Malus domestica (Suckow) Borkh

MONOGRAPH

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TABLE OF CONTENTS

INTRODUCTION

The cultivated apple (***Malus domestica)*** stands as one of the ,ost significant fruit crops in global agriculture, not only for its economic value but also for its ecological adaptability and cultural symbolism. As a member of the Rosaceae family, ***Malus domestica (Suckow) Borkh*** has evolved through a complex history of hybridization, especially from its primary ancestor *Malus sieversii,* native to central Asia and its integration with *Malus sylvestris* in Europe. This rich evolutionary background, combined with centuries of selective human breeding has resulted in over 7,500 different cultivars grown around the world today.

This monograph explores the apple from scientific angles, beginning with its taxonomic classification and ecological distribution, then into its biological life cycle, reproduction, and responses to environmental factors. Propagation methods, orchard management practices, and the species profound commercial importance will also be discussed and the apple's nutritional, medicinal, and cultural uses highlight its importance not only in diets but in the contexts of health and tradition. Through this deep analysis, ***Malus domestica (Suckow) Bork*** *was revealed* as a remarkable crossing of nature, agriculture, and humans.

1 ECOLOGY

1.1 DISTRIBUTIONAL CONTEXT

1.1.1 Affinities

The taxonomy of a plant is divided into several parts,

Table 1

Taxonomy of *Malus domestica (Suckow) Bork*

Kingdom	Plantae
Phylum	Angiosperms or Streptophyta
Class	Eudicots or Magnioliopsida or Equisetopsida
Order	Rosales
Family	Rosaceae
Genus	*Malus*
Species	*Malus domestica*

As shown in table 1, above there is an order to taxonomy starting with the highest division The **Kingdom** : a level that groups all forms of life with similarities. The kingdom **Plantae**, includes all plants, which are multicellular (have more than 2 cells), and eukaryotic (plants who have a nucleus). (*Raven 2019; Campbell 2020)*

Secondly comes the **phylum**, which is a broad taxonomic group, inside of which lies the **Angiosperms** (flowering plants) produce seeds with a fruit, and Streptophyta includes all land plants and some green algae. (*Judd 2016; Simpson 2019*)

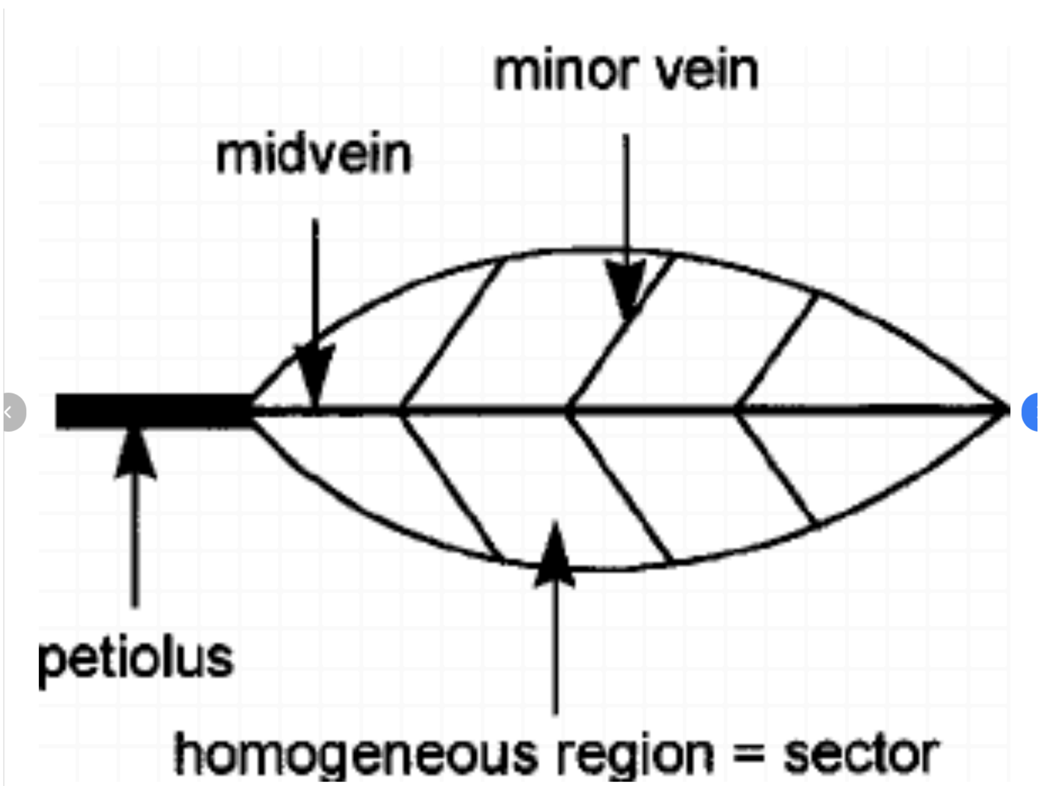
Next is the class. **Class** group organisms share more specific features, **Eudicots** are plants with two embryonic leaves; flower parts occur in multiples of four or five as you can see in Figure 1, below and display net like venation in their leaves as in Figure 2 (*Steven 2001; Campbell et al, 2020*).

Figure 1:

Flower of the *Malus domestica (Suckow) Borkh* (OECD 2019)

Figure 2:

Diagram showing the venation of a typical apple leaf (Magal, C)



An **order** is a group of related families. In this case the *Malus domestica (Suckow) Borkh*is placed in the order **Rosales** which are plants with similar floral structures such as fused stipules and compound leaves. (*USDA 2023*)

The **family** are groups that share close evolutionary relationships. The **rosaceae** family is diverse, including fruiting plants (apples, cherries) and ornamental species (roses). Members usually have flowers with five petals and fleshy fruits. (*Raven 2019; Campbell 2020)*

The **genus** organizes species that share even closer similarities. In this case ***Malus*** groups trees and shrubs known for their apple-like fruits. (*Janick 2005; USDA 2023)*

Lastly comes the **species**, this one is the most specific classification, referring to organisms that can interbreed and produce good offspring. ***Malus domestica (Suckow) Borkh***is the common/cultivated apple which is planted and bred for its sweet edible fruits. (*Janick 2005; USDA 2023)*

The cultivated apple (*Malus domestica*) demonstrates several affinities due to its hybrid origins and history. Genetic studies indicate that the apple comes from the species *Malus sieversii* which is native to Asia.With other contributions from species like *Malus sylvestris* this hybrid plus centuries of human selection resulted in the diverse variations of the apple we see today, optimizing the sweetness, firmness and storability. These traits highlight the impact of both natural evolution and human influence on the apple (Migicovsky and Myles, 2021).

Chemically, the *Malus domestica (Suckow) Borkh is known* for its polyphenolic compounds(in the apple peel). Compounds like chlorogenic acid, catechins and phlorizin helped towards the apples antioxidant properties. These antioxidants offer health benefits such as reducing inflammation and protection against cardiovascular diseases. However it showcases different variations across different apple cultivars. For example wild apples show higher concentrations of these beneficial compounds compared to their domesticated versions which reflect the trade offs made during the breeding and creation of new offsprings (Cendrowski, Jakubowska, & Przybył, 2024).

Ecologically the *Malus domestica (Suckow) Borkh is an important* part of agriculture throughout the world. It blooms in different and various climates which makes it one of the most widely cultivated fruit trees in the world. Its adaptability and nutritional value help to its popularity and importance in the agricultural economy. The high antioxidant capacity of apples underscores their role as functional foods, which are not only consumed for nutrition but also for their potential health benefiting properties (Cendrowski, 2024).

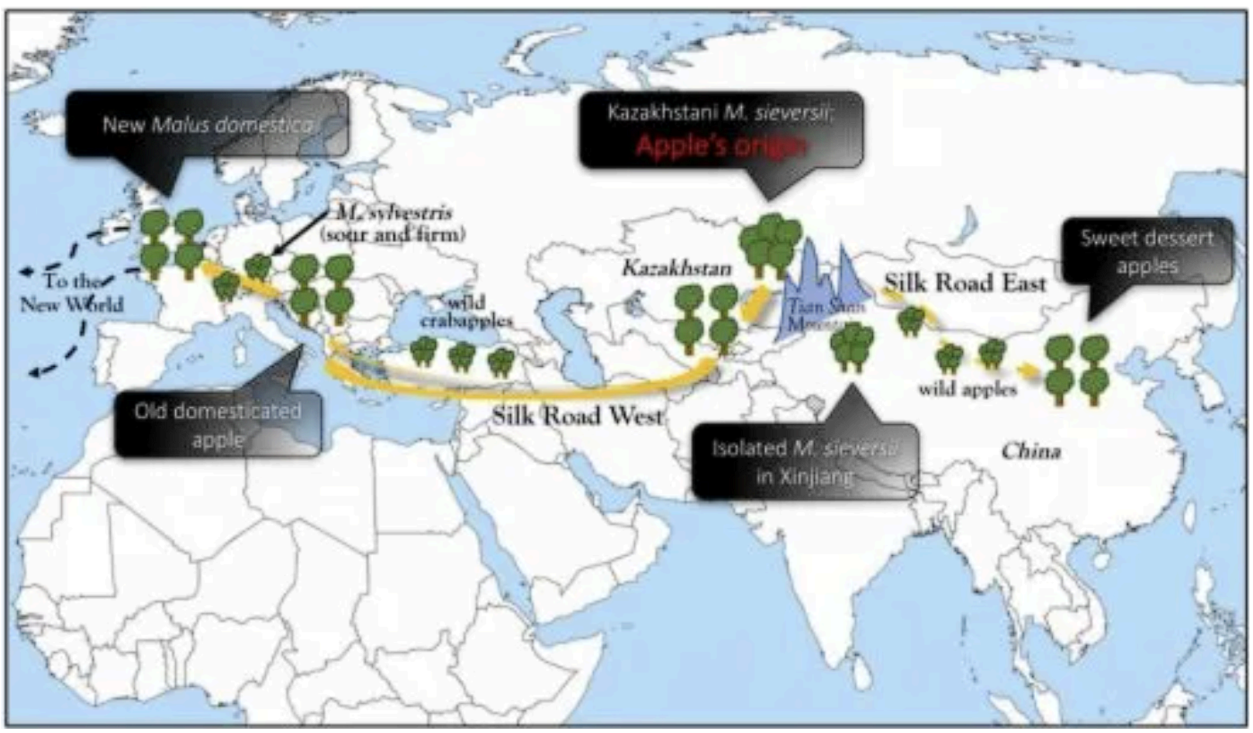
Lastly, domestication has significantly altered the phenotypic traits of *Malus domestica.* All of the breeding that has brought us to the common day apple have been features that were calculated efforts to enhance the fruit size, sweetness and extended shelf life which makes them better than their wild ancestors and progenitors. While cultivated apples have some ties with their ancestors (genetic ties) selective breeding has modified most of the traits to human preference which illustrates clearly the importance of human intervention in natural selection (Migicovsky & Myles, 2021).

1.1.2 Fossil Record and Origin:

*Malus domestica (Suckow) Borkh*originates from the apple species *Malus sieversii*. This species is native to the TIan Shan Mountains in Kazakhstan (Daley, 2017). This ancestor provides characteristics such as a bigger size that made it an early option for early domestication. Some evidence suggests the domestication process began over 4000 years ago; (Schmitz & Bai, 2017).

Figure 3:

Historical map showing the spread of apples from Kazakhstan along the Silk Road (Rathi, A)



Apples spread towards the west by trade routes such as the Silk Road. As the traders carried seeds and fruits the *Malus sieversii* hybridized with local apple species (like with the *Malus sylvestris* known as the European crabapple). This hybridization process introduced new traits to the apple such as firmness and acidity that contributed to the apple's evolution into the one many people enjoy (Daley, 2017).

Some genomic studies have related 46% of the modern apple genome comes from the *Malus sieversii,* 21% from the *Malus sylvestris* and 33% from others. This complex genetic soup is the result from the spread of apples along trade routes, where they cross breed by human intervention with other wild apple species and with the help of selective breeding for specific traits. (Schmitz & Bai, 2017; Daley, 2017)

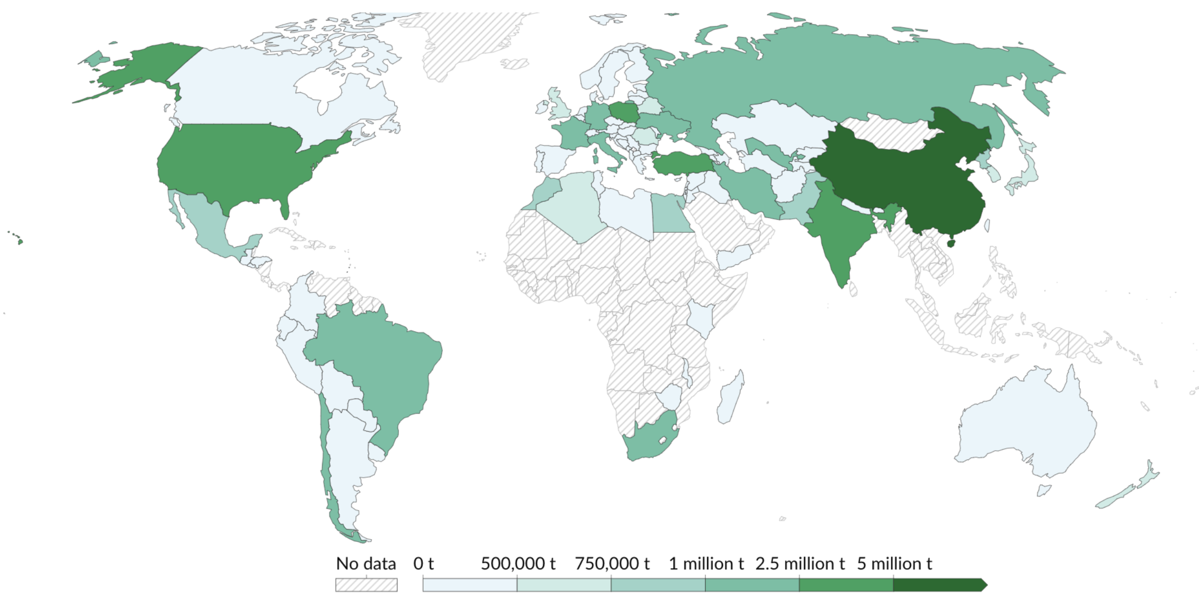
Over time, human cultivation and selective breeding provided an augmentation of fruit size, sweetness and texture. Today there are around 7,500 apple varieties cultivated worldwide, each bred for a different purpose (eating, baking, producing cider). However, the domestic apple continues to evolve as breeders seek to improve them against disease resistance and larger sizes (Schmitz & Bai, 2017).

1.1.3 Present distribution

The domesticated apple is cultivated across temperate regions around the world. It is mostly visible in North America, Europe and Asia where the climate provides necessary conditions such as cold winters from dormancy and mild summers for growth. Some producers include the United States, New Zealand, Poland and China. These regions have established agricultural systems to support large scale apple cultivation. (Encyclopaedia Britannica, 2024; BMC Plant Biology, 2016.)

Figure 4:

A world map highlighting major apple-producing countries (Our World in Data)



1.2 ENVIRONMENTAL FACTORS IN DISTRIBUTION

1.2.1 Elevation and Climate

The apple usually thrives in elevations from lowlands to approximately 2,500 meters above sea level(depending on the region). Throughout history the apple has been growing in seasonal areas with some climate requirements (Canadian Food Inspection Agency, 2013.; Kew Science, n.d.)

1.2.1.1 Climate Requirements

1.2.1.1.1 Temperature

Apples require a temperate climate with cold winters, as chilling hours (typically between 1,000 and 1,500 hours below 7°C) for dormancy and ensuring flowering and fruit development (Canadian Food Inspection Agency, 2013.).

1.2.1.1.2 Precipitation:

While apple trees prefer well-distributed rainfall of 600–1,200 mm annually, excessive moisture can lead to fungal infestations. Irrigation is key in drier regions (Kew Science, n.d.).

1.2.1.1.3 Altitudinal Influence

Elevations with moderate temperature swings and good drainage are perfect. In mountainous regions, apple trees are commonly cultivated in well-ventilated valleys or terraced orchards (BMC Plant Biology, n.d.).

1.2.2.1 Rainfall, potential evapotranspiration and water deficits

In regions like the loess plateau, where annual rainfall is limited (from 450 to 500mm), high evapotranspiration (ET) leads to soil moisture deficits. These negatively affect apple productions. To find this EP the Penman-Monteith method is used to apply an estimate on ET (Li, 2023).

Research on high density apple orchards highlight how limited irrigation reduces the water on the stems potential, impacting fruit size and production amount. Adjusting irrigation to replace 50 to 100% of the ET mitigates this impact. The outcomes depend on the crop load and variety (Neilsen, 2016).

Some studies on drought tolerant *Malus domestica (Suckow) Borkh*demonstrated that transcription factors like MdHB-7 play crucial roles in regulating water stress responses, offering potential frenetic improvements in water-use efficiency (Li, 2023).

In Mediterranean climates, implementing reduced irrigation strategies for cider apple cultivars such as Dabinett and Gold Russe has proven effective in preserving both fruit production and quality while it avoids water stress. This approach highlights the effectiveness of using plant-based irrigation scheduling to optimize water use and support orchard sustainability (Miles, 2022).

1.2.2.2 Temperature regime

The most optimal base temperature for apple tree growth is from 2.6 degrees celsius to 5.0 degrees celsius. Flowering typically requires a cumulative heat sum of 203 till 300 degree days depending on the variety (Kalvane, 2021).

Long term observations in Europe indicate that climate warming has shifted the flowering phase earlier over the decades. This phenomenon has been attributed to higher average temperature during spring season which affects the phenological (growth) stages of *Malus domestica (Suckow) Borkh*(Kalvane, 2021).

Extreme temperatures such as frost or heatwaves present challenges to the *Malus domestica.* Meanwhile moderate winters provide sufficient chilling to break dormancy and ensure a proper development. Also Extreme summer heat reduces fruit quality and production (yield). Orchards in regions with temperatures that vary often apply strategies to mitigate this effects, for instance the select regionally adapted cultivars and improve orchard microclimates (Tumanov, 2005; Kalvane, 2021).

1.2.2.3 Geology and soils

For optimal growth, yield and sustainability key factors such as soil texture, depth, drainage and fertility is needed.

1.2.2.4 Soil type and texture

Apple trees perform the best in fertile and well drained soils. They can tolerate a wide range of different types of soil but thrive in those that are not sandy or clay heavy. Loamy soils provide an ideal balance of water retention and drainage which is crucial for root health (Masats, J. (2024).).

Figure 5:

Picture that shows the difference between, sandy,clay and loamy soil (Kartik Jadav)

1.2.2.5 Soil depth and drainage

Apple trees require soils with a minimum depth of 1.5 meters to allow a deep root penetration. Also proper drainage is crucial to prevent waterlogging, which can lead to root disease and a decrease in nutrient absorption. Planting on slopes or by raising the beds the *Malus domestica (Suckow) Borkh*is planted improves drainage (Robert F. Polomski, Greg Reighard., 2000)

1.2.2.6 Geological Influence

Volcanic regions, for example, are often associated with fertile Andosols which is a soil rich in essential minerals. In contrast, sedimentary regions contribute to nutrient rich soils but need to be more carefully managed to improve drainage properties (Masats, J. (2024).).

1.2.2.7 Soil management practices

To sustain a healthy soil there are several strategies to sustain it such as mulching and planting cover crops to improve soil structure, conserve moisture and microbial activity, creating a favorable environment for apple tree roots (Dr. Diane Doud Miller, Ohio State University, 2019).

1.2.3 Toposequences

1.2.3.1 Soil variation through different slopes

Upper slopes generally have better drainage, which prevents root rot, however this can also lead to water stress in drier periods. In contrast, lower slopes often accumulate more moisture and fertility promoting better growth but potentially risking the *Malus domestica (Suckow) Borkh*into diseases due to high humidity (Ma, Qiao, & Yang, 2021).

1.2.3.2 Vegetation and growth patterns

Apple trees on lower slopes may experience enhanced growth but are more susceptible to fungal diseases. On upper slopes apples were smallest but also more disease resistant (Pustokhina & Gorbatova, 2021).

1.2.3.3 Altitude and fruit quality

Higher altitudes tend to produce apples with more acidic tastes due to the colder temperatures and slower fruit development. On the other hand, lower altitudes have bright sweeter flavors due to warmer temperatures that lead to faster ripening and lower acid content (Ma, Qiao, & Yang, 2021).

1.2.3.4 Microclimates

Topo Sequences create unique microclimates that influence apple tree growth, especially temperature and wind. These microclimates can impact fruit typing times, risk of frost damage and overall yield. For example, areas with less wind or more shelter reduce frost risk during bloom, which is critical for apple production in certain climates (Pustokhina & Gorbatova, 2021).

1.2.4 Evapotranspiration

Evapotranspiration (ET) refers to the process of evaporation and transpiration. It's an important phase in the water cycle since it regulates the levels of humidity of the soil and the overall health of plants. (Cherlinka, V, 2025).

1.2.4.1 ET Factors

Key ET factors include : temperature, humidity, wind speed, solar radiation and the tree's growth stage. The amount of water lost via transpiration depends on the leaf area, tree size and environmental conditions(wind and radiation). When ET rates are high, water stress can occur if irrigation is not carefully managed, leading to reduced growth and fruit development. And insufficient water can affect fruit size,quality and sugar within (Zwart & Bastiaanssen, 2004; Allen, 1998).

1.2.4.2 Modeling ET

The FAO-56 Penman-Monteith model is the standard method used to calculate crop ET based on meteorological data. This model takes into account temperature, radiation and wind speed to estimate the water needs of crops, including apple trees. Using this model it ensures a proper water use to improve fruit yield (Zwart & Bastiaanssen, 2004)

1.2.4.3 Climate impact on ET

Changes in climatic conditions affect ET rates by altering local weather patterns. As for hotter,drier conditions increase ET demand which leads to more stress to the apple orchards (Allen, 1998).

1.3 *Malus domestica (Suckow) Borkh* AS A VEGETATION COMPONENT

1.3.1 Associated Species

1.3.1.1 Family prominence and floristic elements

The *Malus domestica (Suckow) Borkh Belongs* to the Rosaceae family, which is distributed in temperate regions. Within this family it interacts with other genus such as *Prunus (plums)* and *Pyrus*. These plants share pollinators such as bees due to their similar flowering season and floral structures, encouraging the development of mutual pollination networks in mixed orchards (Wu, 2020). The floristic composition also supports biodiversity, providing an optimal habitat for beneficial organisms like birds and insects (Herremans, 2015).

1.3.2 Interactions involving *Malus domestica (Suckow) Borkh*within communities

1.3.2.1 Root system

The root systems of *Malus domestica (Suckow) Borkh*contribute to soil structure and nutrient cycling. The roots interact with mycorrhizal fungi, enhancing nutrient uptake and resistance to some strains like drought (Wu, 2020).

1.3.2.2 Pests and diseases

*Malus domestica (Suckow) Borkh*is susceptible to several pests and pathogens. Some of these include the codling moth (*Cydia pomonella*) and fire blight (*Erwinia amylovora*). This severely influences community dynamics by damaging the plant's health and changing the food web. For example, predatory insects feeding on pests can indirectly benefit other plants by reducing pest populations (Herremans, 2015).

1.3.2.3 Relations with others

Apples have significant ecological and agricultural interactions. They provide food and shelter for a wide range of organisms like pollinators. The species usually supports the cultivation and preservation of trees by stabilizing the ecosystems and enhancing the biodiversity thought to be independent with other flora and fauna (Wu, 2020).

2 BIOLOGY

Malus domestica, has a range of biological characteristics that include its chromosomes, life cycle, phenelogy, reproductive biology and ecophysiology.

2.1 CHROMOSOME COMPLEMENT

The *Malus domestica (Suckow) Borkh*is primarily diploid (meaning it has two complete sets of chromosomes one from each parent), it has 17 chromosomes (2n = 2x = 34). However there are some cultivars being triploid or tetraploid (Canadian Food Inspection Agency, 2013). Triploids (2n = 3x = 51) have 3 sets of chromosomes and tetraploids (2n = 4x = 6) have 4 sets (Velasco R, 2010)

2.2 LIFE CYCLE AND PHENOLOGY

2.2.1 Life cycle

2.2.1.1 Seed germination

It starts with stratification (a cold period that breaks dormancy). Stratification in the *Malus domestica (Suckow) Borkh Requires* 0-5 degrees celsius for 60-90 days to germinate successfully. After stratification the apple seed absorbs water and swells. Then the radicle (embryonic root, seen in Figure 6) emerges first, followed by the shoot (Figure 7) (Abbott et al., 2018).

Figure 6:

Picture that shows the Anatomy of an Apple seed(, 2007)

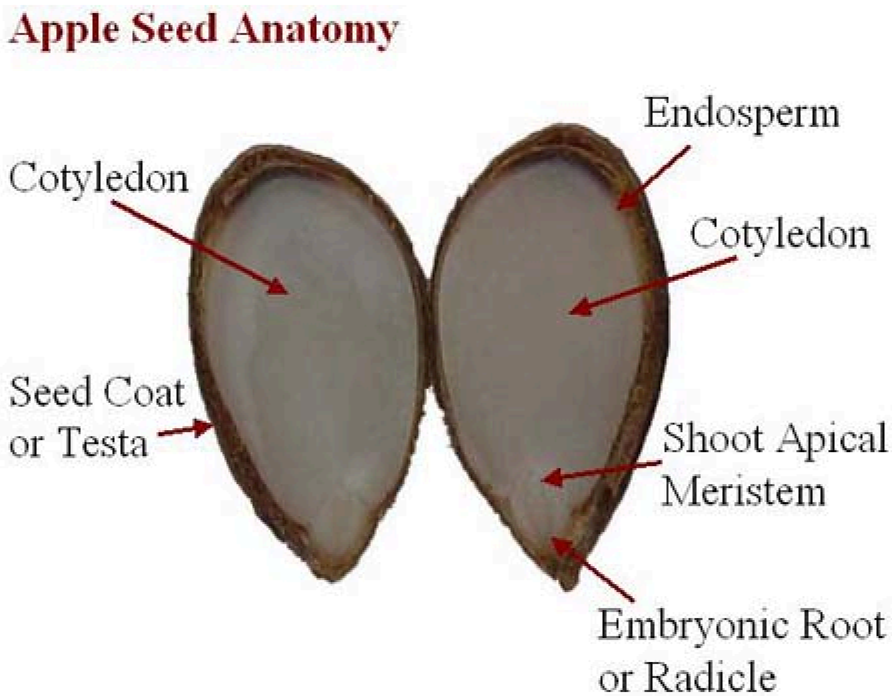
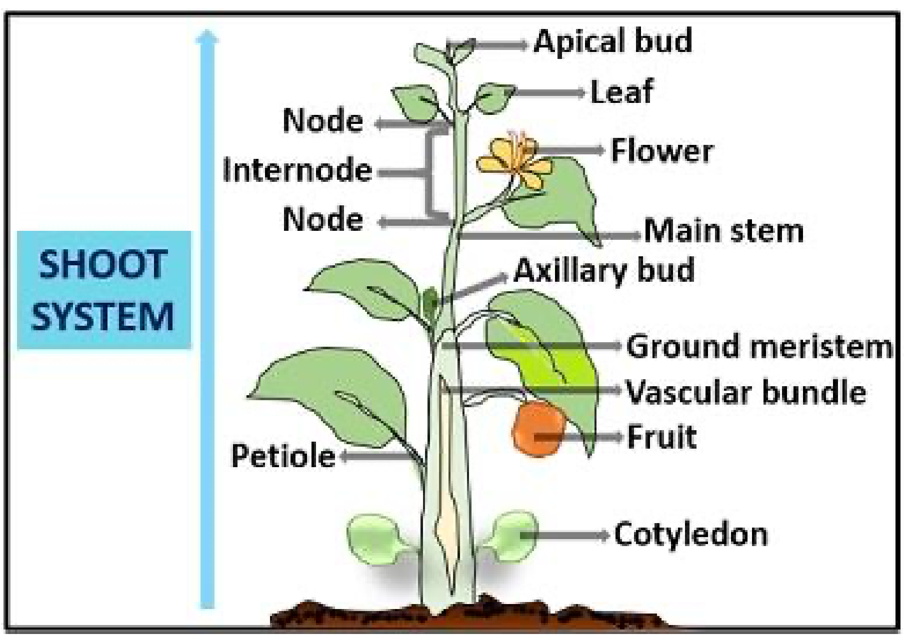


Figure 7:

Picture that shows the shoot system of a plant (Supriya N , n.d.**)**

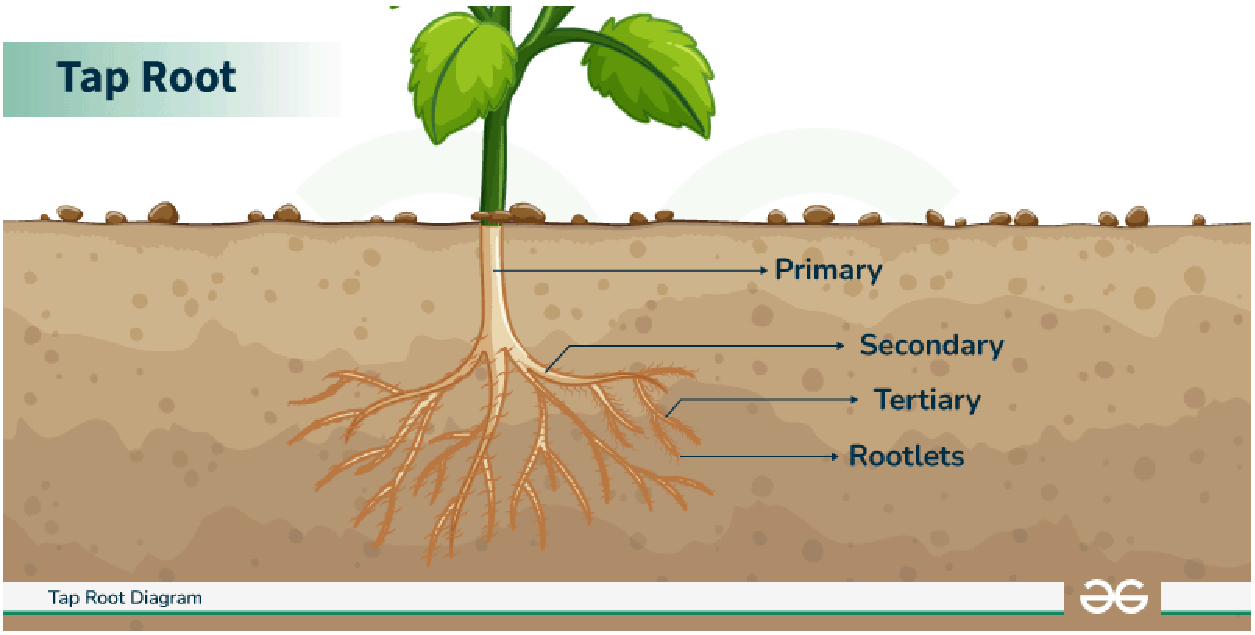


2.2.1.2 Juvenile/Vegetative Stage

The young seedling develops a taproot (Figure 8) and primary shoot (Figure 7) with simple leaves. During this phase (which lasts 4-10 years) the tree focuses on vegetative growth and does not produce flowers. Although the duration depends on environmental conditions and the cultivar (Webster & Wertheim, 2003).

Figure 8:

Picture that shows the tap root system of a plant(GeeksforGeeks, 2024**)**



2.2.1.3 Flowering/reproductive stage

The tree reaches maturity and begins annual flowering and fruit production. Apple trees are deciduous so their leaves fall in autumn and the tree enters dormancy. In spring pollination occurs via bees, as most cultivars are self-incompatible and require cross pollination (Dennis, 2003).

2.2.1.4 Fruit development and Maturation

After successful pollination and fertilization, the ovary of the apple (*Malus domestica*) begins developing into a fruit. During the first 30 days, rapid cell division occurs, which largely determines the potential size of the fruit (Donald E, 2013). This process is regulated by plant hormones, including auxins, gibberellins, and cytokinins, which play crucial roles in fruit expansion and development (Greene, 2000).

Auxins, such as indole-3-acetic acid (IAA), are plant hormones that promote cell elongation and division while preventing premature fruit drop. They also stimulate the differentiation of vascular tissues, ensuring proper nutrient transport to the developing fruit (Teale, 2006).

Gibberellins (GAs) are another group of growth-regulating hormones that stimulate fruit enlargement by promoting both cell division and elongation. They are particularly important in overcoming dormancy and ensuring the development of seedless fruit in some apple varieties through parthenocarpy (Jackson, 2003).

Cytokinins are essential for regulating cell division and delaying aging (senescence) in fruit tissues. They work with auxins to maintain cell multiplication (proliferation) and help in the mobilization of nutrients to support fruit growth (Zhang et al., 2020).

In addition to hormonal regulation, factors such as water availability and carbohydrate accumulation significantly influence fruit volume. Adequate water supply ensures proper cell turgor pressure, while sufficient carbohydrate reserves, mainly derived from photosynthesis, provide the necessary energy for fruit expansion. Conversely, insufficient pollination or fertilization can lead to fruit abortion or premature fruit drop due to inadequate hormone production and resource allocation (Jackson, 2003).

2.2.1.4.1 Sugar Accumulation and Maturation

As the fruit matures, starch reserves are transformed into sugars primarily into fructose and sucrose, affecting taste and sweetness (Brackmann, 2017). A key factor to have in mind is that cool night temperatures enhance sugar accumulation and color development (Saquet, 2020).

2.2.1.4.2 Ripening and Softening

The ripening process is regulated by a plant hormone called ethylene. This triggers change in texture, aroma and color (Johnston, 2009). Then because pectin degradation (which occurs in the cell walls) softens the flesh making the fruit edible (Gwanpua, 2014). Lastly apples shift from a starch based metabolism to a sugar based metabolism to enhance their taste and the ethylene response varies depending on different cultivars affecting storage life (Kumar, 2014).

2.2.1.5 Senescence and Death

Over the decades productivity declines. The tree survives 50-100 years but disease, environmental stress and pruning affect longevity**.** However commercial orchards replace trees after 20-30 years due to reduced productivity (Webster & Wertheim, 2003).

2.2.2 Phenology

2.2.2.1 Deciduousness

Apple trees are deciduous; this means they shed their leaves annually as a response to seasonal changes. This leaf drop occurs in autumn, allowing the tree to conserve resources during unfavourable conditions (Canadian Food Inspection Agency, 2013).

2.2.2.2 Flowering and fruiting

The flowering period of apple trees varies depending on the cultivar and environmental conditions. In regions like Latvia, changes in the meteorological parameter have influenced the phenology of apple trees, affecting both flowering and fruiting times (Kalvāne & Kalvāns, 2021). The flowering period can range from a few days to several weeks, depending on the specific apple variety and environmental factors. In nordic climates temperature fluctuations strongly impact the duration and progression of flowering stages (Gustavsson, 2016).

2.2.3 Year-to-year variation in flowering and fruiting

Annual variations in flowering and fruiting are influenced by factors such as temperature fluctuations, pollinators and tree health. These variations can impact fruit yield and quality from year to year (Canadian Food Inspection Agency, 2013).

2.2.3.1 Temperature fluctuations

Unexpected frost during bloom can damage blossoms, leading to reduced fruit set and lower production. Contrary warm temperatures can cause premature flowering, which may not align with the activity periods of pollinators, further affecting fruit production (Rose, 2025.).

2.2.3.2 Tree health

The overall health of an apple tree affects its flowering and fruiting consistency. A proper orchard management practices, including proper watering, fertilization and pruning are vital for maintaining tree strength. Stress factors such as pest infestations,diseases and nutrient deficiencies can weaken the tree, leading to irregular flowering and fruiting (Nick, 2023)

2.2.4 Impact of Climate Change

Climate change is causing shifts in apple tree phenology, leading to earlier flowering and fruiting in some regions. These changes can disrupt synchronization with pollinators, impacting fruit yield and quality (Chmielewski, 2022). To mitigate climate change effects, researchers are developing apple cultivars with altered flowering times to avoid late spring frost or extreme heat. As an example there are studies in Michigan that are identifying genes responsible for delayed blooming to breed more climate resilient apple trees (Associated Press, 2022).

2.3 REPRODUCTIVE BIOLOGY

2.3.1 Pollen

Apple trees produce pollen within their flower antherns (figure 10) which are inside the stamens (figure 9). The possibility and dispersal of this pollen are crucial for successful fertilization and fruit development (Organisation for Economic Co-operation and Development, 2019).

Figure 9:

Picture that shows the anatomy of a *Malus domestica (Suckow) Borkh*flower(The Holy Habibee, 2024)

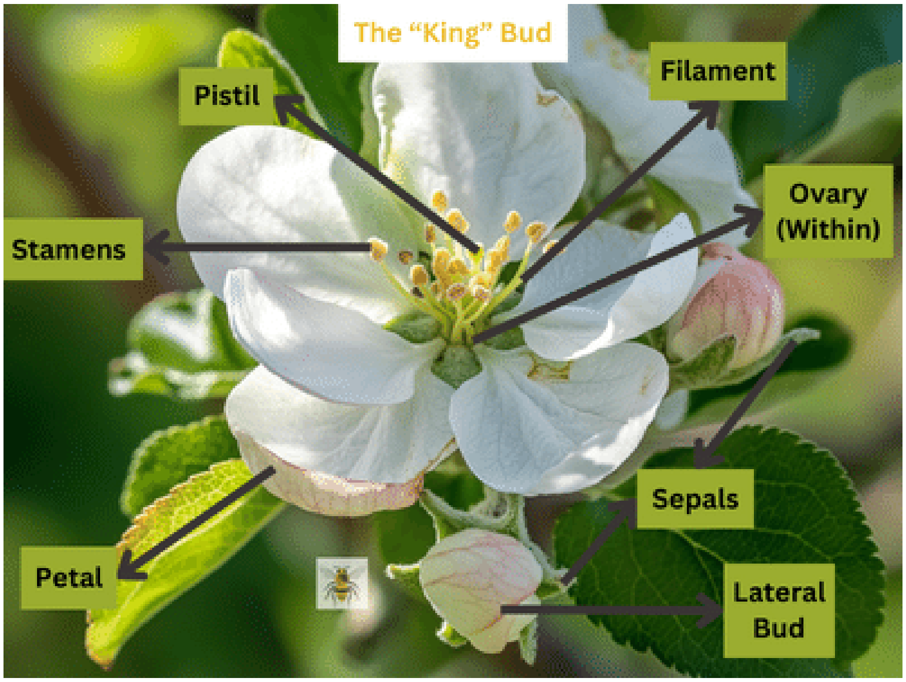
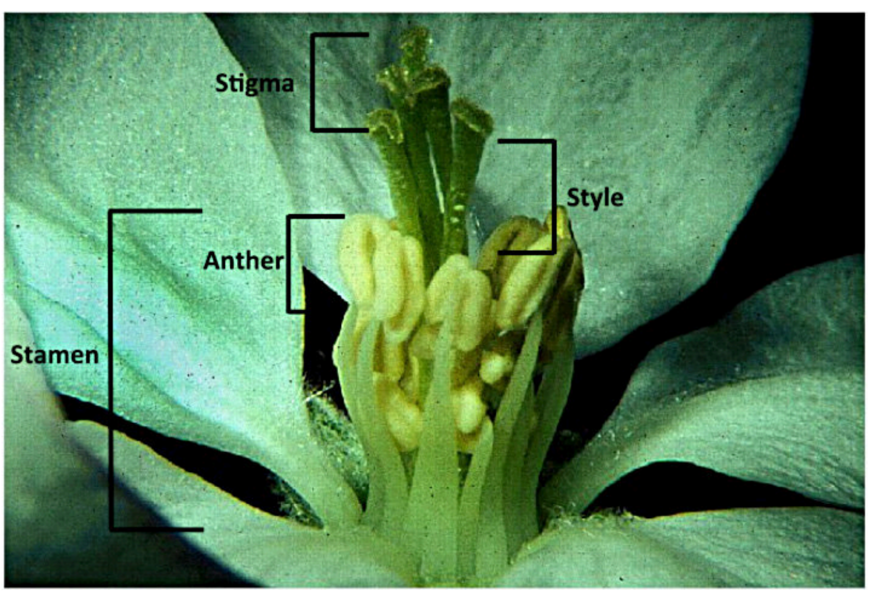


Figure 10:

Picture that shows whip-and-tongue grafting(Goffinet, M. (2012)



2.3.2 Sexuality

Apple trees (*Malus domestica)* are primarily self incompatible, it requires cross pollination between different cultivars to set fruit. This mechanism promotes genetic diversity within apple populations (Organisation for Economic Co-operation and Development, 2019).

2.3.3 Anthesis

Anthesis is the period during which a flower is fully open and functional, and is a critical phase for pollination. In apple trees, this stage's timing can depend on environmental conditions and cultivar characteristics (Organisation for Economic Co-operation and Development, 2019).

Temperature is a key factor that determines the timing of anthesis in the apple tree. Studies have shown that exposure to constant temperatures ranging from 12 degrees celsius to 27 degrees celsius for about 12 weeks with non optimal results meanwhile optimal flowering would occur around 18 degrees celsius and 21°C. Apple trees do not flower at temperatures outside of this range (CABI, 2020). Also apple trees may respond to temperature shifts, with a drop from high to low temperature after 6 weeks impulsing the suspension of growth and initiation of flowering (CABI, 2020).

2.3.4 Pollination and potential pollinators

Pollination in apple trees is primarily helped by insects, with bees being the most significant pollinators. The attraction of these pollinators is essential for the transfer of pollen and farther fruit sets (Organisation for Economic Co-operation and Development., 2019). Bee activity is most strong during temperatures between 18.333°C and 23.889°C which is optimal for pollination (Nick, 2023).

While bees are the primary pollinators other insects, including wasps, flies, beetles and ants can also visit apple blossoms although their effectiveness is usually lower compared to bees (Gardeners Path, 2021).

It is also important to note to reduce pesticide use during the flowering period to protect pollinators. If pesticides are necessary they should be applied during times when pollinators are least active such as early morning or late evening (Nick, 2023).

Since the decline in pollinator population has increased over the years because of habitat loss, pesticide use and climate change, it presents a significant challenge for apple growers. Protecting pollinators through habitat conservation and sustainable agricultural practices is crucial for maintaining effective pollination (FT, 2021).

2.3.5 Fruit development and seed set

2.3.5.1 Ovule development

Following successful pollination, the ovules within the ovary develop into seeds. Proper ovule development is essential for viable seed formation and contributes to the overall fruit quality (Organisation for Economic Co-operation and Development, 2019).

2.3.5.2 Ovary wall development

As the seeds develop, the ovary wall matures into the fruit's flesh, known as the pericarp. The development of the ovary wall determines the fruit size, texture and quality (Organisation for Economic Co-operation and Development, 2019).

2.4 ECOPHYSIOLOGY

Apple trees (*Malus domestica)* exhibit specific physiological responses to environmental factors such as temperature, light and water availability. Understanding these responses is important for optimizing growth conditions and improving fruit yield and quality (Organisation for Economic Co-operation and Development., 2019).

For instance, temperature fluctuations can influence photosynthesis, respiration and flowering patterns, while light availability directly affects photosynthetic efficiency and fruit coloration (Lakso, 2019). Understanding these physiological responses is essential for optimizing growth conditions, improving fruit yield, and enhancing fruit quality. For example, research has shown that controlled irrigation strategies can significantly improve water use efficiency without compromising fruit size or sugar content (Garcia-Tejero, 2018). Similarly, optimizing light exposure through canopy management techniques such as pruning can enhance photosynthetic activity and fruit quality (Robinson, 2020). Besides, the connection between these environmental factors and the tree's physiological process is complex and often requires an exhaustive approach to management. For instance, temperature stress during critical growth stages, such as flowering, can lead to reduced fruit set and yield (Atkinson, 2020).

3 PROPAGATION AND MANAGEMENT

3.1 NATURAL REGENERATION

Apple trees *(Malus domestica)* exhibit limited natural regeneration due to their reliance on cross-pollination and the high genetic variability of seedlings. In the wild, apples regenerate from seeds dispersed by animals, but cultivated varieties are typically propagated vegetative to maintain desirable traits (Baskin & Baskin, 2014).

3.2 NURSERY PROPAGATION

3.2.1 Propagation from seed

3.2.1.1 Pre- preparation and implications for germination

Apple seeds exhibit deep dormancy, requiring stratification to promote germination. This involves chilling seeds at 1-5 degrees celsius for 60-90 days in a moist environment to break dormancy (Baskin & Baskin, 2014). Without stratification, germination rates are significantly lower.

3.2.1.2 Sowing and germination process

After stratification, seeds are planted in well-drained soil at a depth of 1–2 cm. Germination best occurs at temperatures between 15–25°C with an appropriate moisture (Baskin & Baskin, 2014). Seedlings typically emerge within 2–4 weeks.

3.2.1.3 Storage

Storage conditions are essential for maintaining apple seed viability. Seeds stored at 4°C under dry conditions can remain viable for up to two years (Baskin & Baskin, 2014). However, exposure to high humidity reduces longevity.

3.2.2 Vegetative propagation

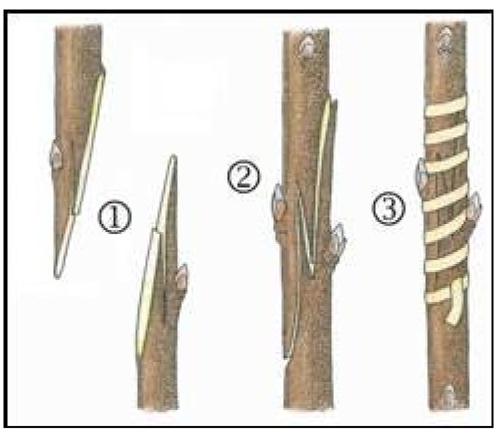
3.2.2.1 Grafting

Grafting is a technique where tissues of plants are joined to continue their growth together, thi is the most common method for propagating apple trees. Techniques such as whip-and-tongue grafting (shown in Figure 11), cleft grafting(shown in Figure 12), and chip budding(shown in Figure 13) ensure genetic consistency and improved tree vigor (Fazio et al., 2018).

Grafting Techniques:

Whip-and-Tongue Grafting involves making matching slanted cuts on both the scion and rootstock, allowing them to fit snugly together, promoting strong bonding. It is effective for similar-sized branches. (Cornell University, 1999)

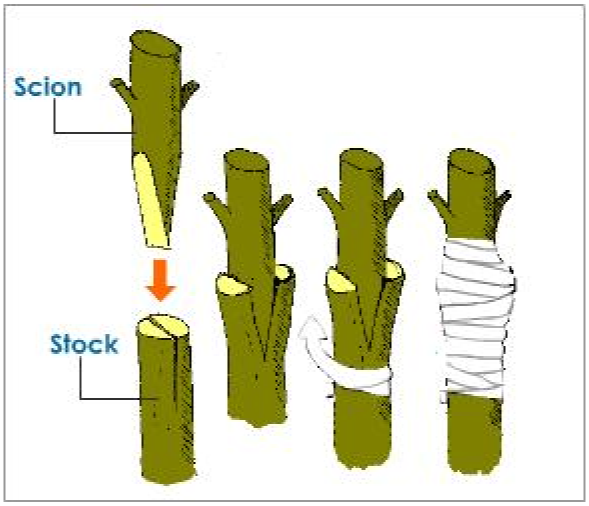
Figure 11:
Picture that shows whip-and-tongue grafting(Hartmann, n.d.)



Cleft Grafting is used primarily for top-working older established trees, cleft grafting involves making a vertical cut into the rootstock and inserting a wedge-shaped scion. This method is suitable for branches 1 to 2 inches in diameter (Gordon Abigail, 2020).

Figure 12:

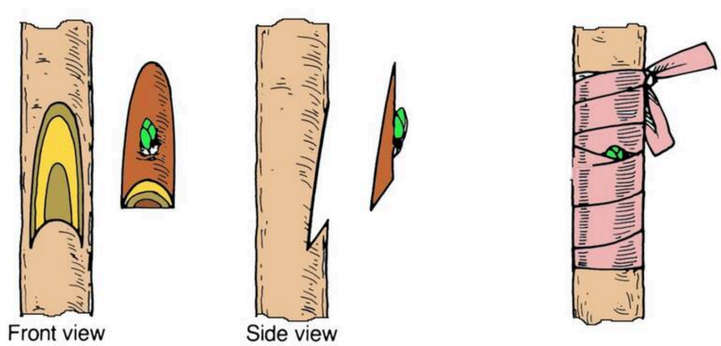
Picture that shows cleft grafting(Heritage Fruit Tree, 2012)



Chip Budding involves cutting a chip from the rootstock and replacing it with a chip containing a bud from the scion. It's commonly used when the rootstock is actively growing, and the bark is not slipping (Cornell University, 1999).

Figure 13:

Picture that shows chip budding(University of Florida, n.d.)



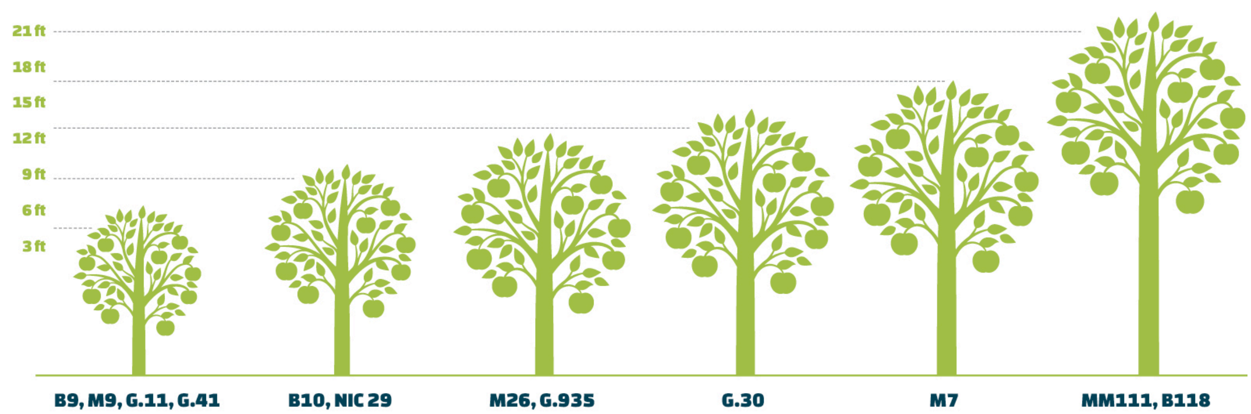
Rootstocks (root system) influence tree size, disease resistance, and fruit productivity, with dwarfing rootstocks like M.9 and M.26 being widely used to control growth and facilitate orchard management therefore gaining more profit (Warrington, 2021). Since Dwarf trees are easier to care for because you don't need ladders for pruning, training, spraying, thinning, and picking. Also dwarf trees come into bearing earlier in life, which can significantly impact the economic returns of the orchard (Orchardly, 2023; Center for Agroecology & Sustainable Food Systems, 2011).

M.9 (Malling 9): Originating from the East Malling Research Station in England, M.9 is a dwarfing rootstock that produces trees about 30-35% the size of standard seedling trees, as shown in figure 14. It is precocious, meaning it induces early fruiting, and is widely used in high-density orchards. However, trees grafted onto M.9 require support due to their weaker root systems and are susceptible to fire blight and Phytophthora root rot (Pennsylvania State University Extension, 2023).

M.26 (Malling 26): Also developed at the East Malling Research Station, M.26 is a semi-dwarfing rootstock resulting from a cross between M.16 and M.9. It produces trees about 40-45% the size of standard trees, as seen in figure 14, and is known for its good anchorage compared to M.9. M.26 is precocious and productive but is susceptible to fire blight, crown rot, and woolly apple aphid (Washington State University Tree Fruit Research & Extension Center, n.d).

Figure 14:

Comparison of different rootstocks(Wafler Nursery, n.d.)



3.2.2.2 Cuttings

Propagation through cuttings(a piece of a plant that has been removed and placed in conditions that allow it to grow into a new plant) is less common because of the low rooting ability of apple hardwood cuttings. However, semi-hardwood cuttings treated with auxins such as indole-3-butyric acid (IBA) can enhance root formation (Fazio et al., 2018). Optimal conditions for rooting include high humidity, bottom heating at 21–24°C, and mist propagation.

3.3 PLANTING

Apple trees are best planted in early spring or autumn. They require well-drained loamy soils with a pH of 6.0–7.0 and full sun exposure. Spacing depends on the rootstock, with standard trees requiring 5–6 meters and dwarf varieties 1.5–3 meters (Delaplane & Mayer, 2019). Proper site selection is crucial for disease prevention and optimal growth.

3.4 MANAGEMENT

3.4.1 Tending

Regular irrigation, especially during fruit set and development, is critical for apple tree health. Placing organic material on top of the solid helps conserve soil moisture and suppress weeds. Pruning is essential for maintaining tree structure, improving light penetration, and enhancing air circulation, which reduces disease risk (Delaplane & Mayer, 2019).

3.4.2 Fruiting

Apple trees typically begin bearing fruit 2–5 years after planting, depending on the rootstock. Thinning fruit clusters(removing them from the branch) to one or two apples per branch improves fruit size and quality by reducing competition for nutrients (Fazio et al., 2018). Cross-pollination is required for fruit sets, requiring compatible cultivars and enough pollinator activity (Delaplane & Mayer, 2019).

3.4.3 Pest and disease control

Common apple pests include codling moth (*Cydia pomonella*), apple maggot (*Rhagoletis pomonella*), and aphids. Integrated pest management (IPM) techniques, such as pheromone traps, biological control, and targeted insecticide use, help reduce infestations (van Emden & Harrington, 2017).

Major diseases affecting apples include apple scab (*Venturia inaequalis*), fire blight (*Erwinia amylovora*), and powdery mildew (*Podosphaera leucotricha*). Management strategies include planting resistant cultivars, applying copper-based fungicides, and maintaining orchard sanitation (Warrington, 2021).

3.4.3.1 Common apple pests:

Codling Moth (Cydia pomonella, Figure 15): A primary pest in apple production, the codling moth's larvae tunnel into fruit, causing internal damage and increasing susceptibility to secondary infections.

Effective control strategies include pheromone traps to monitor and disrupt mating, biological controls like introducing natural predators are effective (Schreiber, K. 2023).

Figure 15:

Codling Moth and its effect on the *Malus domestica (Suckow) Borkh*(Stoneman's Garden Centre. (n.d.)

Apple Maggot (Rhagoletis pomonella, figure 16): This pest lays eggs under the apple skin; the emerging larvae feed on the fruit, causing it to become pitted and misshapen. Management includes using sticky traps to capture adults, applying appropriate insecticides, and removing infested fruit to break the life cycle (Schreiber, K. 2023).

Figure 16:

Apple Maggot and its effect on the *Malus domestica (Suckow) Borkh*(Gardenia.net, n.d)

Aphids(Figure 17): These small insects extract sap from leaves and stems, leading to distorted growth and potentially transmitting viral diseases. Control methods are introducing beneficial insects like ladybugs, applying insecticidal soaps, and ensuring proper tree nutrition to enhance resilience (Schreiber, K. 2023).

Figure 17:
Aphids on stems(EcoGuard Pest Management, 2023.)

Spider Mites: These tiny arachnids feed on leaf cells, causing stippling, yellowing, and potential defoliation under heavy infestations. Management includes promoting natural predators, ensuring adequate irrigation to reduce plant stress, and using miticides when necessary (Schreiber, K. 2023).

Leafrollers: Caterpillars that roll and tie leaves together, feeding on foliage and sometimes the fruit surface, leading to scarring. Control strategies involve monitoring with pheromone traps, encouraging natural enemies, and applying Bacillus thuringiensis (Bt) during early larval stages (Schreiber, K. 2023).

Apple Scab (Venturia inaequalis): This fungal disease presents as olive-green to black spots on leaves and fruit, leading to defoliation and reduced fruit quality. Preventative measures include planting resistant cultivars, applying appropriate fungicides during susceptible periods, and practicing good sanitation by removing fallen leaves and debris (Better Homes & Gardens, 2023).

Fire Blight (Erwinia amylovora): A bacterial disease causing blossoms, shoots, and branches to appear scorched; it can be fatal to young trees. Management includes pruning infected areas during dormant seasons, applying appropriate bactericides, and avoiding excessive nitrogen fertilization, which can promote susceptible new growth (Better Homes & Gardens, 2023).

Powdery Mildew (Podosphaera leucotricha): Characterized by white, powdery fungal growth on leaves, buds, and young fruit, leading to distorted growth and reduced yield. Control involves planting resistant varieties, ensuring proper air circulation through pruning, and applying sulfur-based fungicides as needed (Better Homes & Gardens, 2023).

Cedar-Apple Rust (Gymnosporangium juniperi-virginianae): This disease causes yellow-orange spots on apple leaves and can lead to defoliation and fruit blemishes. It requires juniper species as an alternate host. Management includes removing nearby juniper hosts, applying fungicides during infection periods, and selecting resistant apple cultivars (Better Homes & Gardens, 2023).

Black Rot (Botryosphaeria obtusa): Manifesting as leaf spots, fruit rot, and limb cankers, black rot can significantly reduce apple yield. Effective control includes removing and destroying infected plant material, practicing crop rotation, and applying appropriate fungicides (Better Homes & Gardens, 2023).

4. Malus domestica (Suckow) Borkh COMMERCIAL IMPORTANCE

4.1 EXPORTING AND IMPORTING OF THE PRODUCT

Malus domestica, commonly known as the apple, is a significant commodity in international trade. In the United States, apple production for the 2021/22 crop year was projected to exceed 265.4 million bushels, with an estimated farm-gate value of over $3.2 billion. Washington state led production with approximately 176.2 million bushels, valued at nearly $2.3 billion (U.S. Apple Association, 2021).

Globally, the apple industry has experienced substantial growth. Between 2006 and 2016, the world value of apple production increased by 41.2%, highlighting the fruit's rising demand and economic importance (Desmond O'Rourke, 2021).

4.2 IMPORTANCE IN THE ECONOMY

The apple industry significantly contributes to both local and global economies. In the United States, apples are grown in all 50 states by over 27,000 producers, generating approximately $3.2 billion in farm-gate revenue annually. The industry's downstream value is estimated at $23 billion, underscoring its extensive economic impact (U.S. Apple Association, 2024).

Beyond the United States, apple production plays a vital role in the agricultural economies of many countries. The industry's growth has led to increased employment opportunities and has been instrumental in the economic development of rural areas (Desmond O'Rourke, 2021).

5 COMMERCIAL PRODUCTION AND USES

5.1 FOOD USES

5.1.1 Fruit

Apples (*Malus domestica*) are one of the most widely consumed fruits globally, with over 7,500 cultivars available. They are mostly eaten fresh due to their taste and nutritional value, but they are also processed into various products, including dried apples, applesauce, and cider (Patocka et al., 2020).

5.1.2 Skin

Apple skins are rich in fiber, especially pectin, which is beneficial for digestion. Also, apple peels have antioxidants such as quercetin, which has been linked to anti-inflammatory and cardiovascular benefits (Patocka et al., 2020).

5.1.3 Juice

Apple juice is a widely consumed drink used as a base for products such as apple cider, vinegar, and flavored drinks. While juice has some nutrients, processing often reduces the colour content compared to whole apples (Patel et al., 2012).

5.2 MEDICAL USES

5.2.1 Nutrients

5.2.1.1 Skin

Apple peels have bioactive compounds such as catechins, epicatechins, and quercetin, which help to antioxidant and anti-inflammatory properties. These compounds may help in reducing oxidative stress and preventing chronic diseases (Patocka et al., 2020).

5.2.1.2 Juice/ Nectar

Apple juice has essential vitamins and minerals, including vitamin C and potassium, which help to support the immune system and electrolyte balance. However, it has lower fiber content compared to whole apples, making whole fruit consumption preferable for optimal health benefits (Patel et al., 2012).

5.2.2 Diseases

Consumption of apples has been associated with a reduced risk of chronic diseases such as cardiovascular disease, type 2 diabetes, and certain cancers. The antioxidants (polyphenols) in apples contribute to these protective effects by reducing inflammation and oxidative damage (Patocka et al., 2020).

5.3 TRADITIONAL USES

5.3.1 Magic/ Ritual Significance

Apples have held symbolic significance in several cultures and traditions. In folklore, apples have been associated with health, prosperity, and love. They have been used in rituals, mythology, and religious ceremonies across different civilizations, including Greek and Norse traditions (Patel et al., 2012).

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