin E, which is about 3% of the recommended daily intake.
- **Vitamin K:** Tomatoes are a good source of vitamin K, a nutrient that is important for proper blood clotting and bone health. One medium tomato contains about 22.7 micrograms of

vitamin K, which is about 20% of the recommended daily intake.

- **Calcium:** Tomatoes are a good source of calcium, a mineral that is important for maintaining strong bones and teeth. One medium tomato contains about 10 milligrams of calcium, which is about 1% of the recommended daily intake.
- **Other vitamins and minerals:** Tomatoes are also a good source of other vitamins and minerals, including niacin, folate, and magnesium.

HEALTH BENEFITS

Tomatoes are a nutritious and versatile food that can be enjoyed in many different ways. Here are some potential benefits of including tomatoes in your diet (Priyanka, 2022):

- **Rich in nutrients:** Tomatoes are a good source of several important nutrients, including vitamin C, potassium, and lycopene. They also contain small amounts of other vitamins and minerals, including vitamin E, vitamin K, and calcium.
- **Low in calories:** Tomatoes are low in calories, making them a good choice for people trying to watch their weight. One medium tomato contains only about 22 calories.
- **High in antioxidants:** Tomatoes contain a variety of antioxidants, including lycopene, which is a powerful antioxidant that gives tomatoes their bright red color. These antioxidants may help to protect against chronic diseases such as heart disease and cancer.
- **May help to lower blood pressure:** Some research suggests that the potassium found in tomatoes may help to lower blood pressure. High blood pressure is a major risk factor for heart disease and stroke.
- **May support eye health:** The vitamin A and vitamin C found in tomatoes may help to support eye health. Vitamin A is important for maintaining healthy vision, and vitamin C is important for maintaining healthy skin and connective tissue.
- **May help to reduce inflammation:** Tomatoes contain a compound called chlorogenic acid, which may help to reduce inflammation in the body. Chronic inflammation has been linked to a number of diseases, including heart disease and cancer.
- **Versatile and delicious:** Tomatoes can be enjoyed in many different ways and are a key ingredient in a wide variety of dishes. They can be eaten raw, cooked, or used in sauces and other types of cuisine.

Consumption of tomatoes and tomato-based products has been linked to improved skin health and a lower risk of heart disease and cancer (Bjarnadottir, 2023):

- Heart disease — including heart attacks and strokes — is the world's most common cause of death. A study in middle-aged men linked low blood levels of lycopene and beta-carotene to increased risk of heart attacks and strokes. Increasing evidence from clinical trials suggests that supplementing with lycopene may help lower LDL (bad) cholesterol. Clinical studies of tomato products indicate benefits against inflammation and markers of oxidative stress. They also show a protective effect on the inner layer of blood vessels and may decrease your risk of blood clotting.
- Cancer is the uncontrolled growth of abnormal cells that spread beyond their normal boundaries, often invading other parts of the body. Observational studies have noted links between tomatoes — and tomato products — and fewer incidences of prostate, lung, and stomach cancers. While the high lycopene content is believed responsible, high-quality human research needed to confirm the cause of these benefits. A study in women shows that high concentrations of carotenoids — found in high amounts in tomatoes — may protect against breast cancer.
- Tomatoes are considered beneficial for skin health. Tomato-based foods rich in lycopene and other plant compounds may protect against sunburn. According to one study, people who ingested 1.3 ounces (40 grams) of tomato paste — providing 16 mg of lycopene — with olive oil every day for 10 weeks experienced 40% fewer sunburns.

Tomatoes are now eaten freely throughout the world, and their consumption is believed to benefit the heart among other things. Lycopene, one of nature's most powerful antioxidants, is present in tomatoes, and, especially when tomatoes are cooked, has been found beneficial in preventing prostate cancer. However, other research contradicts this claim. Tomato extract branded as Lycomato is now also being promoted for treatment of high blood pressure (Bionity, 2023).

OTHER INFORMATION

- The town of Buñol, Spain, annually celebrates La Tomatina, a festival centered on an enormous tomato fight. Tomatoes are also a popular "non-lethal" throwing weapon in mass protests; and there is a common tradition of throwing rotten tomatoes at bad performers on a stage, although this tradition is more symbolic today (Bionity, 2023).
- Tomato is widely consumed worldwide. It is a popular species preferred in gastronomy for its characteristic flavour. It is used in several traditional dishes because of its compatibility with other food ingredients and high nutritional value (OECD, 2008).
- With the help of advances in modern technology, tomato can now be cultivated in both tropical and temperate zones in the open field, in home gardens, in small-scale agricultural patches, or as large-scale urban market production or agro-industry. It can be found in traditional farming systems (shifting cultivation) as well as in modern and intensive systems using acclimatised greenhouses, plastic cover nurseries, hydroponics and fertigation. This vegetable species is adapted to grow under different environmental and cultural conditions (OECD, 2008).
- Through pruning, shoots appearing in leaf axils are removed to create a plant architecture which facilitates management. The advantages of pruning are: stimulation of plant development, more efficient phytosanitary control and achievement of higher quantitative and qualitative yield. Pruning of leaves is necessary for phytosanitary control, and a vegetative balance and generative control. Plants may be supported by a trellis, e.g. 2-metre posts (sunk to 50 cm) positioned at regular intervals of 3-5 metre support cotton threads or galvanised metal wire to lift and support the plant and facilitate access for crop management and pest control (OECD, 2008).
- The level of maturity at which fruits are harvested depends on the final production goal. The harvest interval may continue up to seven months (OECD, 2008).

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