Annex 1.

DIPLOMA THESIS

Elman Gadimov

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Annex 2.

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BUDAPEST

Frost protection methods and frost hardiness of apricot cultivars.

Elman Gadimov

The Specialisation of Fruit Production

Made at the Department of: Fruit Growing

Collaborator Department(s): -

Department's supervisor: Professor László Szalay

Supervisor(s): Mr József László Bakos

Reviewers:…………..*will be given by the Dept*.!………………..

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……………………………..
Head of Department

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Supervisor

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1. Introduction:

1.1. Apricot, apricot production and its constraints

Since apricots can be grown anywhere thanks to their broad genetics, they play an outsized role in global fruit production [Jiang et al. 2019]. The apricot accounts for 0.49 percent (3.72 million metric tonnes) of global fruit production [FAOSTAT. 2022; Statista. 2022; Uzundumlu et al. 2021], making it the twenty-fifth most produced fruit in the world. A commercially significant crop, the apricot (Prunus armeniaca L.) is a member of the Rosaceae family, the subfamily Prunoideae, the genus Prunus L., and the subgenus Prunophora [Jiang et al. 2019]. Flavour, aroma, high concentration of bioactive compounds, low fat and carbohydrate content; these all contribute to the fruit's significance as a food in human nutrition [Karatas and Kamisli, 2007; Ali et al., 2015; Hallmann et al., 2019]. These days, the Mediterranean Basin and other temperate areas are the primary locations for apricot cultivation [Moustafa, and Cross, 2019]. The apricot flowers very early and is susceptible to frosts, while the fruits tend to be soft and have a short fresh storage life [Asma, 2007; Gunes, 2006; Okba et al. 2021]. Despite this, total world apricot production is lower when compared to many other important Prunus fruit crops. The reason for that is the most apricot cultivars have very particular ecological needs, and thus cultivars planted in other places frequently provide low yields [Polat and Çalışkan, 2014].

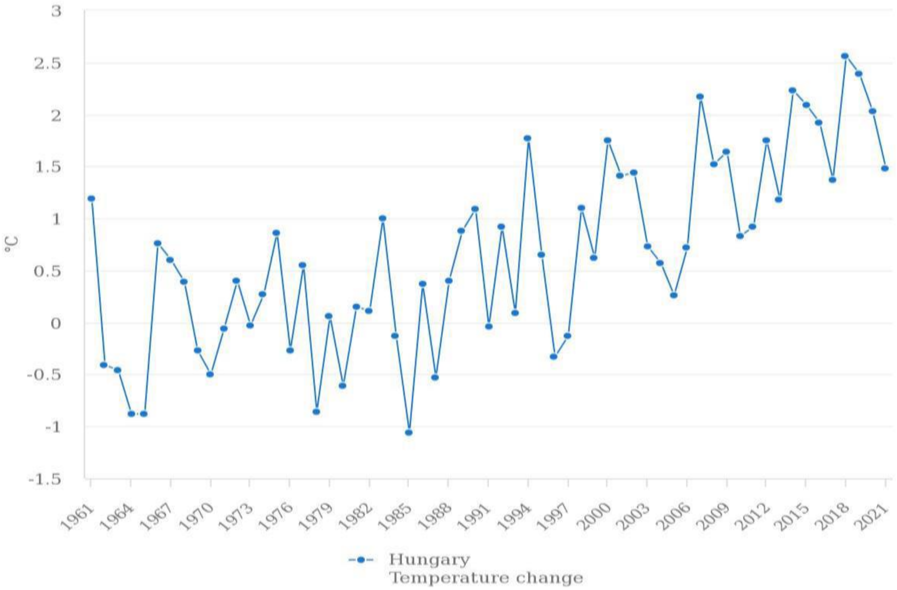
1.2. Frost and the problems it causes.

For an orchard to be financially sustainable, fruit output must be maximised year after year. Losses in quality and quantity, or even total crop loss, can come from frost, especially in the early spring when flower buds are developing. There seems to have been a rise in the frequency of frosts recently. Warmer spring temperatures are to blame, since they have sped up bud formation and made blossoms more vulnerable to frost damage [Technical Report from NOAA, 2012]. Damage to vulnerable crops caused by air temperatures below 0 °C might result in significant yield losses. Farmers have struggled with frost damage to fruit harvests since since they began growing fruit. A single night of cold temperatures can wipe out an entire harvest, even if every other aspect of production is well-managed [Usha,Thakre, Goswami, and Deepak, 2015]. Because of this, frost damage is a worldwide issue. According to White and Haas (1975), frost damage accounts for more economic losses in the United States than any other natural disaster. Therefore, it might have extremely negative effects on the affected farmers and the area economy.

1.3. Production in Hungary.

Although apricots are the most frost-sensitive species [Thurzó et al. 2006], Hungary has a lot of room to grow them [Pleszkó, 2014]. Economically viable apricot production ends in northern Hungary [Szabó et al., 2010; Szalay et al., 2016]. Constraints on apricot cultivation include issues with bud dormancy, complications due to internal and external stress, insufficient chilling, poor agronomic and cultural practises, and climatic factors such as temperature and frost [Bartolini et al., 2019; Campoy et al., 2010; Karakaş and Doğan, 2018]. All of the issues with apricot production may be adjusted for, thus studying the fruit to determine what causes its unpredictable output is essential.

Figure 1: Mean Temperature Change of Meteorological year 1961–2021 in Hungary [source: FAOSTAT. 2022b]



1.4. Objectives:

The implementation of adequate frost protection for crops is one of the most significant techniques to produce an optimal amount of fruit. The purpose of this study was to provide information on different frost protection strategies and to assess the frost damage sustained by five apricot cultivars of foreign and local provenance at Soroksár Botanical Garden throughout the winter of 2021–2022. The precise goals of the research are as follows:

- Educating the public about Frost.
- Providing specific data on Active and Passive frost protection strategies.
- Determining the progression of frost damage to floral buds across selected cultivars.
- Determining the LD50 values, and hence the cold resistance, of the five cultivars.

2. Literature review:

2.1. Frost

The economic viability of an orchard necessitates maintaining an optimum level of yearly fruit yield. Frost occurrences, particularly during early spring flower bud development, can result in crop loss ranging from slight quality and quantity loss to entire crop loss. Recent frost occurrences appear to have increased in frequency. Warmer spring temperatures have been the driving force behind these occurrences, since they have accelerated bud growth and made blooms more susceptible to frost damage. (NOAA Technical Report, 2012). When air temperatures drop below 0 °C, sensitive crops might be damaged, resulting in considerable output losses. Frost damage to fruit crops has been an issue for farmers since the beginning of fruit production. Even if every part of crop production is adequately controlled, a single night of freezing temperatures can cause total crop loss [Usha,Thakre, Goswami, and Deepak, 2015]. This makes frost damage a global concern. Frost damage, for instance, is responsible for greater monetary losses in the United States than any other type of weather-related disaster [White and Haas, 1975]. As a result, the consequences for affected farmers and the regional economy can be devastating.

Technically speaking, "frost" refers to the development of ice crystals on surfaces [Blanc et al., 1963; Bettencourt, 1980; Mota, 1981; Cunha, 1982]. This can occur by the freezing of dew or a phase transition from vapour to ice.; however, the term is commonly used to describe a climatic occurrence in which crops and other plants suffer freezing damage. Growers frequently use the phrases "frost" and "freeze" interchangeably, with the ambiguous meaning being "an air temperature below or equal to 0°C." The following are some literary examples of frost definitions:

- the presence of temperatures below freezing in a "Stevenson-screen" shelter on an altitude of 1.25 to 2.0 metres [Hogg, 1950, 1971; Lawrence,1952];
- without specifying shelter type and elevation [Raposo, 1967; Hewett, 1971] the incidence of air temperatures below 0 °C;
- The occurrence of low air temperature that damages or kills crops, lacking reference to the creation of ice [Ventskevich, 1958; Vitkevich, 1960]; when the surface temperature dips below 0 °C [Cunha, 1952].

Frost is defined as the occurrence of an air temperature of 0 degrees Celsius or below between 1.25 and 2.0 metres above the ground inside a suitable weather shelter [Usha,Thakre, Goswami, and Deepak, 2015]. During a frost occurrence, plant water may or may not freeze, depending on many avoidance variables (e.g. supercooling and concentration of ice nucleating bacteria). When the plant's extracellular water freezes, we say that the plant is "frozen." (i.e. changes from liquid to ice). Whether or not this causes harm to the plant tissue is dependent on tolerance parameters (such as the cellular solute level) [Snyder, Melo-Abreu, and Matulich, 2005]. When ice develops inside a plant cell or tissue, it is considered a freeze event [Usha,Thakre, Goswami, and Deepak, 2015]. When the temperature of plant tissue drops below a certain value, a physiological state is created that leads to the death or dysfunction of plant cells [Snyder, Melo-Abreu, and Matulich, 2005]. Critical temperatures, which are the air temperatures at which damage to plant tissue occurs, are measured in traditional instrument shelters. Reductions in the thermodynamic heat concentration in the air close to the surface cause temperatures below freezing. This is typically caused by a net energy loss via the surface to the sky in the form of radiation frost or by wind carrying colder air to substitute for warmer air (advection frost).

2.1.1. Type of Frost Event

Both [Snyder, Paw U, and Thompson, 1987] and [Kalma et al., 1992] classify two types of frost: advective and radiative. Large-scale intrusions of cold air with a well-mixed, windy environment and a temperature that is frequently sub-zero, even during the day, are linked with advective frosts. Active FP is often inefficient during an advective frost, which happens when a significant amount of cold air flows in from another location and replaces warmer air, such as throughout the polar vortex [Gohil, 2020]. Radiative frosts are connected with energy loss by radiative exchange and temperature inversions during clear, calm nights. Using FP techniques, this frost can be controlled [Gohil, 2020]. In some instances, both advective and radiative conditions coexist. For instance, advective conditions frequently send a cold air mass into a location, resulting in an advection frost. This may be followed by several days of clear, calm circumstances that are favourable for the formation of radiation frosts. Conditions that are referred to as "micro-scale-advection frosts" have also been recorded by the authors [Snyder, Paw U, and Thompson, 1987] along with [Kalma et al., 1992]. This occurs when a region is subjected to radiation frost conditions, yet local cold air drainage causes fast temperature reductions on a small scale within the radiation frost zone.

2.1.1.1. Radiation frost:

Radiation-induced frosts occur often. Radiation frost occurs when the air temperature at nighttime drops below 0 °C but remains above 0 °C during the day, the sky is clear, and the wind speed is less than 5 mph (less than 8km/h) [Usha, Thakre, Goswami, and Deepak, 2015]. Under these conditions the net loss of radiant energy to outer space by the solid objects (plants, soil, etc.) of the earth's surface is high for the percentage of return radiation from the water vapor in the sky is small [Landers and Witte, 1967]. The majority of the temperature drop on nights with radiation frost happens within a few hours around sunset, when the surface's net radiation quickly switches from positive to negative. Since solar radiation is at its maximum at midday and its lowest at dusk, and since net long-wave radiation continually remains negative [Snyder, Melo-Abreu, & Matulich, 2005], the net radiation quickly shifts. At some point above the earth's surface, the air temperature will begin to fall as a function of altitude. (a lapse condition). The ceiling is defined as the altitude at which a temperature inversion gives way to a lapse state [Snyder, Melo-Abreu, & Matulich, 2005]. A modest inversion (high ceiling) occurs when temperatures aloft are just slightly higher than those near the surface, whereas a severe inversion (low ceiling) is characterised by temperatures that increase fast with height. Low ceiling and severe inversion circumstances, which are typical of radiation frosts, are optimal for energy-intensive protection strategies.

Radiation frosts may be broken down into two groups:

- When atmospheric moisture condenses and freezes on a surface, a white frost or hoar frost appears [Usha,Thakre, Goswami, and Deepak, 2015]. It is less harmful than the black frost and goes by the name "frost" [Snyder, Melo-Abreu, and Matulich, 2005].
- When temperatures drop below 0 degrees Celsius and the lower atmosphere is excessively dry, a phenomenon known as "black" frost develops [Usha,Thakre, Goswami, and Deepak, 2015]. Surface temperatures may not exceed the freezing point temperature and frost may not form if humidity levels are low enough [Snyder, Melo-Abreu, & Matulich, 2005]. Hoar frost and ice deposition are more likely to occur under conditions of high relative humidity. Since heat is produced during the ice deposition process, black frost is more damaging than hoar frost [Usha,Thakre, Goswami, and Deepak, 2015]; similarly, black frost is more damaging than hoar frost [Snyder, Melo-Abreu, and Matulich, 2005].

2.1.1.2. Advection frost:

When the weather changes, cold air moves in and displaces the warmer air that had been there previously [Snyder, Melo-Abreu, & Matulich, 2005]. This results in a frost known as an advection frost. When temperatures drop below zero, you may expect winds of up to 15 miles per hour [Landers and Witte, 1967]. A moderate to strong breezes, a lack of humidity, minimal temperature inversion, and a dew point below freezing are all hallmarks of the cloudy, cold, and windy conditions that give rise to advective frost [Usha, Thakre, Goswami, and Deepak, 2015]. It is not uncommon for the temperature to fall to and stay at or below zero degrees Celsius for a whole day. Because many active protection strategies are more effective when an inversion is present, advection frosts are harder to fight. In many instances, a sequence of sub-zero nights will begin with advection frost and then transition to radiation frost.

2.1.2. How does frost occur?

During the day, the soil in an orchard heats up and grows warmer, while at night the soil and, to a lesser degree, the fruit trees and vines lose heat. At ground level, frost occurs when the temperature falls to 0°C. This temperature reduction depends mostly on the following factors:

- The daytime soil heat storage capacity
- Radiative heat loss throughout the night
- Radiation transfer from the ground up to a plant's leaves.
- The relative humidity of the atmosphere. [Usha,Thakre, Goswami, and Deepak, 2015]

- On a clear night, heat loss from radiation is greatest, but clouds have a blanketing effect and wind will mix the air layers, sending warmer air downward. The transformation of water vapour into water (dew) is caused by heat, and as the temperature drops at night, the air in contact with plants and soil cools below the "dew point," causing moisture to condense and produce dew. This emits heat and delays the temperature decline. When the temperature begins to dip below 0 degrees Celsius, it freezes and heat is lost when dew turns to frost. If the temperature reduction continues, cell walls of plants are broken as water inside them freezes, giving the plant a characteristically scorched look. When a mix of dry soils, clearer spring days and nights occurs, the danger of frost increases dramatically.

2.1.3. Air Temperature

Frost can form when the ambient temperature falls below 0 degrees Celsius. The hourly rate of temperature decline and It is also important to keep in mind the projected lowest temperature. Nonetheless, the recorded ambient temperature may differ from the temperature actually experienced by trees [Gohil, 2020]. To determine the temperature of the flower buds, farmers must account for the cooling impact of evaporation of the tree's moisture, also known as the wet-bulb temperature. The wet-bulb temperature is the lowest temperature encountered when the relative humidity of the air is measured. The wet-bulb temperature accounts for the cooling produced by air moisture evaporation. Except at 100% relative humidity, the wet-bulb temperature is often a few degrees below the dry-bulb temperature [Gohil, 2020]. In the field, portable and digital psychrometers can be used to determine the wet-bulb temperature. Wet-bulb temperature may be easily calculated by subtracting one-third of the difference between the ambient temperature and the dew point from the ambient temperature, as demonstrated recently by researchers at the University of Georgia [Knox et al. 2017]. Modern frost alarms detect wet-bulb temperature and can communicate data immediately to the user's mobile device or PC.

2.1.4. Relative Humidity

In orchard frost control, relative humidity is frequently disregarded. However, it is crucial in measuring the level of frost damage. When the temperature drops below freezing, the moisture condenses around the flower's delicate parts, forming crystals of ice [Gohil, 2020]. Frostbite occurs when ice forms outside of the cell wall as well as within the plant tissue, as stated by [Levitt, 1980]. For a given temperature at which frost can form, higher relative humidity might result in more damage than low relative humidity [Gohil, 2020].

Figure 2: After a frost occurrence in a New Jersey peach orchard, the pistils of closed flowers (left) and open flowers (centre) were injured, but those of open flowers (right) were unharmed. (Photo by H. Gohil).

2.1.5. Dew point

The dew point is an accurate representation of the amount of water vapour in the air and is defined as the temperature at which the air cools to 100% relative humidity [Snyder, Melo-Abreu, & Matulich, 2005]. Air moisture condenses from a gas into a liquid when the temperature drops below the dew point. When the dew point is greater, the temperature drops more slowly. When the dew point is lower, surface moisture evaporates more rapidly in general [Gohil, 2020].

2.1.6. Inversion Layer

When the air at a greater elevation is warmer compared to the air near the ground, this is called an inversion [Gohil, 2020]. This is the opposite of typical temperature behaviour. A strong inversion layer can serve as a source of warmer air, which may be significantly warmer than air near the ground. Therefore, inversions must be carefully monitored.

2.1.7. Cloud Coverage

The outside temperatures are often lower when the sky is clear because less radiant energy from the earth's surface is trapped by clouds [Gohil, 2020]. On a clear, frost night [Niemann, 1957] suggests an average value of 60 kcal/m2 per hour for vegetation surfaces, and [Brooks, 1959] measured the same value for the net nocturnal radiation loss of a California citrus orchard.

2.1.8. Wind Speed

Wind is a crucial factor in determining the rate of thermal energy loss. When the wind speed is more than 10 miles per hour, almost all frost protection measures become ineffective [Gohil, 2020].

Effective frost prevention necessitates various sensors and meteorological stations for each field to be monitored and protected. Local weather station data may not always be reliable. On-farm weather stations provide the most reliable weather information and should be linked to a frost alarm. This warning will sound dependent on the relative humidity and should be accurate to the nearest 0.1°F. We should never install a temperature sensor or weather station adjacent to a building or body of water so that the sensor's output is correct. Place the sensor so that it is not lower to the ground compared to the lowest flower bud. Sensors should be put in direct touch with or close to the tree's buds or leaves. If your orchard has large slopes, you may consider purchasing two temperature monitoring systems to monitor both the lowest and highest places.

2.2. Geographical assessment of frost damage:

Frost damage occurs when the temperature drops below the freezing point of water (0 degrees Celsius) and can happen practically anywhere outside of tropical zones [Snyder, Melo-Abreu, and Matulich, 2005]. The likelihood for frost damage is mostly dependent on local circumstances. Therefore, it is challenging to provide a geographical evaluation of probable harm. The average duration of the frost-free period, which extends from the final occurrence of sub-zero temperatures in the spring to the first in the fall, is occasionally used to assess the potential for damage regionally. Frost damage rises with latitude, as shown by a global map of average frost-free duration (Figure 3) [Snyder, Melo-Abreu, & Matulich, 2005]. Within the tropics of Capricorn and Cancer, there are large stretches where temperatures seldom drop below freezing. There are occurrences of frost damage on greater altitudes regardless of these tropical climates. Due to the moderating impact of the marine environment on temperature and humidity, and therefore temperature variations and dew or frost development, the likelihood of damage is reduced where the land block is downwind or accompanied by large bodies of water [Snyder, Melo-Abreu, and Matulich, 2005]. Although the map shows the average length of frost-free time is a good general reference for determining where frost damage is most likely to occur, it is not a comprehensive map. Again, the likelihood of freezing temperatures is influenced by local variables that cannot be accurately depicted on a global map. Even though frost damage happens seldom, it can nevertheless result in economic losses for producers.

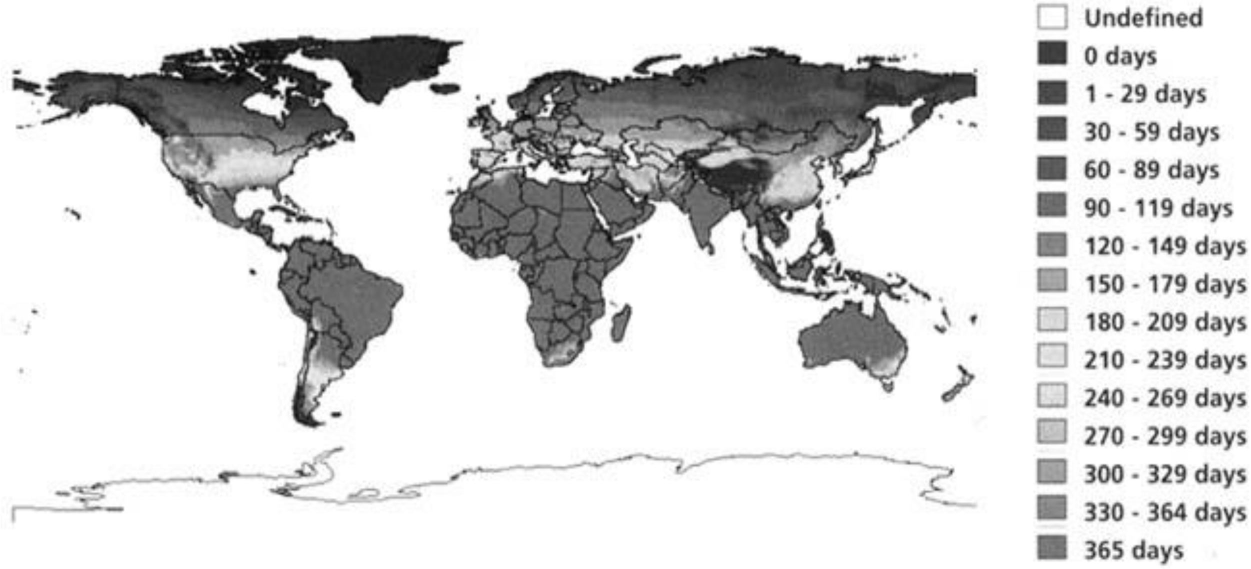


Figure 3: The average number of frost-free days around the world. [Snyder, Melo-Abreu, and Matulich, 2005]

While more and better geographical information on the danger of frost damage is necessary, reliable local knowledge and monitoring are vital. The majority of farmers have a strong understanding of the location of cold spots in their region. Before planting sensitive crops in a particular location, it is highly advisable to discuss with neighbours. Low locations where chilly air pools should typically be avoided. Avoid situations where natural or manmade terrain prevents cold air from escaping the site. Since ground fog occurs earliest in low areas, a good rule of thumb is to avoid regions where it forms first. Before planting frost-sensitive crops on high-risk areas, it is important to consult local topographical maps.

2.3. Frost protection methods:

Direct and indirect approaches to frost protection [Bagdonas, George, and Gerber, 1978] and passive and active approaches [Kalma et al., 1992] are two common classifications. Preventative or passive approaches are those that are implemented well in advance of a frost occurrence. These include cultural practises such site as well as cultivar the choice, orchard floor care, and modulation of orchard nutrition [Gohil, 2020]. Active procedures are transient and either labour or energy intensive, or both. Passive measures include biological and ecological actions, such as those implemented before to a frost night to limit the risk for harm. Methods that are physically based and energy consuming are considered active. They necessitate work on the day or night preceding the frost occurrence. During the frost night, active protection consists of heaters, sprinklers, and wind turbines that compensate natural energy losses.

2.3.1. Passive methods:

Passive methods are the ones that are selected beforehand the frost occurances. They are also called preventative methods:

2.3.1.1. Site selection:

Site selection is the most significant frost protection measure. Considerations include soil type, slope and aspect, and cold air drainage. Most cultivators are aware of areas that are more susceptible to harm than others. Low points in the local topography typically experience lower temperatures and hence more damage. Nevertheless, damage can often occur in one region of a cropped area but not in another despite the absence of obvious topographical distinctions.

For certain crops, cold temperatures are favourable; however, temperatures below zero that induce frost damage are undesirable. The challenge is to identify areas with favourable microclimates for high-quality cultivation without yield loss from harmful temperatures.

The next stage in picking a place for a new planting is speaking with locals about which crops and kinds are suitable for the region. Typically, local farmers and extension agents have a solid sense of which areas may be troublesome. Avoid planting in regions where low-lying ground fogs occur initially. Radiation fogs originate near the ground, similar to radiation frosts [Snyder, Melo-Abreu, & Matulich, 2005]. This is not to be confused with high inversion fogs, which occur much above the surface, or ocean or huge body of water-generated steam fogs. In fact, regions with significant inversion or steam fogs are less susceptible to frost damage.

The next step in finding a suitable planting location is to search for climate information that describes the possibility and danger of frost damage. Before incurring losses due to frost damage, it is important to undertake a minimum temperature study of the place of planting during a minimum of one frost season, especially in areas where climatic data is restricted or unavailable [Snyder, Melo-Abreu, and Matulich, 2005]. A Stevenson screen conventional weather shelter equipped with a constantly recording sensor would be ideal for daily air temperature monitoring [Snyder, Melo-Abreu, & Matulich, 2005]. A benefit of utilising a Stevenson screen (Figure 4) is that the temperatures can be compared to climatic data from weather services that shelter their equipment with Stevenson screens. Also useful, if

Figure 4: Stevenson screen weather shelter. Photo by Metcheck weather instrumentation.

available, are measurements of relative humidity, wind speed and direction. Digital humidity and temperature detectors have become more prevalent in recent decades.

Temperature sensors are commonly positioned between 1.25 and 2.0 metres above the earth, regardless of the sensor shield. The selected height should correspond to that utilised by the local weather service. A wooden stand with an unshielded thermometer is called a "actinothermal index" and is used by certain meteorologists and farmers [Durand, 1965; Perraudin, 1965; Schereiber, 1965]. The unprotected thermometers ought to indicate roughly the same temperature as a twig or branch of a plant. Gathering night-time data on ten to twenty frosty nights should be enough to evaluate a site's appropriateness and determine the likelihood of frost damage [Bouchet, 1965].

2.3.1.2. Effects of different soil types on frost protection:

Growers under the same basic meteorological and topographical circumstances sometimes see inexplicable variances in frost damage. Possible factors include variations in soil type, groundcover, soil water content, and concentrations of ice-nucleating bacteria. Without a doubt, soil composition plays a significant role in deciding where to establish. For instance, marshes that have just been drained are particularly vulnerable to freezing temperatures [Blanc et al., 1963]. Dry, highly organic soil close to the surface decreased thermal conductivity and heat capacity, which was believed to be the reason of the lower minimum temperatures. Soil temperatures can rise by as much as 3 degrees Celsius when organic matter is added to mineral soil [Valmari, 1966]. In general, the surface temperature range is narrower (i.e. the variation between the surface highest and lowest temperature is less) in soils with higher levels of thermal conductivity and heat capacity [Snyder, Melo-Abreu, and Matulich, 2005]. When the temperature range is narrower, the crop's lowest surface and air temperatures are often higher.

Soils that are dark in color, have a high moisture content, and have a poor thermal conductivity [Snyder, Melo-Abreu, & Matulich, 2005] likely to absorb greater amounts of sunlight than lighter, drier, sandier soils. This makes them less diffusive and more vulnerable to frost damage. While compared to sand and clay, organic (peat) soil has a lower heat capacity while dry, but a higher heat capacity when wet [Snyder, Melo-Abreu, & Matulich, 2005]. Nevertheless, regardless of soil moisture content, thermal conductivity is fairly low. Due to the poor diffusivity, crops grown on organic soils are significantly more susceptible to frost damage. Avoid growing on organic (peat) soils when picking a location in a frost-prone zone.

2.3.1.3. Cold air drainage:

As shown in Figure X from the research of [Snyder, Melo-Abreu, and Matulich 2005], air that is cold is denser compared to warm air and hence moves downward and gathers in low areas. That is the reason locations which are low-lying, chilly should be avoided unless sufficient, cost-effective, active protection mechanisms are incorporated into the long-term management plan. This is crucial on both the regional and agricultural levels.

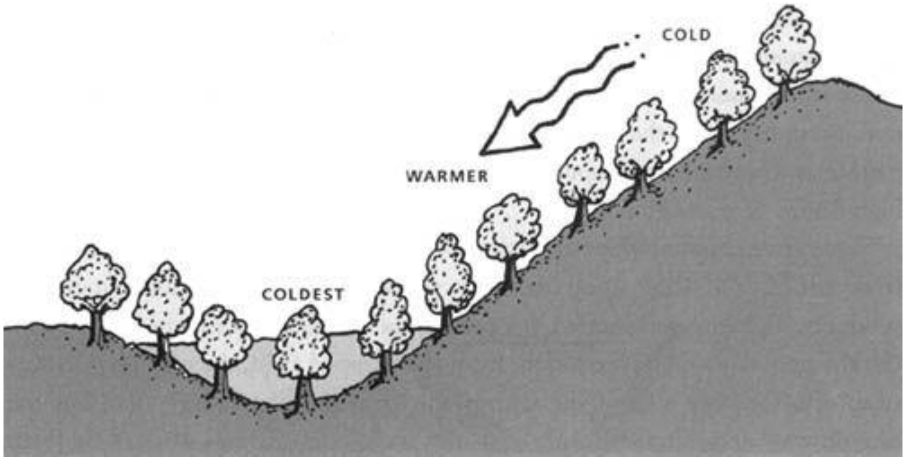


Figure 5: Cold air drains downhill and settles in low spots, where frost damage is most likely.

Trees, shrubs, mounds of soil, stacks of hay, and fences are sometimes utilised to manage air movement around agricultural areas, and the arrangement of these elements might alter the likelihood of frost damage. Blocking the flow of cold air away from a cropped field might increase the risk of frost damage [Snyder, Melo-Abreu, and Matulich, 2005]. This is because the air will pool behind the obstacle and stay colder for longer. This phenomenon occurs frequently when the terrain of an area is altered by road or building construction. A thorough examination of topographical maps may frequently avert significant frost damage issues. Smoke bombs and similar smoke generating devices can be useful for studying the night-time down slope movement of cold air [Snyder, Melo-Abreu, and Matulich, 2005]. These experiments must be conducted on nights with features of radiation frost, although not necessary when the temperature is below zero. Once the cold air drainage flow pattern is determined, diversion barriers may be strategically placed to give a high level of protection.

Deciduous crops planted on south-facing slopes typically blossom later in the spring and receive substantial shade from the afternoon sun [Snyder, Melo-Abreu, & Matulich, 2005]. As the spring progresses, the likelihood of freezing reduces significantly, and deciduous plants on slopes facing the sun will bloom sooner. Consequently, deciduous crops on sun-facing slopes are more sensitive to frost damage.

2.3.1.4. Plant selection:

There are substantial variances in the susceptibility of crop kinds to frost damage, and local agricultural experts often know which varieties are more or less susceptible to frost damage. It is essential to pick plants that prevent harm by developing and maturing during low-risk seasons, as well as those that are more resistant to cold temperatures. Most deciduous fruit trees including vines, for instance, are immune to frost damage in the full extent of their structure, including their trunk, branches, and latent buds [Snyder, Melo-Abreu, & Matulich, 2005]. Selecting deciduous plants with a delayed bud break and blooming pattern gives excellent protection against frost damage, since the likelihood and risk of frost damage diminishes dramatically in the spring.

Consider the timing of sensitive phases and the critical damage temperature in relation to the chance and danger of sub-zero temperatures when selecting a crop or variety to grow in a certain region. If times with a high possibility of freezing cannot be avoided, plants are selected based on their capacity to withstand subfreezing temperatures. What is also important is the choosing of deciduous species to plant within a region on locations with varying exposure. For instance, early blooming kinds may be planted on a hill facing away from the sun, which may delay flowering, but late blooming varieties may do better on a slope facing the sun.

2.3.1.5. Canopy trees:

In general, tree temperatures are higher compared to the clear sky; hence, the downward long-wave radiation from trees is larger than the sky. This method can occasionally be used to protect crops against frost damage. Intercropping citrus and date palms in the Southern California desert, for instance, is a common practise because the date palms provide a few frost protections to the citrus plants while also yielding a marketable product themselves [Snyder, Melo-Abreu, & Matulich, 2005].

2.3.1.6. Plant nutrition management:

Nitrogen fertiliser and other nutrients have been shown to affect frost susceptibility. Generally, unhealthy trees seem to be more prone to harm, whereas fertilisation enhances plant health. Inadequately fertilised trees tend to shed their leaves faster in the fall, blossom earlier in the spring, and be more susceptible to bud frost damage. Summer pruning and/or fertilisation was suggested by [Powell and Himelrick, 2000] to increase fruit production and vitality in peaches and blueberries but was not suggested for apples and pears.

When plants store photosynthates in their vulnerable tissues, they are better able to withstand damage from cold [Proebsting,1978]. As a result, plants that are well-nourished and well-maintained are more likely to adapt to their environment and endure cold temperatures [Alden and Hermann, 1971; Bagdonas, Georg, and Gerber, 1978].

However, the link between particular nutrients and enhanced frost resistance is unclear. Frost damage can also be exacerbated by parasitic infections, defoliation, heavy harvests, and harvest delays.

Nitrogen, in general, makes plants more vulnerable to frost damage [Alden and Hermann, 1971; Bagdonas, Georg, and Gerber,1978]. To promote plant hardening, avoid applying nitrogen fertiliser in late summer and early fall. New growth often contains less solutes than older, hardened plant components. Since solutes in water contribute to lowering the freezing point, every management action that promotes growth reduces solute concentration and heightens freezing sensitivity.

Plants' acclimatisation is aided by phosphorus, but fresh development is more vulnerable to freezing temperatures after receiving the nutrient [Bagdonas, Georg, & Gerber, 1978]. The healing of frozen tissue, however, relies on phosphorus since it is required for cell division. Many frost-tolerant cultivars are able to acclimatise to their environment by taking up more phosphorus from cold soils [Alden and Hermann,1971].

Potassium aids in water regulation and photosynthesis in plants. Because protoplasm dehydration is a common cause of frost damage, increasing potassium levels can enhance photosynthesis and acclimatisation. The merits of potassium for frost protection are debated amongst academics [Alden and Hermann,1971; Ventskevich, 1958; Bagdonas, Georg, and Gerber, 1978].

2.3.1.7. Proper pruning:

Pruning encourages new growth of trees, so late pruning is recommended for deciduous trees and grape vines. Pruning peaches later, around the time they show their pink buds, minimises the amount of fruit buds lost to winterkill and puts off blooming [Powell and Himelrick, 2000]. The late pruning increases the number of living buds and delays blossoming. Early pruning promotes growth close to the wounds, but in areas where winter temperatures are frequently below freezing, it also permits pathogenic bacteria to enter the plant through the cuts and spread more quickly [Savage, Jensen, and Hayden,1976].

Even if frost destroys buds stimulated by early pruning, double pruning ensures that sufficient wood is still available for harvest [Blanc et al., 1963; Bouchet, 1965]. Lower branches should be pruned before the possibility of frost damage, as suggested by [Powell and Himelrick, 2000]. Damage from a radiation frost typically works its way up from the ground in deciduous orchards. This method will therefore improve the prospects for a fruitful crop in the case of a frost.

2.3.1.8. Cooling to delay bloom:

It is well known that operating sprinklers during warm days in the winter can delay bloom and hence provide a measure of frost protection [Anderson *et al.,* 1973; Proebsting, 1975]. The crop is cooled by sprinklers because evaporation transforms sensible to latent heat, which lowers the temperature. In the spring, the probability of sub-zero temperatures drops considerably over short periods of time, therefore delaying the blooming of crops by chilling them reduces the likelihood of frost damage.

Research on several deciduous tree species has shown that bloom delays of two weeks or more are possible by sprinkling from breaking of rest to bloom whenever the air temperature is above 7 °C [Powell and Himelrick, 2000]. However, the advantages of sprinklers depend on the temperature and humidity. When sprinklers are activated, the temperature will decrease close to the wet-bulb temperature; hence, there is no value to attempting to cool by sprinkling in humid conditions when the dew-point temperature is close to the air temperature.

Although research has shown that fruit tree bloom is delayed by sprinkler operation, [Powell and Himelrick, 2000] noted that the method was not widely adopted because of crop production reductions that are not understood [Powell and Himelrick, 2000]. [Evans, 2000] also reported the use of sprinklers for bloom delay in apple and peach trees. However, he recommended against the procedure because, although bloom is delayed, the increased sensitivity of buds to frost injury counteracts the benefits of bloom delay. [Evans, 2000] noted that the buds regain hardiness after being wetted if allowed to dry during a cool period. Although there is no known study on the subject, an alternative to using sprinklers may be to fog or mist the air. Without adding water to the soil, this might chill the air. Depending on the frequency and severity of freezing in the region, this may or may not be a cost-effective solution.

2.3.1.9. Plant covers:

Plant row coverings improve night time downward long-wave radiation and decrease heat convection losses (and advection). Covers should ideally have a low coefficient of conductivity and are opaque to long-wave radiation. Since dry soil has a poorer heat conductivity, it is frequently utilised to protect young tree trunks during relatively brief sub-zero periods.

Row coverings are occasionally used to safeguard high-value crops. Woven and spun-bonded polypropylene plastics are typically used and the degree of protection varies with the thickness of the material (e.g. from 1°C for thin sheet plastic to 5 °C for thick plastic) [Snyder, Paw U and Thompson, 1987]. White plastic offers some protection and is occasionally used for nursery plants. It is not commonly used for protecting fruit and vegetable crops.

During the day, transparent plastic coverings enable sunlight to flow through and reduce heat loss at night. The downward radiation from the sky at night relies on the apparent temperature of the sky; thus, when covered with plastic, the downward radiation mostly depends on the temperature of the plastic cover. As the sky is significantly cooler than the air near the ground and the plastic will have a temperature closer to that of the air, covering the plants increases their downward radiation. If condensation accumulates below the plastic, it will produce latent heat, which will warm the plastic and give even more protection. Under situations of advection frost, plastic covers may also block wind and provide some protection. Some features of above-plant row coverings are described in Table X [Snyder, Paw U and Thompson, 1987].

Numerous techniques are used to cover the plants and secure the plastic. On occasion, plastic coverings are installed on hoops to prevent plants from being handled. Otherwise, the plastic may float on the canopy and rise as the plants develop, but disease issues are more likely to occur.

A prevalent issue is that the labour requirements for applying coverings are significant, necessitating a high crop value. In addition, the plants grow less resistant to cold and pollination issues often arise if the coverings are not removed after a frost occurrence. The expense of labour has hindered widespread usage of plastic coverings.

Tunnels and plastic greenhouses are heated during extremely severe frost episodes. The tunnels are heated using hot water, electricity, water vapour, hot air, and so on. Ventilation and mechanisation challenges have increased the use of large tunnels, with or without heating. Many materials enable water and insecticides to permeate through the coverings, which somewhat restrict light penetration.

Table 1: Row cover characteristics for frost protection

Type of cover	Protection	Comments
Clear polyethylene (hooped)	Fair	Inexpensive- Labour intensive

Clear polyethylene(floating)	Fair	Excessive heat build up
Slitted polyethylene	Fair	Allows heat escape- Hard to install
Perforated polyethylene	Fair	Excessive heat build up
Spun bonded polyester(floating)	Good	Possibly abrasive- High cost
Spun bonded polypropylene (floating)	Good	High cost
Extruded polypropylene(floating)	Fair	Inexpensive- Tears easily

SOURCE: From University of Georgia Extension Publication Cold Weather and Horticultural Crops in Georgia: Effects and Protective Measures [Snyder, Paw U and Thompson, 1987].

2.3.1.10. Avoiding soil cultivation:

Plants should not be cultivated at times when frost is predicted to pose a threat. There are many air voids in the soil, and the air is a poor conductor with a low specific heat. Therefore, soil with a greater number and size of air gaps will transport and store less heat. Cultivation tends to generate air pockets in the soil, which chills the soil. For instance, [Smith, 1975] found that in Holland, ploughing in the spring resulted in more frost damage than ploughing in the fall. By lowering soil pore sizes and improving thermal conductivity and heat capacity, rolling to break up clods and compress the soil, followed by watering, improves heat transmission and storage [Brindley, Taylor, and Webber, 1965].

2.3.1.11. Irrigation:

Heat capacity and thermal conductivity of soils are greatly affected by soil water content, with large differences between dry and wet soils in thermal conductivity and heat capacity. Nearly all publications on preventing frost recommend keeping the top soil layer moist, but not drenched. [Snyder, Paw U and Thompson, 1987] recommend wetting to a depth of 30 cm because diurnal temperature variation is insignificant below 30 cm. The amount to be applied varies based on soil type and initial moisture level. Normal rainfall requirements range from 25 mm for light (sandy) soils to 50 mm for heavy (clay) soils.

Typically, heat transfer beneath 30 centimetres of soil depth is substantial and may affect frost protection if a soil remains dry for a lengthy period. If the soil is dry and limited precipitation is expected prior to the frost season, irrigation to depths of 1 to 1.5 metres will enhance the soil surface temperature throughout frost-prone times. Growers may irrigate their soil prior to a sub-zero night to darken the soil and boost solar radiation absorption; however, there is greater evaporation from a wet soil surface, thus the benefit of soaking to darken a soil is frequently offset by increased energy loss to evaporation.

2.3.1.12. Removing cover crops:

When grass or weeds are prevalent in an orchard or vineyard, more sunlight is reflected from the ground and daylight evaporation is increased. Cover crops lower the amount of energy stored in the soil throughout the day; hence, less energy is available for upward heat exchange during frost nights. The vegetation also impacts the transmission of energy from the soil to the radiating surface at the top of the plant, which may have an effect on the temperature variations between bare soil and cover crops. Therefore, frost damage is more likely to occur in an orchard or vineyard that has a grass or weed cover crop instead of bare soil between the rows [Blanc et al., 1963; Bouchet, 1965; Snyder, Paw U, and Thompson 1987]. The literature reports a variety of temperature impacts of cover crops, but all agree that the existence of a cover crop will enhance the possibility for frost damage.

[Snyder and Connell, 1993] used an infrared thermometer and found that during the months of February and March, the surface temperature of bare soils was usually 1 to 3 degrees Celsius warmer than soils with grass and weed cover crops higher than 0.05 metres. The cover crop was eradicated with a herbicide at the beginning of December, so the orchard floor had approximately 2 months to establish temperature and canopy variations. During the winter, however, the weather was often overcast and foggy. On most days, they discovered that the grass-covered orchard floor was cooler, but an exception occurred after many days of high, dry wind. The wind seemed to dry the surface layer of bare soil more than grass-covered soil, reducing thermal conductivity and preventing heat storage. After this time, the bare earth was much cooler than the grass-covered soil. Therefore, after several days of drying wind, it is suggested to water exposed soil surfaces to increase heat transmission and storage.

In a comparison done by [Snyder, Melo-Abreu, and Matulich, 2005] Table X displays the number of days where the lowest temperature in the mowed or sprayed plots was higher, lower, or approximately the same as in the cultivated plots. Mowing and horticulture have comparable impacts on the lowest temperature, with mowing having a slightly cooler effect. However, applying pesticide to suppress weeds resulted in days with the same or higher minimum temperature. According to a frequency analysis and chi-square test, the lowest temperature was typically 0.25 to 0.5 degrees Celsius higher than the other treatments. In a different experiment, [Leyden and Rohrbaugh, 1963] discovered an average temperature rise of 0.9 °C at 1.5 m height on frost nights only when grass was destroyed using sprays as opposed to having a grass cover crop. Due to the many climatic, soil, and plant elements that influence the temperature observed over cover crops, it is not feasible to provide uniform protection statistics for cover crop management. However, it is well established that removing or reducing cover crops in orchards and vineyards is advantageous. Numerous instances exist of farms suffering major crop losses when cover crops were used, yet losses were low when cover crops were not utilised.

Table 2: Days where the lowest temperature in the mowing or herbicide spray treatments was higher, lower, or the same as the cultivation treatment in grape vines from March to May, 1987 to 1989. Source: [Snyder, Melo-Abreu, and Matulich, 2005]

Year	Mowing			Spraying		
	Warmer	Same	Colder	Warmer	Same	Colder
1987	7	39	18	24	21	4
1988	13	44	22	58	21	1
1989	4	32	7	17	23	2

Tall cover crops (such as grasses and weeds) shield the soil from heat transmission and may impede the drainage of cold air, resulting in increased frost damage. However, under-tree sprinkler frost protection devices may benefit from taller cover crops since they give a larger freezing surface area [Evans, 2000]. The use of under-tree sprinklers is aided by a tall cover crop, according to studies conducted in Bologna, Italy [Anconelli et al.,2002]. Their theory is that the surface temperature of a wet surface is kept near to 0 °C, and that by growing a cover crop, the surface height may be increased, so increasing the 0 °C level. Although protection may be boosted by the presence of a tall cover crop, it is more probable that an active means of protection will be required if a cover crop is present.

Their premise is that the wetted surface temperature is maintained at a level close to 0 °C and that increasing the surface altitude by cultivating a cover crop would increase the 0 °C level. Although protection may be boosted by the presence of a tall cover crop, one is more likely to require an active protection approach if there is a cover crop.

2.3.1.13. Soil covers:

- **Plastic soil covers:**

Plastic may be used to directly cover the soil to increase the surface temperature and give some protection. This is particularly true for tiny plantations (such as gardens or small orchards) for whom alternative security strategies are unavailable. Any management that increases the lowest surface temperature will increase protection [Snyder, Melo-Abreu, & Matulich, 2005]. This is because the air temperature over the ground is connected to the surface temperature. If the nightly minimum surface temperature is consistently higher for the plastic-covered area compared to the uncovered surface, the plastic should be left on the soil. If the plastic-covered soil has a lower minimum temperature, it must be removed.

Soil heat storage is often improved and the lowest surface temperature is raised when plastic mulches are used [Snyder, Melo-Abreu, and Matulich, 2005]. Due to the strong relationship between surface temperature and air temperature in a plant canopy, a greater surface temperature will offer some protection. Black plastic absorbs significant amounts of radiation, but the air gap between it and the ground prevents heat transmission to the earth, which has a larger heat capacity. As a result, black plastic is less efficient at protecting against frost. Wetting the soil prior to covering it with plastic enhances heat storage, which increases the surface's minimum temperature and offers further protection. More radiant energy is able to penetrate the soil surface through transparent plastic [Snyder, Melo-Abreu, & Matulich, 2005]. Water evaporating from the soil and condensing on the bottom of the plastic when the covering cooled down to the dew-point temperature contributes to the higher surface temperature when the soil is wetted prior laying the plastic. This will convert latent heat beneath the plastic to perceptible heat and assist preserve a higher surface temperature.

- **Organic mulches:**

In very cold environments where soil water freezes, soil heaving may cause root injury. Because snow insulates against substantial daily variations in soil temperature, frost heaving damage to roots is less frequent in areas with a snow cover [Snyder, Melo-Abreu, and Matulich, 2005]. In the absence of snowfall, organic mulches are occasionally utilised to prevent daily soil temperature fluctuations and frost-induced root damage. However, in orchards where the soil does not freeze, organic mulches should be avoided since the earth stores less heat throughout the day. The presence of organic mulch (such as straw or sawdust) minimises evaporation but increases the minimum daily air temperature. Minimum surface temperatures are lowered by the mulch, which in turn causes a decrease in the minimum air temperature [Snyder, Melo-Abreu, and Matulich, 2005].

2.3.1.14. Painting trunks:

Sometimes, the bark of deciduous trees cracks owing to extreme temperature variations. When the light is unexpectedly blocked, the temperature of a tree's bark may decrease drastically, resulting in longitudinal fissures. On the sunny side of deciduous tree trunks, where damage is most severe, temperature differences between the air and bark are often on the order of 20 °C. Painting the trunks with interior-grade liquid-based latex white paint mixed with 50% water to reflect light during the day is one way to mitigate this issue [Powel and Himelrick, 2000]. Avoid using toxic paints that include oil. When the outside temperature is over ten degrees Celsius in the late fall, it is the best time to paint tree trunks. Wrapping peach trees in white paint, insulation, or other materials has been shown to increase their resistance to frost damage [Jensen, Savage, & Hayden, 1970].

Late winter's high cambial temperatures induced by noon radiation on the trunk are mitigated by the paint or wrapping, which otherwise would have weakened the tree. It has been found that painting apple tree bark white significantly lowers bark temperature and delays blooming by a few days [Zinoni et al., 2002 a], both of which lessen the likelihood of frost damage.

2.3.1.15. Trunk wraps:

Insulating wraps are composed of air-filled fabrics that restrict heat transmission. However, if the gaps are filled with water, the material's conductivity rises significantly. A crucial aspect of employing insulating wraps is preventing the material's air gaps from being saturated with water.

Wrapping tree trunks in fibreglass or polyurethane raises the temperature inside by roughly 8 degrees Celsius over the ambient temperature, as stated by [Fucik, 1979]. Trunk wraps reduce the time spent in potentially dangerous conditions by slowing the pace at which heat is lost. Wrap efficiency may be estimated by dividing the hourly rate of change in bark temperature by the hourly rate of change in air temperature [Fucik and Hensz, 1966]. The value 0.45

was proposed for wraps that provide adequate protection. On a night when the air temperature was falling at 1.11 °C per hour, [Fucik, 1979] recorded the ratios of 0.47, 0.58, and 0.92 for 76mm polyurethane, 25mm polyurethane, and "air flow" wraps. The trunks coated in 76 mm polyurethane were unharmed, however the trunks wrapped in the other two materials were frozen. [Savage, Jensen and Hayden, 1976] found bark to air temperature ratios of an aluminium foil lined with fibreglass wrap was 0.38, which is comparable to the 75 mm polyurethane.

Compared to the yearly cost of constructing and removing soil banks, the cost of tree trunk wraps is only around $0.20 more per tree, according to a calculation by [Fucik, 1979]. Since permanent tree wraps don't require any upkeep and the only additional cost is about $0.15 per tree for removing after 3 to 4 years, they are more affordable than temporary wraps. Polyurethane does not attract rodents, and the wrappings protect the tree trunk from more harm. The biggest disadvantage is the increased likelihood of illness complications. Root rot (Phytopthora parasitica) may be a concern when employing tree covers. Consequently, the bud unions must be at least 0.15 metres above the ground. Before wrapping, fungicide treatments assist to prevent root rot. To minimise damage to exposed surfaces, the wrappings must be carefully wrapped around the trunk.

2.3.1.16. Bacteria control:

At 0 degrees Celsius, water melts but does not always freeze. To cause freezing, the ice forming process must be begun (i.e. ice nucleation). Homogeneous ice nucleation happens when liquid water is cooled to extremely low temperatures (typically below -40 °C), and the water molecules organise themselves to a crystalline (ice) structure without the presence of any external materials or agitation [Snyder, Melo-Abreu, and Matulich, 2005]. When super-cooled water is agitated or when foreign (ice-nucleating) particles are added to initiate the ice crystal formation process, heterogeneous nucleation occurs. When silver iodide is sprayed into clouds, for instance, it causes super-cooled cloud droplets to freeze because it starts the phase shift from water to ice.

Most ice formation on plant surfaces is caused by ice-nucleation active (INA) bacteria when temperatures are above -5 °C [Lindow, 1983]. In fact, until temperatures hit about -8 °C to -10 °C [Lindow, 1983], some comparatively sterile greenhouse plants do not exhibit ice-nucleation. Major INA bacteria that nucleate ice include Pseudomonas syringae, Erwinia herbicola, and P. fluorescens. P. syringae and E. herbicola may nucleate ice down to -1 °C [Lindow, 1983]. After developing on the plant surfaces, ice then propagates into the plants via holes on the surface (e.g. stomata) and into the extracellular spaces. Depending on the sensitivity of the plant, the production of ice in the extracellular spaces may or may not cause harm.

Although a single bacterium may initiate the ice nucleation process, a significant number of INA bacteria increases the likelihood of harm. Consequently, decreasing the number of INA bacteria minimises the risk of freezing. Commonly, insecticides (such as copper compounds) or competitive non-ice-nucleation active (NINA) bacteria are used to compete with and lower INA bacteria concentrations. Although INA bacteria make up only around 1–10% of the bacteria on plant surfaces, competition from NINA bacteria helps keep the INA bacteria population in check [Lindow, 1983]. Therefore, spraying the plants with more NINA bacteria may assist to compete with and lower the concentration of INA bacteria. Typically, one application of NINA is adequate, since the NINA bacteria continue to expand in population and compete with INA bacteria as the plants develop. Bacteria are killed by bactericides, but rapidly repopulate the plants, necessitating repeated reapplication of bactericides to maintain a low INA bacteria concentration. In addition, the nucleation is caused by amino acids in the bacteria, therefore bactericides must be applied enough in advance of projected frost episodes for the amino acids to breakdown. Additionally, early administration of NINA bacteria is essential to enable the competition to diminish INA bacteria levels. This is problematic if bactericides are employed for a reason other than frost protection.

Concentrations of INA bacteria were reduced by 10- to 100-fold following three weekly administrations with bactericide (i.e. cupric hydroxide) commencing at almond bud break or one application of NINA (competitive) bacteria at 10% bloom [Lindow and Connell, 1984]. Shortly after application, the NINA bacteria had no impact on the population of INA bacteria, but this changed with time. The application of NINA bacteria decreased the concentration of INA, and both the bactericide and NINA treatments reduced frost damage on spurs that were removed and chilled to -3.0 degrees Celsius. In addition to sprays that eliminate or outcompete INA bacteria, there are compounds that impede the capacity of the bacteria to nucleate ice. In vitro studies showed that the activity of INA bacteria is pH-dependent, as well as sensitive to soluble heavy metals (such as copper and zinc) and cationic cleansers [Lindow et al.,1978]. Bacterial ice-nucleation inhibitors are chemicals that block INA action [Lindow, 1983]. These chemicals can kill bacteria in minutes to hours. In an experiment using Bartlett pear trees, when the temperature dropped to -3 °C, the inhibitors $Na2CO3$ (0.1 M), Urea (0.5 M) + $ZnSO4$ (0.05 M), and Urea (0.5 M) +$NaCO3$ (0.1 M) had 0.11, 0.16, and 0.29 fractions of fruit damage, respectively, whereas the control had 0.95 fractions of fruit injury. The materials can be applied just before a frost night, which is a significant benefit. One downside of these compounds is that they might sometimes produce phytotoxicity in plants. It may be necessary to reapply the mixture if it rains, as the active chemicals are water soluble and might be washed away from the plants. [Snyder, Melo-Abreu, & Matulich, 2005].

Numerous commercially marketed sprays claim to give frost damage prevention. In most situations, however, there is little or no proof that they function. Eliminating, outcompeting, or deactivating INA bacteria will lessen the likelihood of freezing and assist prevent frost damage; however, the majority of commercial frost protection sprays are not known to have any impact on INA bacteria. Before buying in frost protection spray, one should obtain a university or credible laboratory's scientific explanation of how a protection spray works. This does not suggest that the spray is useless; rather, it indicates that the data is limited and that it may not function. Purchase no chemicals that claim to prevent frost damage by decreasing desiccation. Frost damage arises from internal dehydration of plant cells, which damages cell walls. It has nothing to do with transpiration

Rarely have growers utilising chemical sprays to prevent frost damage achieved success. The bulk of reliable results come from scholarly controlled experiments. Chemical sprays (such as zinc, copper, and anti-transpirants) were shown to have no noticeable benefit in the few scientific research undertaken on deciduous trees grown in Washington State, USA [Evans, 2000]. Similarly, sprays designed to kill "ice nucleating" bacteria are not being shown effective since "natural" ice-nucleation materials present in the bark, stems, etc. more than make up for any bacterial deficiencies [Evans, 2000]. Clearly, the outcomes of chemical sprays for frost protection are inconsistent. The considerable variety in INA bacteria on various crops contributes to the problem. Deciduous trees and grasses, for instance, often contain far larger populations of INA bacteria than citrus and grapevines. Some of the variation in results can be attributed to these distinctions. Additionally, research is being done to determine the optimal time and chemical concentration for spraying. In conclusion, it is generally known that INA bacteria are involved in ice nucleation on plants, hence lowering INA bacteria densities can give some frost protection. However, further study is certainly needed to identify if and when suppression of INA bacteria is advantageous, and which treatment will yield acceptable outcomes.

2.3.1.17. Seed treatment with chemicals:

Seed and plant treatments with micro- and additional metals (Cu, B, Mg, Zn, Al, Mo, Mn) have been shown to boost freeze resistance in several situations [Bagdonas, Georg, and Gerber, 1978].

2.3.2. Active methods

Methods of active protection include actions taken during a frost night to lessen the consequences of sub-zero temperatures. These strategies include:

2.3.2.1. Heaters

In a frost condition, one way to compensate for the crop's energy losses is to burn a large amount of fuel (solid, liquid, or gas) in a variety of heaters. Depending on the position of the heaters in relation to the plants, a portion of the radiation is directly intercepted by plant parts, thereby increasing the temperature of the plants. Calm conditions with little to no wind and the existence of a severe inversion favour the effectiveness of this technique.

The heaters generally fall into two groups. There are heaters that heat metal items (such as stack heaters) and those that function as open fires. Safeguarding with heaters is theoretically reliable, and growers favoured this strategy until pollution issues and high fuel prices relative to crop value rendered it too costly for many crops. Currently, heaters are used mostly as a supplement to other measures during serious frost events and for crops with high value.

2.3.2.1.1. Theory of operation

During a frost night, the crop's natural energy losses exceed its energy gains, causing the temperature to decrease. Energy is primarily lost to net radiation, with a portion of these losses being restored by soil heat transfer toward the surface. If condensation (such as dew or frost) happens, then latent heat can be produced to compensate for some of the energy loss. Heaters give additional energy that helps compensate for the net energy loss. If enough heat is added to the crop volume to compensate for all losses, the temperature will not drop. Nevertheless, there is an inefficiency in the functioning of heaters, and under some conditions it is prohibitively expensive to supply sufficient energy to compensate for the inefficiency of the system. Effective planning and management can increase the crop's protection against the majority of radiation frost conditions. When there is no or little inversion and the wind is blowing, the heaters may not be able to provide effective frost protection since they give frost protection through direct radiation to the plants surrounding them and by producing convective circulation of air within the inversion zone.

The majority of a heater's energy is emitted in the form of hot gases and warm air, which mostly heats the surrounding air by convection. Plants in close proximity to the heaters that have a clear line of sight to the heaters will benefit directly from the heaters' radiation. Nevertheless, based on the crop structure and canopy density, only a tiny fraction of the radiant energy from stack heaters gets absorbed.

The temperature of the air exiting a stack heater ranges from 635 °C to 1000 °C [Snyder, Paw U, and Thompson, 1987], hence the less dense heated air will quickly ascend after leaving a heater. As hot air rises, it rapidly cools due to entrainment with cooler surrounding air until it reaches a height where the ambient air temperature is approximately the same. The air then disperses and mixes with other air above. Ultimately, the mixed air will cool down, get denser, and descend, therefore establishing a circulation pattern in the inversion layer. If the inversion is weak or if the flames are too large and intense, the heated air will ascend too high, preventing the formation of a circulatory pattern in the inversion.

Modern heaters exert a greater influence on the temperature of released gases in order to decrease buoyancy losses and increase efficiency. The most effective systems have minimal flame and no smoke above the stack. Maintaining the heaters at an excessively high temperature will also shorten their lifespan.

When there is a severe inversion, heated air expands to a lower altitude, and the volume affected by the heaters decreases. Under severe inversions, heaters are more successful at improving the air temperature as the heated volume is less. In situations of mild inversion, heater operation is less effective in increasing air temperature because there is a larger volume to heat. Under situations of mild inversion, the use of a fuel with a greater proportion of energy output to radiation than the air heating will enhance protection. This proportion is often enhanced by adding additional and smaller heaters with heat-retaining exhaust funnels. Also, when flames are very large or hot, the heated air could rupture through the top of the inversion and if the circulation in the inversion layer is reduced, heaters are less effective at warming the air. [Snyder, Paw U, and Thompson, 1987].

2.3.2.1.2. Smoke effects

Nowadays, it is common knowledge since the protection from heaters is provided by the heat emitted by the flames, not by smoke creation. [Collomb, 1966]. Smoke does obscure the sky and impede vision, but its effect on the perceived temperature of the sky is insignificant. The average smoke particle has a diameter of less than 1.0 mm [Mee and Bartholic, 1979], thus lowers radiation in the visual range (0.4-0.7 mm) but has no influence on long-wave radiation transmission. Consequently, the majority of the upward long-wave radiation from the ground flows through the smoke without becoming absorbed. Smoke has little influence on upward or downward long-wave radiation at night, and hence provides no frost protection benefit [Snyder, Paw U, and Thompson, 1987]. Since smoke provides little or no value and pollutes the air, it is preferable to limit smoke generation and optimize the thermal efficiency of combustion. Smoke before sunrise obstructs solar radiation and retards field heating, which can result in increased fuel use and potential crop damage. There are claims that progressive thawing of frozen citrus minimizes damage [Bagdonas, Georg, and Gerber, 1978], although there is no evidence to support this claim, according to other claims. [Burke et al., 1977]. If real, smoke may be advantageous, but contemporary pollution rules prohibit its usage in most regions.

2.3.2.1.3. Heater placement and management:

The distribution of heaters should be relatively uniform, with a concentration of heaters along the perimeter, particularly upwind and in low areas. If the crop is situated on a slope, additional heaters should be positioned on the upslope edge, where frigid air drains into the crop. When the wind speed surpasses 2.2 m s -1 (7.9 km h -1) in frigid conditions, significant heat loss occurs primarily because of horizontal advection, necessitating greater numbers of heaters on the upwind border. Low areas, which are cooler, should have a greater number of heaters. The perimeter heaters should be ignited first, followed by additional heaters as the demand increases.

2.3.2.1.4. Types of heaters:

2.3.2.1.4.1. Solid fuel heaters:

Before liquid or gas fuels were used for frost protection, solid fuels were utilized. As the price of liquid fuels decreased, there was a shift from solid to liquid fuels. When it was discovered that the proportion of radiation to the overall energy emitted was approximately 40 % for burning solid fuels as opposed to twenty-five percent for burning liquid fuels [Kepner, 1951], the use of solid fuels was revived.

As conditions become windier, a higher proportion of radiation to overall energy release is crucial. The main drawback of solid fuels is the fact that the amount of energy production decreases as the fuel is consumed, limiting energy release when it is required most. [Hensz, 1969a; Martsolf, 1979b]. In addition, solid fuels are complicated to ignite, necessitating an early start.

2.3.2.1.4.2. Gas and Liquid fuel heaters:

In the early 1900s, liquid-fuel radiators were devised for frost protection. As hydrocarbon prices and environmental concerns rose, the method became less popular. The use of liquid-fuel radiators for frost protection remains viable in situations where it is not prohibited by law and the value of fuel is not burdensome. In addition to the cost of the heaters and the fuel, liquid-fuel heaters require significant labour for installation, refuelling, and maintenance. Typically, there are seventy-five to one hundred oil stack heaters or around 150 to 175 propane-fuel heaters on a single hectare, as well as a properly constructed and maintained heater system will generate approximately 1.23 MW ha -1 (or 123 W m -2) of electrical power [Snyder, Paw U, and Thompson, 1987]. The approximate rate of consumption for oil- and kerosene-fuelled heaters is 2.8 litres per hour per heater, while the rate for propane-fuelled heaters is 1 m3 per hour per heater [Snyder, Paw U, and Thompson, 1987]. On an average radiation frost night, over fifty percent of the energy production generated by the heaters is wasted as radiation absorbed by the sky along with convective heat losses, so the heater output is greater than the heat acquired by the crop.

Every second or third heater in a series should be ignited first as one of the most effective methods for lighting heaters. Then return and ignite any remaining warmers. This serves to minimize the loss of convective heat by passing through the inversion layer's uppermost stratum. Carbon will accumulate in free-flame burners and impair their fuel efficiency. Utilizing catalytic solutions can minimize carbon accumulation. They need to be refilled with fuel prior to being run out and then cleansed with the help of a stick or tapped to remove the ash accumulation that lowers their efficacy.

Due to the labour-intensive nature of refilling liquid-fuel heaters, some cultivators have abandoned the use of individual heaters in favour of centralized distribution systems. The systems deliver the fuel directly to the heaters via tubing. The fuel may consist of natural gas, propane in liquid form or gasoline. In advanced systems, additionally to fuel distribution, ignition, combustion rate, and closure are also automated. The installation of centralized systems has a high capital cost, but low operational costs. Propane-fuelled heaters require less maintenance and are simpler to regulate than oil-fuelled heaters. Due to the lower combustion rate, more heaters are required, yet their defence is greater. A vaporizer needs to be implemented to avoid the gas pipe from freezing when the propane supply canister freezes under extreme conditions.

2.3.2.2. Foam insulation:

Deployment of foam insulation to low-growing crops during prevention of frost has been extensively studied, primarily in North America, and indicated to raise the minimal temperature by as much as 12 degrees Celsius. [Braud, Chesness and Hawthorne, 1968]. However, the technique has not been commonly utilized by farmers due to the high cost of labour and supplies, as well as the difficulty of covering whole areas in a brief period of time due to inaccurate frost forecasts. [Bartholic, 1979]. Foam is composed of a variety of substances, but it is primarily air that provides its insulating properties. The foam, when applied, prevents radiation loss from plants and captures energy transmitted upward from the soil. Protection is greatest on the initial night while decreases over time, as the foam prevents energy from warming the soil and plants throughout the day and degrades over time. The secret to producing foam with minimal thermal conductivity is to combine air and liquid in the proper proportions to generate numerous small bubbles.

2.3.2.3. Sprinklers

In comparison to other frost protection strategies, using sprinklers to apply water is more cost-effective. The operational expenses are minimal in comparison to heaters and even wind turbines since the energy consumption is much lower than that utilised in frost protection [Gerber and Martsolf, 1979]. Work is mostly required to prevent a breakdown of the system and the formation of ice on the heads during the night. Sprinklers have several uses besides warding off frost, including watering, improving fruit colour with evaporative cooling, minimising solar damage with watering, postponing bloom till just before bud break, applying fertilizer, and so on. The process also produces minimal environmental impact. The major drawback of sprinklers is the hefty initial investment and the vast volume of water required. The usage of sprinklers is sometimes constrained due to a scarcity of water. Overuse can also produce root issues and impede cultivation along with other management tasks by causing soil water logging. Heavy use of sprinklers has been shown to inhibit soil microbes, which can slow fruit and nut development [Blanc et al., 1963].

When rain or dew falls on a flower, bud, or young fruit, the plant's temperature suddenly rises when the water freezes and releases latent heat. Water vaporises from ice-coated plant tissue, releasing energy as latent heat. As a result, the temperature drops until the sprinklers spin and spray the plant with fresh water, after which the cycle repeats. Keeping the crop's tissue temperature from dropping below freezing between pulses of water is the key to protection when using traditional over-plant sprinklers. Water can be constantly applied at a reduced application rate, but directed to a smaller area with non-rotating, low-volume, over-plant, focused sprinklers.

Applying water at an interval and application frequency that keeps the soil's surface temperature around 0 °C is the goal of traditional under-plant sprinklers. In comparison to an unprotected crop, this boosts long-wave radiation and sensible heat transmission to the plants. The purpose of under-plant micro sprinklers, which use much less water than traditional sprinklers, is to focus and boost radiation and sensible energy transfer upward into the plants by maintaining a temperature of around 0 °C exclusively on the ground underneath them.

2.3.2.3.1. Types of sprinklers:

2.3.2.3.1.1. Under-plant sprinklers.

In areas where frost protection for deciduous tree crops is not necessary until temperatures drop by a few degrees, under-tree sprinklers are a frequent method of frost prevention. The system offers various advantages over over-plant sprinklers, including cheap operational cost, the ability to be used for irrigation, and less disease concerns. In addition, sprinkler system failure or broken branches from ice loading are not issues with under-plant irrigation. Under-plant sprinkler systems need less water each application. The level of protection provided is proportional to both the intensity of the frost night as well as the amount applied. In particular, for low temperatures above -3 °C, [Anconelli et al. 2002] discovered minimal advantage difference between rates of application and sprinkler head types. A higher rate of outflow (65 l/h/tree) was more effective than a lower rate (45 l/h/tree) below -3 °C [Snyder, Paw U, and Thompson, 1987].

The major objective of using under-plant sprinklers is to keep the wetted surface heat at or below 0 °C. Liquid ice provides some insulation since it emits more heat than would an untreated surface. Temperatures in an unheated orchard are typically lowest at ground level and rise as one ascends. The use of sprinklers raises the ground temperature to above freezing, which in turn warms the air surrounding the surface relative to an unprotected crop. Due to the upward sensible heat flow caused by the warmer air at the surface, both the air and the plants are warmed. Furthermore, the sprinkler action raises the water condensation content of air in the orchard, causing precipitation or the formation of ice on frigid plant surfaces, both of which release latent heat and shield the plants. The application rate is appropriate if the soil is coated with a liquid-ice combination and the soil's surface temperature is 0 °C. The application rate is inadequate once all the water that is applied freezes and the soil temperature drops below zero degrees Celsius. It's important to not get the lower branches soaked.

2.3.2.3.1.1.1. Conventional rotating sprinklers:

When employing spinning under-plant sprinklers, [Perry, 1994] estimated that temperatures would climb by 0.5 °C to 1.7 °C up to a height of roughly 3.6 m during a regular radiation frost. According to [Evans, 2000], in a 2.0 m high, cold water-protected orchard, temperatures can rise by as much as 1.7 °C. An almond orchard protected by a gear-driven rotational sprinkler head system instead of impact sprinklers saw an increase of roughly 2 °C at 2.0 m height [Connell and Snyder, 1988]. The sprinkler heads released water at a temperature of around 20 °C, at a velocity of 2.0 mm h -1.

Once the sprinklers have been turned on, they should run without interruption or delay. Irrigate frost-prone regions or locations upwind from exposed orchards if water is scarce. Instead of applying too little water to a greater area, it is preferable to concentrate it on places requiring more protection. Protection is enhanced with a well-balanced application.

2.3.2.3.1.1.2. Micro sprinklers:

The use of under-plant micro sprinklers for watering and frost protection has gained popularity among producers in recent years. Micro sprinklers with two patterns of spray (90° and 360°) and application rates of 38, 57, and 87 litres per hour per tree were used to provide frost protection, as described by [Rieger, Davies, and Jackson, 1986]. Irrigated tree trunks were 1° to 5° warmer than non-irrigated tree trunks on a night as the temperature dropped to -12°C. Temperatures were similar for the 57 and 87 litres per hour per hectare applied rates, but somewhat higher for the trunk than with the 38 litres per hour per hectare applied rate. When the air temperature dropped to -12 °C, the trunk temperatures following the 38 litre h -1 treatment still only dropped to -2.5 °C, thus obviously the use of micro sprinklers plus trunk wraps was advantageous. The authors also noted that a 90-degree spray pattern was more effective than a full 360-degree one. Air temperature and humidity were not significantly different between the irrigated or non-irrigated treatments, although the irrigated plots received more upward long-wave radiation.

Covering a bigger area with water provides more protection, but water put under the plants provides even more protection because of radiation and convection compared to water placed in the spaces between the rows of crops. On the other hand, the ice will cool more quickly if the same volume of water is dispersed over a bigger surface. Again, the ideal course of action is to provide enough water to cover as much ground as possible and guarantee that a layer of liquid ice combination covers the surface even when the weather is at its worst.

2.3.2.3.1.1.3. Drip irrigation:

Frost protection with drip irrigation systems has mixed success. The major reason that water applications are helpful is that freezing water upon the ground releases latent heat. Yet, if rates of evaporation are high enough, more energy may be wasted to evaporate water than is obtained through the freezing process. It is challenging to generalise about the efficacy of drip irrigation systems due to the large variation of system elements and application rates. Water near the ground's surface is considered useful if it is a liquid-ice combination at 0 degrees Celsius. However, if all of the water solidifies and turns white from ice, the system failed to work as intended. It's important to remember that using a drip irrigation system when frost is present might cause harm if the freezing is very severe. Heating the water will make it less likely that damage will occur and will offer additional protection. However, heating might not be financially viable.

2.3.2.3.1.1.4. Heated water:

It was found by [Davies et al., 1988] that the primary mechanism of heat delivery to orchards while under-plant sprinkling is the cooling of water droplets as they travel across the air. They argued that air receives very little sensible heat when water is frozen at the surface and the latent heat of fusion is released. Since the under-plant sprinkle has a lower trajectory than that of over-plant systems, evaporation is minimised; thus, preheating water may be beneficial for under-plant sprinklers. In a Florida orange grove, [Martsolf, 1989] showed that applying water heated to 70 °C with a micro sprinkler system had no influence upon the temperature of leaves 3 m above the sprinkler heads. Yet, he discovered a spike in leaf temperature of up to 4 °C in the dense tree canopy just above their heads. Depending on the distance from the sprinkler nozzles, temperatures rose between 1 and 2 degrees Celsius on average.

When comparing the expenses of a heating system, fuel, and labour, it is likely more economical to establish the sprinkler system with a greater application rate for farmers in areas with a sufficient supply of water and mild to moderate frost conditions. Growers that have severe frost difficulties, have access to cheap electricity, or have a short water supply might benefit from using hot water. Heat exchangers for under-plant sprinklers are nearly twice as expensive as wind turbines, with estimates ranging from \$6,180 to \$8,650 ha-1 [Evans, 2000].

2.3.2.3.1.2. Over-tree sprinklers.

Low-growing crops and certain deciduous fruit trees benefit from over-plant spray irrigation, but crops with fragile scaffold branches, where the weight of ice on plants might shatter branches, should not be protected in this way. Except for immature lemon trees, which are more pliable, it is not frequently utilized on subtropical trees. If the application rates are high enough and the application is consistent, over-plant sprinkling provides good frost protection even during advection frosts down to approximately -7 °C [Snyder, Paw U, and Thompson, 1987]. The practise can actually do more harm than an unprotected crop would suffer from under windy circumstances or if the air temperature drops to the point that the treatment rate is insufficient to deliver additional heat than is lost via evaporation. The significant damage that may take place if the sprinkler system doesn't work, the high quantity of water needed, the possibility of damage from ice loading, and the possibility of root disease in poorly drained soils are all drawbacks of this technique.

Over-plant sprinklers with traditional rotation, variable rate, and low-volume targeting have different application rate needs. Additionally, the wind speed, exposed minimum temperature, crop surface area, and distribution consistency regarding the sprinkler system all influence the rate of precipitation.

2.3.2.3.1.2.1. Conventional rotating sprinklers:

Traditional sprinkler systems that cover a whole field are an excellent method of frost prevention. A greater application rate is required for taller plants than shorter ones since the taller ones possess greater surface area. Over-plant sprinklers are most efficient when they evenly wet all plant components and then re-wet them every thirty to sixty seconds. Higher application rates are needed for longer rotation intervals.

Systems built expressly for frost protection are ideal, but any over-plant irrigation system that gives an enough application rate can be employed [Rogers and Modlibowska, 1961; Raposo, 1979]. The system must be operational throughout the winter. It is not allowed to relocate a system that has been set up and is running on a frost night. Utilizing an equilateral triangle for head spacing instead of a rectangular one tends to provide more consistent distributions. As long as the rate of precipitation is sufficient and there is acceptable consistency, systems intended to provide irrigation instead of frost prevention can be utilised. Sprinkler heads should typically be installed at least 0.3 m above the crown of the plant canopy so that foliage does not hinder the spray [Snyder, Paw U, and Thompson, 1987]. Specially constructed springs with enclosures to avoid head icing are commonly used for frost protection. Using river as well as lagoon water requires clean filters to ensure optimum system operation.

2.3.2.3.1.2.1.1. Application rate requirements:

The rotation speed, wind speed, and exposed minimum temperature determine the application rate required to perform over-plant sprinkling with traditional sprinklers. Additional water needs to get frozen to make up for increased evaporation and sensible loss of heat from plant surfaces when wind speeds are greater. In order to compensate for the loss of sensible heat once the unprotected ambient temperature is less, more energy must be extracted from the freezing process. Wet plant parts heat up as water freezes, but cool off when water vaporises and radiative losses persist between water pulses. This highlights the importance of sprinkler rotation rates. Frequent watering of the crop is required to shorten the duration of sub-zero temperatures experienced by the plants. In most cases, a rotation period of less than 60 seconds is optimal.

Sprinkler efficiency is mostly determined by the rate of evaporation, which is heavily affected by wind velocity. However, a low minimum temperature indicates that there is a lack of perceptible heat in the air, necessitating a higher application rate. If the plants are covered with a transparent liquid-ice combination and water is dropping off the ice, presumably the application pace is adequate to prevent harm. If the entire body of water freezes over and turns a milky white colour similar to rime ice, the application frequency is excessively low. Damage might occur on plant portions that are not thoroughly wetted where the application pace is insufficient for covering all of the leaves. In the case of trees, this might mean that the buds, blooms, fruit, or nuts on lower branches don't get enough wetted and hence suffer harm. More harm will occur when the weather gets worse. In high-wind, high-evaporation circumstances, the effects of insufficient spray rates might be much more detrimental than not using sprinklers at all.

2.3.2.3.1.2.2. Variable-rate sprinklers:

Most farmers can only make one decision about the sprinkler system's precipitation rate during installation. Typically, the maximum quantity of application required by the region is built into the system. Because of this, excessive amounts are used on nights when circumstances are mild. Some growers get around this by creating systems with interchangeable riser heads that allow for either more or less intensive application. In addition, intermittently operating sprinklers, or variable rate sprinklers, have been the subject of substantial research as a means to decrease application rates [Gerber and Martsolf, 1979; Proebsting, 1975; Hamer, 1980]. For instance, [Hamer, 1980] successfully protected their crops from a frosty night with half the usual water by implementing an automatic variable rate sprinkler system. An electrical sensor, installed throughout the orchard to simulate a bud, recorded temperatures and triggered watering anytime they dropped below -1 degrees Celsius. He did emphasize, however, that the location of the temperature sensors was crucial because of the uneven nature of the application. Ice formation on the sensor retarded the temperature response, which resulted in overwatering at the conclusion of protracted frost protection periods. Over-tree sprinkling for frost protection in an apple orchard can result in up to 75 percent water savings with cycling water on and off with solenoids, as described by [Koc et al., 2000]. The switching between on and off durations were modelled using data collected from the environment and the temperatures at which the buds opened.

2.3.2.3.1.2.3. Low-volume targeted sprinklers:

It has been claimed that in the south-eastern United States, single over-plant micro-sprinkler for each tree provides enough protection with decreased water usage [Powell and Himelrick, 2000]. They did point out that the technology has not been extensively adopted by farmers because of the hefty installation expenses involved. According to [Evans, 2000], installing a single over-plant micro sprinkler for every tree can cut the required application rate for tree-covered areas from 3.8 to 4.6 mm h -1 (the range for conventional sprinklers) to 2.8 to 3.1 mm h -1. Grape vineyard frost protection using targeted over-plant micro sprinklers was studied by [Jorgensen et al., 1996]. They tested a pulsing action that, unlike traditional micro sprinklers, creates droplets with a huge diameter while still applying at low rates. There were however no severe frost episodes throughout the two-year experiment, despite the fact that the targeted system saved water by 80%.

2.3.2.3.1.3. Sprinklers over coverings.

Sprinkling over protected crops within greenhouses and frames is an effective method. Plant coverings may be kept at a temperature of around 0 °C in the same way that water sprinkled over the plants can. It is much warmer when compared to the apparent air temperature because a thin covering of water intercepts the rising terrestrial radiation and reflects it downward at a temperature around zero degrees Celsius. Therefore, the net radiation received by the plant canopy is much more than it would be if the canopy had been open to the sky. In a two-year study, [Hogg, 1964] found that a Dutch frame sprinkled with irrigation provided an average temperature buffer of 2.4 °C. The insulation was around 4.5 °C on the coldest nights. However, the rate of precipitation was rather significant, reaching 7.3 mm h-1. Greenhouses with plastic coverings only 0.2 mm thick were able to sustain temperatures as much as 7.1 °C higher than those outdoors, despite the below-freezing temperatures that were recorded [Pergola, Ranieri, & Grassotti, 1983]. The sprinklers might save as much as 80% of the energy used to heat a plastic greenhouse to the same temperature. Sprinklers worked on and off, and even on the coldest nights, the typical precipitation rate was close to 10 mm h-1.

2.3.2.4. Surface irrigation

Using furrow, graded border, or flood irrigation to directly apply water to the soil is one of the most prevalent forms of frost protection. In a citrus orchard treated with water at 23 °C, [Jones, 1924] discovered a 1 °C rise in air temperature. In this technique, water is introduced to a field, and as the water cools, heat is released into the air. The water's temperature is essential; as warmer water will discharge additional energy as it cools. Protection is most effective during the first night after inundation and decreases as the land becomes saturated. Tolerant plants can be completely or partially submerged with water; however, fungal infections and root suffocation are sometimes issues. During radiation frosts, the method is most effective to low-growing tree and vine crops.

2.3.2.4.1. Types of Surface Irrigation:

2.3.2.4.1.1. Furrow Irrigation

Commonly used for preventing frost damage, furrow irrigation follows similar principles to flood irrigation. The flow of water that is warmer down the furrows aids both the natural conduction of air heated by the water as well as the upward radiation. The best results are attained when the furrows are positioned immediately under the plant sections that need protection since the major orientation of both radiation and sensible heat flow is vertical [Snyder, Paw U, and Thompson, 1987].

It's important to begin furrow irrigation early enough for the water to travel the length of the field before the air temperatures fall below the critical damage temperature. When ice forms on the water's surface, it acts as a barrier to the flow of heat away from the body of water and increases its vulnerability. Increased protection is provided by higher application rates since ice development is delayed further down the row. Water from storm drains should not be reused if it is cold. While it's true that boiling the water is safer, it's debatable whether or not the added expense is worth it. Capital, energy, and labour expenditures must be weighed against the expected value of the harvest.

2.3.2.4.1.2. Flooding

In many countries, frost is prevented via direct flooding. Growers in Portugal and Spain, for instance, may subject a whole field to a steady stream of water, drowning the plants either partially or entirely [Cunha, 1952; Diar-Queralto, 1971]. It has mostly been employed to safeguard ryegrass and Castilian grass pastures in Portugal [Cunha, 1952], nevertheless it has been put to good use in California and elsewhere in the United States on a wide range of crops. The economic benefits of using flood irrigation for frost protection are substantial, despite the little initial investment required. The total amount of water to be applied is conditional on the water temperature and the intensity of the frost. According to [Businger, 1965], this technique can provide up to 4 °C of protection from frost if irrigation is performed ahead of a frost occurrence. However, [Georg, 1979] notes that direct flooding has resulted in temperature increases of up to 3 °C in an apimento pepper crop on a frost night.

2.3.2.5. Wind machines

In the 1920s, frost protection in California was revolutionised with the introduction of wind turbines (or fans) that blast air practically horizontally. But it wasn't until the 1940s and 1950s that they found widespread use. They are now widely utilised all around the globe. Wind machines are employed on many different types of crops, from grapevines to citrus trees to deciduous trees. Wind devices are used to safeguard practically all citrus crops in California.

Most wind turbines look like a cylindrical steel tower featuring a huge fan mounted towards the top. The diameter of the fan, which may be anywhere between 3 to 6 m, is normally made up of two or four rotor blades. Fans are usually placed between 10 and 11 metres in the air. However, lower canopies require lower heights. Propeller speeds in the range of 590 to 600rpm have proven to be optimal for wind turbines. The tower's fans complete a full rotation every four or five minutes. The efficiency of wind machines is maximised by having their fans blow at a modest downward inclination (for example, roughly 7 °) towards the tower direction [Snyder, Paw U, and Thompson, 1987]. To maximise the efficiency of the mixing process, it is recommended that the fans be rotated around their towers in synchronization.

The use of wind machinery is more efficient and cheaper to run than conventional techniques. Particularly applicable to electric wind turbines. Similarly, efficient but more labour-intensive are internal combustion wind turbines. The initial investment in wind turbines is comparable to that of sprinkler systems, but ongoing maintenance expenses are more.

Wind machines are generally safe for the environment; despite the noise they produce. Growers that situate their crops near populated areas often face difficulties with wind turbine noise. When deciding on a system of frost protection, this factor must also be taken into account.

2.3.2.5.1. Theory of operation:

The microscale boundary layers that form over plant surfaces are disrupted by the wind machines, which in turn increases the downward trend of sensible heat flow density. Fans do not generate heat, but rather move about the air's existing sensible heat. The fans combine warmer air from higher up with cooler air from the ground. In addition, they contribute by displacing the coldest air near the leaves with somewhat warmer ambient air. The strength of the unprotected inversion has a significant impact on the level of safety provided. In an unheated orchard, the severity of the inversion is determined by the temperature differential between 10 metres and 1.5 metres. The average air temperature at 1.5 m inside the zone impacted by a wind machine rises by roughly 1/3 of the inversion strength. The tower of the wind turbine provides the best protection in the immediate vicinity. The real effect is conditional on specific inversion features and is hence not generalizable. However, it is obvious that greater inversions provide more safety. A 75-kilowatt wind turbine is typically required per 4 to 5 hectares [Snyder, Paw U, and Thompson, 1987].

2.3.2.6. Foggers

Natural fog has been shown to protect against frost damage, therefore artificial fogs are also being researched as potential frost damage prevention strategies. It has been claimed that under light wind situations, fog lines that employ high-pressure lines and particular nozzles to create tiny (i.e. 10 to 20 mm diameter) fog droplets to give effective protection [Mee and Bartholic, 1979]. Protection is primarily provided by water droplets capturing radiation with long wavelengths from the ground and re-emitting it downward at a temperature substantially higher than the apparent temperature of the clear sky. The water particles should have diameters of approximately 8 mm to maximise the absorption of radiation while preventing them from falling to the ground. Protection requires a fairly dense shroud of dense fog that entirely covers the crops. This depends on the existence of a gentle breeze and moderate humidity.

2.3.2.7. Combinations of active methods

2.3.2.7.1. Sprinklers and heaters

Although no academic material was located on the topic, one farmer in Pennsylvania, USA, used sprinklers and warmers together with great success, as described by [Martsolf, 1979b]. To keep the water from flooding the heater, the cultivator devised a cover (a round metal snow sledge mounted laterally on a pole about 1.5 metres above the heater). The cultivator would turn on the heaters before the irrigation whenever the air temperature dropped too low. This combination decreased ice formation on the plants to the point where sprinklers were sometimes unnecessary. Unknown was whether water striking the heater decreased heat production or increased vaporisation and beneficial fog formation.

2.3.2.7.2. Wind machines and heaters

It is known that a system with wind machines along with heaters provides superior frost protection than either method alone [Martsolf, 1979a]. According to [Brooks, 1960], a wind machine alongside 50 heaters per hectare are approximately equivalent to 133 heaters per hectare. In California, the combination of methods was 53%, 39%, and 0% less expensive in years with 100, 50, and 10 hours of protection, respectively [Snyder, Paw U, and Thompson, 1987]. Combining the two has reduced the number of heaters needed to preserve citrus groves in California by half, allowing them to remain productive even at temperatures as low as -5 °C [Snyder, Paw U, and Thompson, 1987]. Within 50 metres of a wind machine, no heaters are required, and the wind machines are initiated first. If the temperature continues to drop, then the heaters are activated.

3. Materials and Methods:

3.1. Place of Observation:

Prior to and flowering time of apricot cultivars in 2021 and 2022, research was carried out at the Experimental Station of the Hungarian University of Agriculture and Life Sciences in Soroksár (47° 23' 42.03" N, 19° 8' 51" E). In 2014, a small experimental apricot orchard was planted in Soroksár. Ten trees of each cultivar were planted in a randomly assigned block configuration in the experimental orchard. The plant spacing is 5 m by 3 m, and the canopy form is a low-trunk compact vase. Annually, in March, the plantation underwent woody pruning for maintenance, and in August, green pruning with significant shoot and branch thinning took place. The tractor alley has grass, which is maintained by frequent mowing, and the lane beneath the trees has been herbicide-treated. A drip irrigation system has been installed in the plantation. The plantation incorporates plant protection technologies. The plantation has sandy loam soil. The Department conducted a soil examination and found that it had a pH of 7.86, a loose texture (KA 30), a humus content of 0.891%, and a calcium content of 2.44%. Plants are frequently stressed by the dry, continental environment. The yearly temperature swing is 21.1 degrees Celsius, with an average annual temperature of 11.3. Yearly precipitation averages 533 mm, and yearly sunlight totals 1,930 hours. However, there is a large amount of variation from year to year. The average monthly duration of sunshine is highest in the summer (250-270 hours), and shortest in the winter (50-70 hours). The wind is coming from the northwest.

The remaining part of the experiment performed in the Fruit Growing Department of the Buda Campus of Hungarian university of Agriculture and Life Sciences under the supervision of Dr. Laszlo Szalay and Mr. Jozsef Bakos. The Buda Campus is located at Villanyi street 29, 1114 Budapest, Hungary.

3.2. Time of Observation:

The experiments were conducted from 12th of October, 2021 until the early March, 2022.

3.3. Observed apricot cultivars:

Table 3: List of the observed cultivars and their origins.

Cultivar	Origin
Aurora	Italy
Magyar Kajszi C.235	Hungary
Pinkcot	France
Rózsakajszi C.1406	Hungary
Sweet Red	France

3.4. Methods of observations:

3.4.1. Collecting samples:

Based on the amount of the flower buds, a couple of branches were collected from the each of 10 trees of the selected cultivars in Soroksar Botanical Garden and then they were transported to Fruit Growing Department in Buda campus where they were grouped into 3 stacks based on the cultivars to prepare a sample for each freezing experiment. After that, the first stack goes into the freezing chamber while other 2 stacks left outside of the window for chilling until the previous experiment finishes. Each experiment, on average, took 10 days where in the initial day the selected stack gets into the freezing chamber to chill for approximately 24 hours on selected temperature to imitate the natural freezing conditions and then flower buds of each shoot of the stack get manually checked for frost damages to determine the rate of damaged buds in the course of remaining 9 days. This is the first cycle of the experiment and there are 3 cycles in a month as 1 stack of shoots is used per experiment.

3.4.2. Freezing chamber:

The Freezing chamber used in our experiment was Rumed 3301 manufactured by Rubarth Apparate GmbH in Laatzen, Germany. It has the internal volume of 210 Liters with the temperature range of 0 °C to +50 °C. It has the dimensions of 1180 mm of height, 730 mm width, and the depth of 820 mm. Inside is consist of 2 shelves with the maximum load of 25 kg per shelve. Net weight of the standard unit is 80 kg.

Figure 6: Freezing chamber: Rumed 3301. [Photo by Elman Gadimov]

3.4.3. Checking for frost damages in selected samples:

Once the samples are removed from 24 hours of freezing chamber treatment, damage of flower buds caused by imitation of frost is checked by using a knife. This procedure is operated by cutting the outer layer of flower buds and the checking the core of the buds from frost damages which represented by darkening on the insides. This procedure takes place on at least 50 flower buds and ratio of the damaged to total amount of buds checked represents the frost damages percentages.

4. Results:

4.1. October experiment:

The first test took place on October 12, 2021, at which sampling time three freezing temperatures were used. The climate chamber was always set to whole temperature values, but the actual temperature of the samples differed from this for technical reasons. With the sensors placed at the samples, we measured the actual temperature of the samples with an accuracy of one decimal place, and used them to determine the LT_{50} values. The values of frost damage caused by different treatment temperatures are shown in Table 4. The experimental results are shown in Figure 7.

Table 4: Results of October experiment and LT50 values.

cultivar	treatment temperature			LT_{50}
	-4.8 °C	-8.1°C	-10.5 °C	
Sweet Red	5.56 %	45 %	94 %	-8.4 °C
Aurora	2.73 %	39 %	93 %	-8.7 °C
Pinkcot	4 %	36 %	96.3 %	-8.8 °C
Magyar kajszi C.235	3.33 %	35 %	90 %	-8.9 °C
Rózsakajszi C.1406	3.92 %	28 %	89 %	-9.1 °C

4.1.1. Sweet Red cultivar:

Experiments were run on the Sweet Red cultivar in October of 2021, and the Figure 7 shows that at -4.8 degrees Celsius, the flower bud mortality rate for the Sweet Red cultivar was 5.56%, the highest of all the cultivars tested. In terms of comparison, the second experiment was not any different as frost damage percentage on -8.1 degrees Celsius was 45% which is the highest in second October experiment. On the third survey, however, Sweet Red cultivar was able to score average results which is 94% on -10.5 °C.

According to the supplied statistics, at a temperature of -8.4 °C, around half of the flower buds of the Sweet Red cultivar would be damaged.

4.1.2. Aurora cultivar:

The Figure 7 represents the results of the experiment on Aurora cultivar conducted during the October, 2021. On the first part of the experiment it can be seen that the freezing chamber temperature was set to -4.8 °C to imitate a mild frost and result of survey illustrates that the frost damage percentage was rather low at 2.73%. In the second part of the experiment results were considerably higher at 39% with the freezing chamber temperature set to -8.1 degrees Celsius. In the 3rd experiment it can observed that the limits of frost hardiness of Aurora cultivar are tested at -10.5 degrees Celsius and, unfortunately, it produced rather disappoint results of 93% frost damage which is much higher than the previous results.

With all the data collected based on the experiments, it is decided that the LT50 value of the cultivar in October, which represents the temperature which 50% of all observed flowers buds are damaged, is -8.7 °C.

4.1.3. Pinkcot cultivar:

The graph on the right illustrates the results of October, 2021 experiments of Pinkcot cultivar. The first survey was conducted on -4.8 degrees Celsius and the results are slightly higher than previous cultivars with 4%. However, Pinkcot cultivar demonstrated an average result in the second experiment with -8.1 °C as the results were 36%. Nevertheless, the results of the third experiment was quite poor compared to other cultivars as Pinkcot flower buds had 96.3% fatality rate at the temperature of -10.5 °C. According to the rates of the experiments it is determined that LT50 value of this cultivar is -8.8 °C.

4.1.4. Magyar Kajszi C.235 cultivar:

The data in this graph are from an experiment ran on the Magyar Kajszi C.235 cultivar started on October 8th, 2021. The first portion of the experiment shows that the freezing chamber temperature was adjusted to -4.8 °C to simulate a moderate frost, and the results of the survey show that the percentage of frost damage was rather low, at 3.33%. The second half of the experiment, conducted at a freezing chamber temperature of -8.1 degrees Celsius, had materially higher results (35%). The third experiment shows that the frost hardiness of the Magyar Kajszi C.235 cultivar at -10.5 degrees Celsius were fairly disappointing, with 90% frost damage, far greater than the previous results. Based on the gathered data, it was determined that in October, at a temperature of -8.9 °C, 50% of the observed flower buds would be injured on this cultivar.

4.1.5. Rózsakajszi C.1406 cultivar:

Data of experiment conducted on Rózsakajszi C.1406 cultivar on October, 2021 is illustrated on the graph and in the first experiment it can be seen that the fatality rate of flower buds of Rózsakajszi C.1406 cultivar on -4.8 degrees Celsius is 3.92% which can be credited as average compared to other cultivars in the same test. In the second test this cultivar scored the best results of 28% on the imitated temperature of -8.1 °C created by the freezing chamber Rumed 3301. On the last experiment of the month, ratios were again in the lower spectrum of the results compared to other 4 cultivars. The flower buds of Rózsakajszi C.1406 cultivar had the fatality rate of 89% in the temperatures of -10.5 degrees Celsius.

Based on the data provided it can be calculated that at a temperature of -9.1 °C, half of the observed flower buds of Rózsakajszi C.1406 cultivar would be injured.

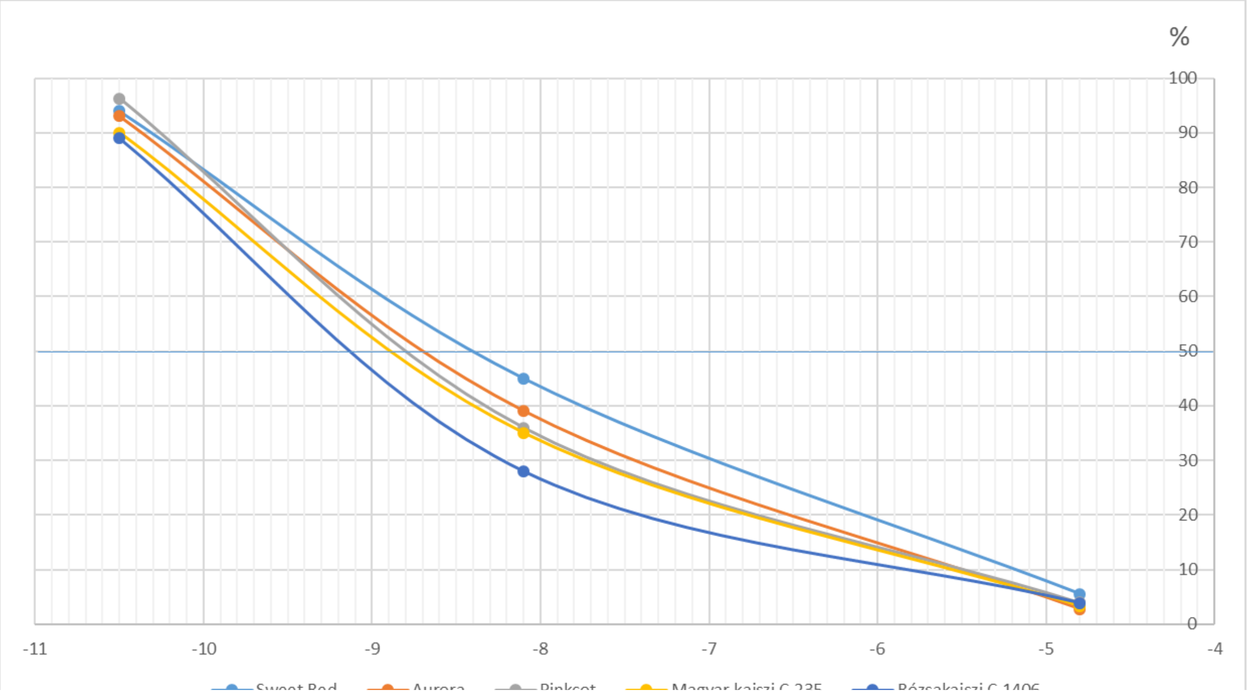


Figure 7: Results of artificial freezing of flower buds of apricot cultivars (12 October 2021)

As a result of -4.8 degrees C, the flower buds of the tested apricot varieties were only slightly damaged (Fig 7). The Sweet Red variety suffered the greatest frost damage, for which we measured 5.6% damage. As a result of treatment at -8.1 degrees C, the difference between the varieties was greater. Here too, the Sweet Red variety suffered the greatest frost damage, and the Rózsakajszi C.1406 suffered the least. Frost damage to flower buds at this temperature remained below 50% for all cultivars. The next treatment temperature was -10.5 degrees C, which resulted in severe frost damage to the flower buds of the tested apricot varieties. The degree of frost damage was between 89 and 94 %. Based on our test results, we determined the LT50 value of the flower buds of the varieties, which are shown in the last column of Table 1. The most frost-sensitive variety was Sweet Red, for which the LT50 value was -8.4 degrees C, and the most frost-tolerant was Rózsakajszi C.1406, for which this value was -9.1 degrees C.

4.2. November experiment:

The second experiment was conducted on November 8, 2021, and three different freezing temperatures were employed for sampling. The temperature in the climate chamber was maintained at whole numbers, but for practical reasons, the samples were kept at a slightly different temperature. With the sensors positioned at the samples, we determined the LT50 values by measuring the actual temperature of the samples with a precision of one decimal place and using the data to calculate the LT50 values. Table 5 displays the values of frost damage induced by varied treatment temperatures. Figure 8 displays the outcomes of the experiments.

Table 5: Results of November experiment and LT50 values.

	treatment temperature			
cultivar	-11.3 °C	-14°C	-17.2 °C	LT_{50}
Sweet Red	18 %	78 %	98 %	-12.6 °C
Aurora	8 %	61 %	96 %	-13.3 °C
Pinkcot	2 %	48 %	96 %	-14.1 °C
Magyar kajszi C.235	6 %	44 %	76 %	-14.5 °C
Rózsakajszi C.1406	4 %	41 %	80 %	-14.7 °C

4.2.1. Sweet Red cultivar:

The table illustrates the result of the experiments carried on November 8, 2021 on Sweet Red cultivar. On the first sight it can be visualized that compared to the last month, the experiment temperatures drastically decreased however the LT50 value has the same proportion but different value. Reason behind is that once outside air temperature average gets colder, the overall frost hardiness of the plant adjusts and adapts. This phenomenon can be observed depending on the average natural weather conditions.

Based on the initial phase of the inquiry, it was observed that the level of frost damage was relatively elevated, reaching 18%, in comparison to other cultivars. This was despite the moderate frost conditions that were simulated in the freezing chamber, which maintained a temperature of -11.3°C. During the following phase of the research, conducted in a freezing chamber at a temperature of -14 degrees Celsius, the Sweet Red variety exhibited the least favourable outcomes, achieving an overall score of 78%. The aforementioned occurrence persisted during the third experiment conducted at a temperature of -17.2 degrees Celsius, resulting in an almost complete fatality rate of 98%. Based on statistical analysis, it has been determined that subjecting this particular cultivar to temperatures of -12.6°C during the month of November would lead to approximately 50% of its flower buds being harmed.

4.2.2. Aurora cultivar:

Overall, it can be seen that the temperature set for the first experiment was -11.3 degrees Celsius and the product of that is 8.0% fatality rate among the flower buds of Aurora cultivar. On the second survey a drastic decrease on the temperature set for the freezing chamber can be seen at -14 °C and it resulted in higher frost damage rates as well which went up to 61%. This serious downfall continued on the third experiment where the average temperature set for the Rumed 3301 was -17.2 °C. This change almost eradicated the majority of living flower buds and resulted in 96% frost damage.

LT50 values of Aurora cultivar during November, 2021, as it can be observed on the fourth section of the Figure 8, is -13.3 °C.

4.2.3. Pinkcot cultivar:

The experimental procedure illustrated in Figure 8 was initiated on November 8th, 2021, utilising the Pinkcot cultivar. As per the initial phase of the study, the percentage of frost damage was observed to be significantly minimal, measuring only 2.0%, owing to the moderate frost conditions simulated in the freezing chamber at a temperature of -11.3°C. During the second phase of the experiment, conducted in a freezing chamber at a temperature of -14 degrees Celsius, Pinkcot exhibited an average results, achieving an overall score of 48%. Nevertheless, the frost hardiness of the subject at a temperature of -17.2 degrees Celsius exhibited a significantly poor outcome, resulting in a 96% fatality rate during the third trial. Based on statistical data, it has been determined that if subjected to temperatures of -14.1°C during the month of November, approximately 50% of flower buds on this particular cultivar would incur damage.

4.2.4. Magyar Kajszi C.235 cultivar:

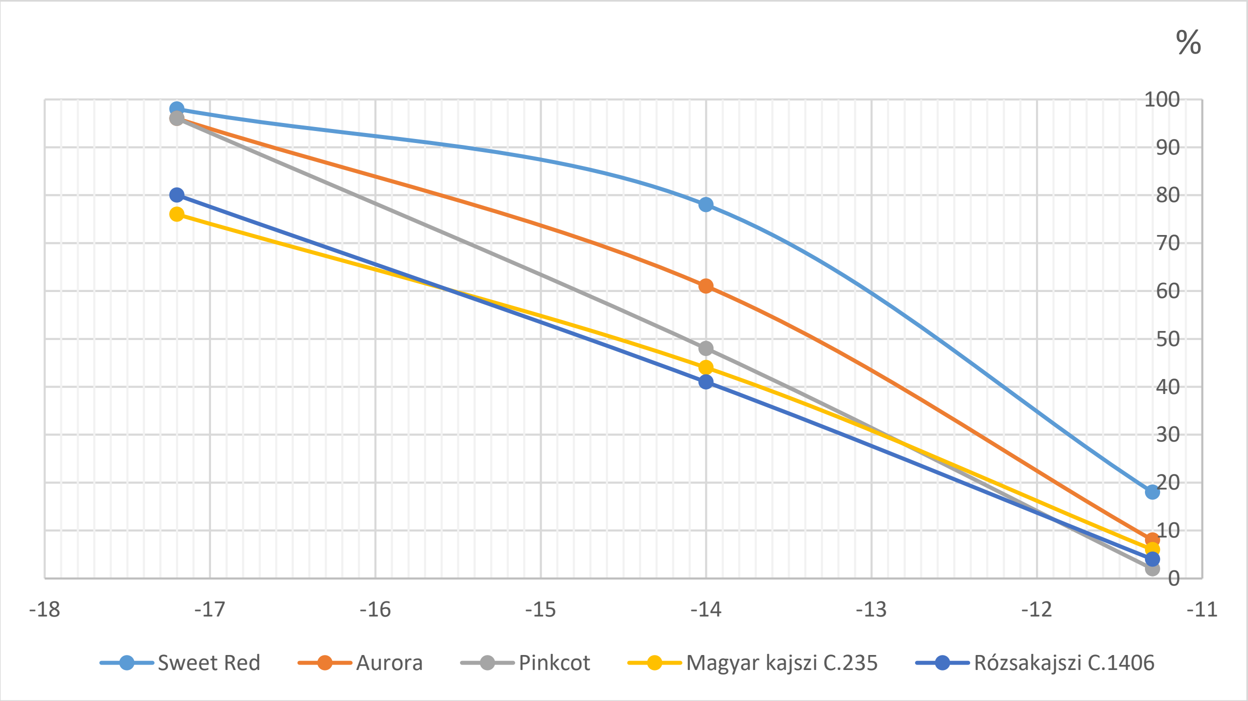
The experiment depicted in Figure 8 began on November 8, 2021, and used the Magyar Kajszi C.235 cultivar. According to the first part of the experiment, the frost damage percentage was only 6.0% since the freezing chamber temperature was set at -11.3 °C to represent moderate frost. In the second part of the experiment, which was carried out in a freezing chamber at -14 degrees Celsius, the results were more substantially low (44%). The Magyar Kajszi C.235 cultivar's frost hardiness at -17.2 degrees Celsius was the best as measured by 76% frost damage, in the third trial. According to the statistics, half of the reported flower buds on this cultivar would be damaged if exposed to temperatures of -14.5 °C in the month of November.

4.2.5. Rózsakajszi C.1406 cultivar:

The experimental protocol depicted in Figure 8 was commenced on November 8th, 2021, employing the Rózsakajszi C.1406 cultivar. According to the preliminary stage of the investigation, the degree of frost impairment was found to be minimal, quantified at 4.0%, due to the moderate frost circumstances replicated in the cryogenic chamber at a temperature of -11.3°C. In the subsequent stage of the study, which took place in a freezing chamber with a temperature of -14 degrees Celsius, the Rózsakajszi C.1406 variety demonstrated commendable results, attaining an aggregate score of 41%. The subject demonstrated a significant level of frost hardiness at a temperature of -17.2 degrees Celsius, leading to a mortality rate of only 80% during the third trial.

According to statistical analysis, it has been ascertained that exposing this specific cultivar to temperatures of -14.7°C in the month of November would result in damage to around 50% of its flower buds.

Figure 8: Results of artificial freezing of flower buds of apricot cultivars (8th of November, 2021)



The flower buds of the examined apricot varieties were only mildly injured by -11.3 degrees Celsius (Figure 8). The Sweet Red variety suffered the most frost damage, 18%, according to our measurements. Due to treatment at -14 degrees Celsius, the disparity between the species increased. Again, the Sweet Red variety sustained the most frost damage, while the Rózsakajszi C.1406 variety sustained the least. Frost damage to flower blooms at this temperature was greater than forty percent across all cultivars. The subsequent treatment temperature of -17.2 degrees Celsius caused extensive frost injury to the flower buds of the examined apricot varieties. The level of frost damage ranged from 76 to 98%. Based on the outcomes of our tests, we determined the LT50 value of the flower buds for each variety, which is shown in the final column of Table 1. The variety most susceptible to frost was Sweet Red, with an LT50 value of -12.6 degrees Celsius, while the variety most resistant to frost was Rózsakajszi C.1406.

4.3. December experiment:

The third experiment was conducted on December 13, 2021, and samples were collected at three distinct frigid temperatures. The temperature in the climate chamber was maintained at whole integers, but the samples were stored at a slightly different temperature for practical reasons. We determined the LT50 values by measuring the actual temperature of the samples to a decimal place and using the data to calculate the LT50 values, with the sensors positioned at the samples. The values of frost damage caused by varying treatment temperatures are displayed in Table 6. Figure 9 represents the results of the investigations.

Table 6: Results of December experiment and LT50 values.

	treatment temperature			
cultivar	-15 °C	-17.4°C	-20.5 °C	LT_{50}
Sweet Red	20 %	72 %	100 %	-16.3 °C
Aurora	16 %	55 %	100 %	-17.1 °C
Pinkcot	15 %	50 %	100 %	-17.5 °C
Magyar kajszi C.235	10 %	39 %	100 %	-18.0 °C

Rózsakajszi C.1406	4 %	18 %	90 %	-18.9 °C

4.3.1. Sweet Red cultivar:

The depicted research methodology in Figure 9 was commenced on December 13th, 2021, employing the Sweet Red cultivar. The preliminary investigation revealed that the extent of harm inflicted by frost was substantial in contrast to alternative cultivars. Specifically, when exposed to simulated frost conditions of -15°C in the freezing chamber, the damage level was measured at 20%. In the subsequent phase of the study, carried out within a freezing chamber set at a temperature of -17.4 degrees Celsius, it was observed that the Sweet Red cultivar demonstrated the poorest outcome, attaining a cumulative score of 72%. This pattern persisted on the third experiment, when it was discovered through inquiry that the subject's level of frost hardiness was significantly insufficient when exposed to a temperature of -20.5 degrees Celsius, leading to full mortality.

The findings of the statistical analysis indicate that the flower buds of this specific cultivar would incur an estimated 50% damage if exposed to temperatures of -16.3°C in the month of December.

4.3.2. Aurora cultivar:

The experimental protocol depicted in Figure 9 was commenced on December 13th, 2021, employing the Aurora cultivar. According to the preliminary stage of the investigation, the degree of frost impairment was found to be considerably high, registering at 16.0%, under the simulated frost conditions of -15°C in the cryogenic chamber. In the subsequent stage of the study, which took place within a freezing chamber at a temperature of -17.4 degrees Celsius, the Aurora cultivar demonstrated poor performance, attaining an aggregate score of 55%. However, the subject's frost hardiness was found to be inadequate at a temperature of -20.5 degrees Celsius, leading to a 100% mortality rate during the third trial.

According to statistical analysis, it has been ascertained that when exposed to temperatures of -17.1 °C in December, around 50% of flower buds of this specific cultivar would suffer harm.

4.3.3. Pinkcot cultivar:

On December 13th, 2021, the research procedure depicted in Figure 9 was commenced, using the Pinkcot cultivar. According to the preliminary stage of investigation, it was ascertained that the extent of harm inflicted by frost was considerable, quantifying at 15% under the simulated frost circumstances of -15°C in the freezing compartment. In the subsequent phase of the study, carried out within a freezing chamber at a temperature of -17.4 degrees Celsius, the Pinkcot cultivar demonstrated a marginally suboptimal performance, attaining an aggregate score of 50%. The findings indicate that the subject's ability to withstand frost was inadequate when subjected to a temperature of -20.5 degrees Celsius, leading to total mortality during the third iteration of the experiment.

The findings of statistical analysis indicate that the exposure to temperatures of -17.5°C in December would lead to an estimated 50% damage to the flower buds of the specified cultivar.

4.3.4. Magyar Kajszi C.235 cultivar:

The research procedure illustrated in Figure 9 was initiated on December 13th, 2021, utilising the Magyar Kajszi C. 235 cultivar. Based on the initial phase of the inquiry, it was determined that the level of damage caused by frost was not significant, measuring at 10.0% when subjected to simulated frost conditions of -15°C within the freezing chamber. During the following phase of the research, conducted in a freezing chamber at a temperature of -17.4 degrees Celsius, the Magyar Kajszi C. 235 variety exhibited a slightly optimal performance, achieving a total score of 39%. The investigation revealed that the frost hardiness of the subject was insufficient when exposed to a temperature of -20.5 degrees Celsius, resulting in complete mortality during the third experimental trial.

Based on statistical analysis, it has been determined that exposure to temperatures of -18 °C during the month of December would result in approximately 50% damage to the flower buds of this particular cultivar.

4.3.5. Rózsakajszi C.1406 cultivar:

The experimental procedure illustrated in Figure 9 was initiated on December 13th, 2021, utilising the Rózsakajszi C.1406 cultivar. Based on the initial phase of the inquiry, it was determined that the level of damage caused by frost was relatively minimal, with a recorded value of only 4.0% under the simulated frost conditions of -15°C in the freezing chamber. During the following phase of the research, conducted in a freezing chamber at a temperature of -17.4 degrees Celsius, the Rózsakajszi C.1406 variety exhibited impressive outcomes, achieving a total score of only 18%. Nevertheless, the research revealed that the frost hardiness of the subject was insufficient when exposed to a temperature of -20.5 degrees Celsius. Despite this, it was still superior to other cultivars, resulting in an 90% mortality rate during the third trial.

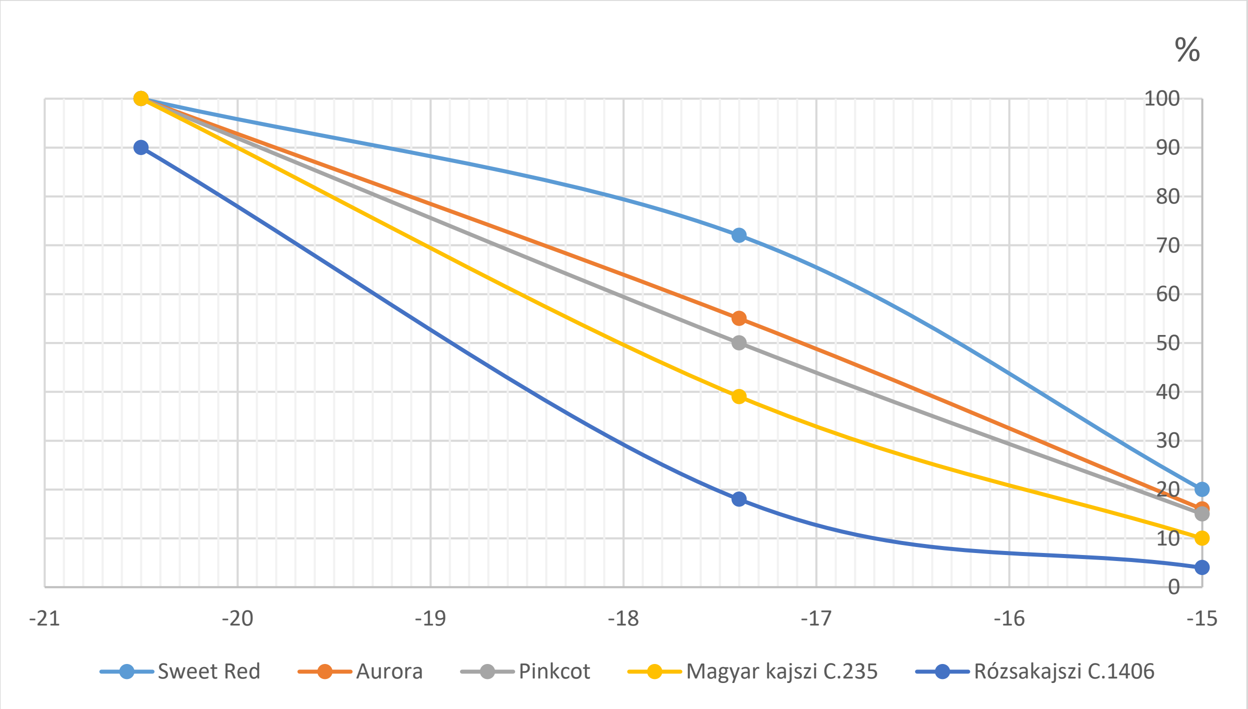


Figure 9: Results of artificial freezing of flower buds of apricot cultivars (13th of December, 2021)

Based on statistical analysis, it has been determined that exposure to temperatures of -18.9 °C during the month of December would result in approximately 50% damage to the flower buds of this particular cultivar.

As it can be observed in the Figure 9, at the temperature of -15 degrees Celsius, the flower stems of the examined varieties of apricots were only mildly damaged. In accordance with our measurements, 20% of the Sweet Red variety was damaged by ice. The disparity between species widened as a result of treatment at -17.4 degrees Celsius. Again, the Sweet Red variety sustained the most harm from frost, while the Rózsakajszi C.1406 variety suffered the least. Frost damage to flower buds was between 18% and 72% at this temperature. The ensuing treatment temperature of -20.5 degrees Celsius significantly damaged the flower buds of the examined apricot varieties. The range of frost injury was from 90% to complete annihilation. Based on the results of our experiments, we determined the LT50 value for each flower variety, which is shown in the final column of Table 1. Sweet Red was the most susceptible to frost, with an LT50 value of -16.3 degrees Celsius, while Rózsakajszi C.1406 was the most resistant, with an LT50 value of 18.9 degrees Celsius.

4.4. January experiment:

The first test took place on January 10, 2022, at which sampling time four freezing temperatures were used. The climate chamber was always set to whole temperature values, but the actual temperature of the samples differed from this for technical reasons. With the sensors placed at the samples, we measured the actual temperature of the samples with an accuracy of one decimal place, and used them to determine the LT_{50} values. The values of frost damage caused by different treatment temperatures are shown in Table 7. The experimental results are shown in Figure 10.

Table 7: Results of January experiment and LT50 values.

cultivar	Treatment Temperatures				LT_{50}
	-13.1 °C	-14.9 °C	-17.6 °C	- 19.9 °C	
Sweet Red	52 %	74 %	100 %	100 %	-12.8 °C
Aurora	20 %	45 %	90 %	100 %	-15.2 °C
Pinkcot	22 %	36 %	65 %	100 %	-16.3 °C
Magyar kajszi C.235	9 %	42 %	56 %	98 %	-16.7 °C
Rózsakajszi C.1406	2 %	14 %	40 %	90 %	-18.2 °C

4.4.1. Sweet Red cultivar:

The experimental procedure illustrated in Figure 10 was initiated on January 10th, 2022, utilising the Sweet Red cultivar. The initial assessment for this particular cultivar is being conducted at a temperature of -13.1 degrees Celsius. It is noteworthy that even at this temperature, the flower bud's frost damage remains significant, with a recorded rate of 52%. The aforementioned occurrence persisted in the subsequent trial, wherein the sample of the previously mentioned crop was subjected to a temperature of -14.9 °C alongside other cultivars, resulting in a significant mortality rate of 74%. The outcomes did not exhibit any improvement as the flower buds were impaired in the third trial conducted at a temperature of -17.6 degrees Celsius. This phenomenon continued in the fourth trail as in the temperatures of -19.9 °C, flower buds of Sweet Red cultivar experienced total death rate.

According to the results of the statistical analysis, it can be inferred that the flower buds of a particular cultivar are likely to suffer approximately 50% damage if subjected to temperatures of -12.8°C during the month of January.

4.4.2. Aurora cultivar:

The research methodology illustrated in Figure 10 was initiated on January 10th, 2022, utilising the Aurora cultivar. According to the initial inquiry, it was found that the degree of damage caused by frost was not significant as in the temperature of -13.1 degrees Celsius this cultivar experienced 20% flower bud damage. In the second trial, under simulated frost conditions of -14.9°C in the freezing chamber, the level of harm was quantified at 45%. During the subsequent phase of the research, conducted in a freezing chamber maintained at a temperature of -17.6 degrees Celsius, it was observed that the Aurora cultivar exhibited an inferior performance, achieving a cumulative score of 90%. In the last experiment of this month, it was observed that the subject's frost hardiness level was considerably inadequate upon exposure to a temperature of -19.9 degrees Celsius, resulting in complete mortality.

The statistical analysis reveals that the flower buds of the particular cultivar would suffer an approximate damage of 50% upon exposure to temperatures of -15.2 °C during the month of January.

4.4.3. Pinkcot cultivar:

The depicted research methodology in Figure 10 was commenced on January 10th, 2022, employing the Pinkcot cultivar. In the initial experiment which the temperature of freezing chamber was set to -13.1 degrees Celsius, flower buds of Pinkcot cultivar experienced considerable damage with 22%. Based on the secondary investigation, it was determined that the extent of harm resulting from frost was substantial. The study determined the level of damage at 36% under replicated frost conditions of -14.9°C within the freezing chamber. In the subsequent phase of the study, a freezing chamber was utilised to maintain a temperature of -17.6 degrees Celsius. The results indicated that the Aurora cultivar demonstrated a comparatively substandard performance, with a cumulative score of 65%. The findings of the fourth experiment indicate that the subject's frost hardiness level was significantly inadequate when subjected to a temperature of -19.9 degrees Celsius, leading to complete mortality.

Based on the statistical analysis, it can be inferred that the flower buds of the specific cultivar would incur an estimated 50% damage if subjected to temperatures of -16.3°C in the month of January.

4.4.4. Magyar Kajszi C.235 cultivar:

On January 10th, 2022, the research methodology depicted in Figure 10 was commenced, employing the Magyar Kajszi C.235 cultivar. In the first experiment, in which the chilling chamber temperature was set to -13.1 degrees Celsius, 9% of the flower blossoms of the Magyar Kajszi C.235 cultivar were damaged. Based on the secondary investigation, it was determined that the extent of harm resulting from frost was substantial. The study measured the level of damage at 42% under imitated frost conditions of -14.9°C in the freezing chamber. In the subsequent phase of the study, which was carried out in a freezing chamber with a temperature of -17.6 degrees Celsius, it was observed that the Magyar Kajszi C.235 cultivar displayed poor performance, with a cumulative score of 56%. The findings of the last experiment indicate that the subject's level of frost hardiness was significantly insufficient when subjected to a temperature of -19.9 degrees Celsius, leading to a near-total mortality rate of 98%.

The results of the statistical analysis indicate that the flower buds of the specific cultivar would incur an estimated 50% damage when subjected to temperatures of -16.7°C in the month of January

4.4.5. Rózsakajszi C.1406 cultivar:

The experimental protocol depicted in Figure 10 was commenced on January 10th, 2022, employing the Rózsakajszi C.1406 cultivar. In the first experiment, in which the chilling chamber temperature was set to -13.1 degrees Celsius, only the 2% of the flower bud of the Rózsakajszi C.1406 cultivar were damaged. According to the secondary stage of investigation, it was ascertained that the extent of harm inflicted by frost was relatively insignificant, with a documented magnitude of merely 14.0% under the simulated frost circumstances of -14.9°C in the freezing chamber, which underlies the frost hardiness of the cultivar. In the subsequent phase of the study, which was carried out in a freezing chamber with a temperature of -17.4 degrees Celsius, the Rózsakajszi C.1406 cultivar demonstrated notable results once more, attaining a cumulative score of merely 40%. However, the study demonstrated that the subject's frost hardiness was inadequate when subjected to a temperature of -20.5 degrees Celsius. Notwithstanding this fact, it exhibited superiority over other cultivars as evidenced by a mortality rate of 90% during the third trial.

The findings of statistical analysis indicate that the flower buds of this specific cultivar would incur an estimated 50% damage if exposed to temperatures of -18.2 °C in the month of January.

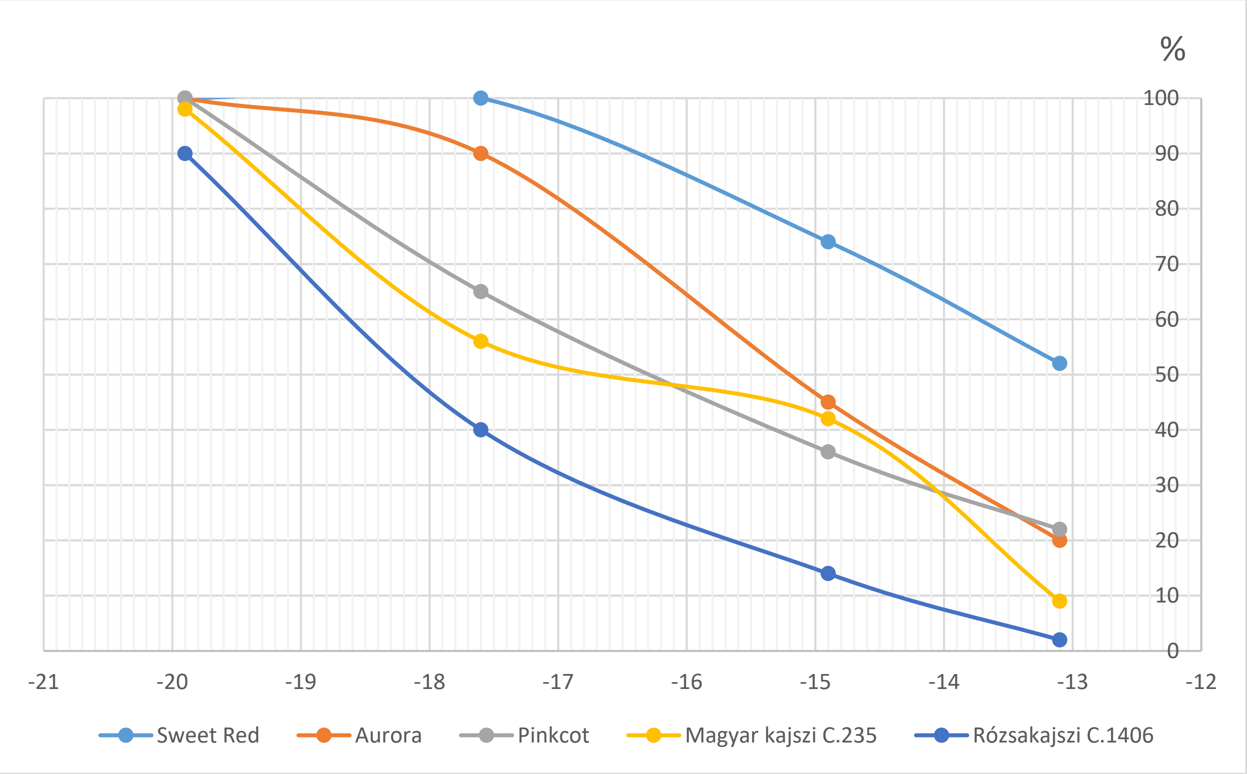


Figure 10: Results of artificial freezing of flower buds of apricot cultivars (10th January 2022)

As a consequence of -13.1 degrees Celsius, the flower buds of the examined apricot varieties were only minimally damaged (Fig. 10), with the exception of the Sweet Red variety, for which we measured 52% frost damage. Due to treatment at -14.9 degrees Celsius, the disparity between the species increased. Again, the Sweet Red variety sustained the most frost damage, while the Rózsakajszi C.1406 variety sustained the least. Frost damage to flower buds at this temperature continued to be between 74% and 14%. The next temperature treatment was -17.6 degrees Celsius, which caused severe frost injury to the flower buds of the examined apricot varieties. Frost damage ranged between 40% and utter extinction. The cultivar with the highest susceptibility was Sweet Red, and the cultivar with the highest resistance was Rózsakajszi C.1406. On the final experiment, the chilling chamber temperature was set to 19.9 degrees Celsius, and the results were catastrophic, with all cultivars except Rózsakajszi C.1406 experiencing utter mortality. Rózsakajszi C.1406 had a result of 90% Based on the results of our tests, we determined the LT50 value for the flower buds of each variety, which is displayed in the final column of Table X. The variety most susceptible to frost was Sweet Red, with an LT50 value of -12.8 degrees Celsius, while the variety most resistant to frost was Rózsakajszi C.1406.

4.5. February experiment:

The first test was conducted on February 8, 2022, when four frigid temperatures were sampled. The climate chamber was always set to whole temperature values, but for technical reasons, the actual temperature of the samples varied. We determined the LT50 values by measuring the actual temperature of the samples with an accuracy of one decimal place using sensors mounted on the samples. Table 8 displays the values of frost damage induced by varied treatment temperatures. The experimental outcomes are depicted in Figure 11.

Table 8: Results of February experiment and LT50 values.

	Treatment Temperatures				
cultivar	-9 °C	-10.4 °C	-11.2 °C	- 12.1 °C	LT_{50}
Sweet Red	42 %	70 %	88 %	100 %	-9.4 °C
Aurora	22 %	44 %	78 %	99 %	-10.6 °C
Pinkcot	10 %	30 %	75 %	80 %	-10.8 °C
Magyar kajszi C.235	5 %	22 %	35 %	86 %	-11.5 °C
Rózsakajszi C.1406	2 %	14 %	22 %	53 %	-12 °C

4.5.1. Sweet Red cultivar:

The research methodology illustrated in Figure 11 was initiated in February 2022, utilising the Sweet Red cultivar. The initial assessment for this particular cultivar is conducted at a temperature of -9 degrees Celsius and demonstrated a poor result of 42%. According to the secondary inquiry, the degree of damage caused by frost was significantly greater in comparison to other cultivars. The damage level was measured at 70% when subjected to simulated frost conditions of -10.4°C in the freezing chamber. During the subsequent phase of the research, conducted in a freezing chamber at a temperature of -11.2 degrees Celsius, it was observed that the Sweet Red cultivar exhibited a significantly low performance, achieving a cumulative score of 88%. The fourth experiment revealed a persistent pattern wherein it was discovered through inquiry that the subject's level of frost hardiness was significantly insufficient when exposed to a temperature of -12.1 degrees Celsius, ultimately resulting in full mortality. According to the statistical analysis results, it can be inferred that the flower buds of the particular cultivar would suffer approximately 50% damage if subjected to temperatures of -9.4°C during the month of February.

4.5.2. Aurora cultivar:

Figure 11 displays the outcomes of the Aurora cultivar experiment that was conducted in February 2022. The initial assessment for Aurora cultivar is conducted at a temperature of -9 degrees Celsius and demonstrated a slightly poor result of 22%. In the second phase of the study, it was observed that the temperature of the freezing chamber was adjusted to -10.8 °C in order to simulate a moderate frost environment. The findings of the survey indicate that the percentage of frost damage was notably high, reaching 44%. The suboptimal outcomes persisted in the subsequent phase of the study, wherein the outcome registered a significant value of 78% when the temperature of the freezing chamber was configured to -11.2 degrees Celsius. The last experiment revealed that the frost hardiness limits of the Aurora cultivar were assessed at -12.1 degrees Celsius and it remained unsatisfactory, with 99% of the crop experiencing frost damage.

Based on the experimental data collected, it has been determined that the LT50 value of the cultivar in February is -10.6°C. This value represents the temperature at which 50% of all observed flower buds are damaged.

4.5.3. Pinkcot cultivar:

The results of the experiment conducted in February 2022 on the Pinkcot cultivar are presented in Figure 11. The first assessment for Pinkcot cultivar is conducted at a temperature of -9 degrees Celsius and demonstrated a relatively optimal result of 10%. During the secondary stage of the investigation, it was noted that the temperature of the cryogenic chamber was set to -10.8 °C with the intention of replicating a mild frost condition. According to the survey results, the incidence of frost damage was marginally elevated, with a recorded rate of 30%. The study's subsequent phase demonstrated the persistence of suboptimal outcomes. Specifically, the outcome yielded a significant value of 75% when the temperature of the freezing chamber was set to -11.2 degrees Celsius. The findings of the last experiment indicate that the Pinkcot cultivar's frost hardiness limits were evaluated to be -12.1 degrees Celsius. The outcomes of this experiment were relatively satisfactory as the cultivar exhibited an 80% mortality rate in the flower buds.

The experimental data collected has led to the determination that the LT50 value of the cultivar during the month of February is -10.8°C. The aforementioned value denotes the temperature threshold at which half of the flower buds that were observed have incurred damage.

4.5.4. Magyar Kajszi C.235 cultivar:

The results of the experiment conducted in February 2022 on the Magyar Kajszi C.235 cultivar are presented in Figure 11. The first assessment for Magyar Kajszi C.235 cultivar is conducted at a temperature of -9 degrees Celsius and demonstrated an optimal result of 5%. During the second stage of the investigation, it was noted that the temperature within the freezing chamber was set to -10.8 °C with the intention of replicating a moderate frost-like atmosphere. According to the results, the frost damage percentage was the second lowest (22 % mortality rate) among the chosen cultivars. The study's subsequent phase demonstrated persistent optimal outcomes, with a moderate value of 35% recorded when the freezing chamber temperature was set to -11.2 degrees Celsius. The findings of the last experiment indicate how the frost hardiness limits of the Magyar Kajszi C.235 cultivar have been found to be -12.1 degrees Celsius. Notably, the results exhibited an improvement over the preceding experiment, wherein only 86% of the crop was affected by frost damage.

The experimental data indicates that the LT50 value of the cultivar during the month of February is -11.5°C. The aforementioned value denotes the temperature threshold at which half of the flower buds that were observed have incurred damage.

4.5.5. Rózsakajszi C.1406 cultivar:

Figure 11 displays the findings of the experiment performed in February 2022 on the Rózsakajszi C.1406 cultivar. The initial assessment for this particular cultivar is conducted at a temperature of -9 degrees Celsius and demonstrated the best result of solely 2%. It was reported that a light frost state was being replicated by setting the freezing chamber temperature to -10.8 °C and the survey findings showed that the occurrence of frost damage was quite low, with a reported rate of 14%. The later stage of the investigation showed that satisfactory results persisted.

Particularly, the result produced a mere score of 22% when the freezing chamber's temperature was adjusted at -11.2 degrees Celsius. The result of the fourth trial was not disappointing since the cultivar showed an 53% death rate in the flower buds, indicating that the Rózsakajszi C.1406 cultivar's frost hardiness limitations were up to the temperature of -12.1 degrees Celsius.

According to the experimental information gathered, the cultivar's LT50 value for the month of February is -12°C. The aforementioned number is the temperature at which half of the observed flower buds suffer damage.

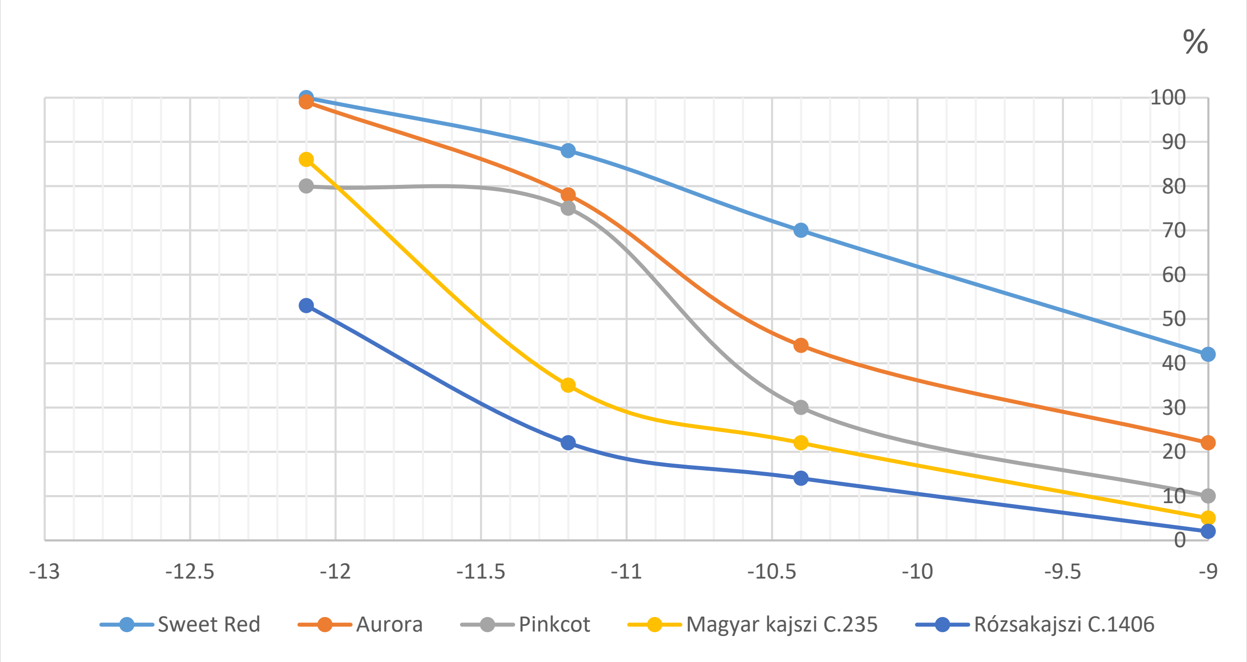


Figure 11: Results of artificial freezing of flower buds of apricot cultivars (8th February 2022)

With the exception of the Sweet Red variety, for which we measured 42% frost damage, -9 degrees Celsius caused only minor damage to the flower blossoms of the examined apricot varieties (Figure 11). The disparity between the species increased due to treatment at -10,4 degrees Celsius. Again, the Sweet Red variety sustained the most harm from frost, while the Rózsakajszi C.1406 variety suffered the least. Frost damage to flower blossoms remained between 70% and 14% at this temperature. The subsequent temperature treatment of -11.2 degrees Celsius caused moderate frost damage to the flower buds of the examined varieties of apricot. Frost damage ranged between 22% and 88%. Sweet Red was the cultivar with the highest susceptibility, while Rózsakajszi C.1406 had the highest resistance. On the final experiment, the temperature of the refrigeration chamber was set to -12.1 degrees Celsius, and the results were generally satisfactory with the exception of the death of Sweet Red. Rózsakajszi C.1406 demonstrated the highest results with a score of 53%. Based on the results of our experiments, we determined the LT50 value for each flower variety's buds, which is displayed in the final column of Table X. Sweet Red, with an LT50 value of -12.8 degrees Celsius, was the most susceptible to frost, while Rózsakajszi C.1406 was the most resistant.

5. Conclusion:

In conclusion, the experiment, which is one of the fundamental part of this academic work, conducted to determine the frost hardiness of selected cultivars and the change of this variable throughout the preparation of this survey. The selected cultivars include Aurora from Italy, Magyar kajszi C.235 from Hungary, Pinkcot from France, Rózsakajszi C.1406 from Hungary, and Sweet Red from France.

Regarding frost tolerance, as illustrated in Figure 12, all cultivars exhibited comparable outcomes with slight variations in October 2021. In November of 2021, discernible distinctions emerged among the cultivars as Rózsakajszi C.1406 exhibited the highest degree of frost hardiness, registering at -14.7 °C. Conversely, the LT_{50} scores of the remaining cultivars, namely Magyar kajszi C.235, Pinkcot, Aurora, and Sweet Red, decreased in descending order, with Sweet Red exhibiting the lowest score of -12.6 degrees Celsius. The LT_{50} value for the Magyar Kajszi C.235 and Rózsakajszi C.1406 cultivars experienced a significant shift in particularly in the latest month of 2021, with the latter exhibiting a lower temperature of -18.9 degrees Celsius compared to the former's -18 degrees Celsius. The Pinkcot and Aurora cultivars exhibited comparable scores, whereas the Sweet Red cultivar displayed a notably subpar performance with a score of -16.3 °C. The performance trends of the chosen cultivars were observed to exhibit a slight variance between the January 2022 and December 2021 experiments. Rózsakajszi C.1406 continued to rank highest with a temperature of -18.2 degrees Celsius, while Aurora, Pinkcot, and Magyar kajszi C.235 demonstrated comparable results, ranging from -15.2 to -16.7 °C. The Sweet Red cultivar exhibited suboptimal performance once more, with a significant increase in the LT_{50} score gap between it and other cultivars, which recorded a score of -12.8 °C. The trend of Rózsakajszi C.1406 continuing to rank highest expanded into Ferbraury with a temperature of -12 degrees Celsius. Magyar kajszi C.235 demonstrated the second highest score with -11.5 °C and Pinkcot tied for third with a temperature of -10.8 °C. The Aurora cultivar exhibited a relatively lower level of performance when subjected to a temperature of -10.6 °C, whereas the Sweet Red variety displayed the poorest outcome once again, with a temperature of -9.4 degrees Celsius.

The Figure X illustrates discernible variations in the LT_{50} values of the cultivars, which are also apparent across different months. The primary determinant of the variations observed among the months is the mean temperature

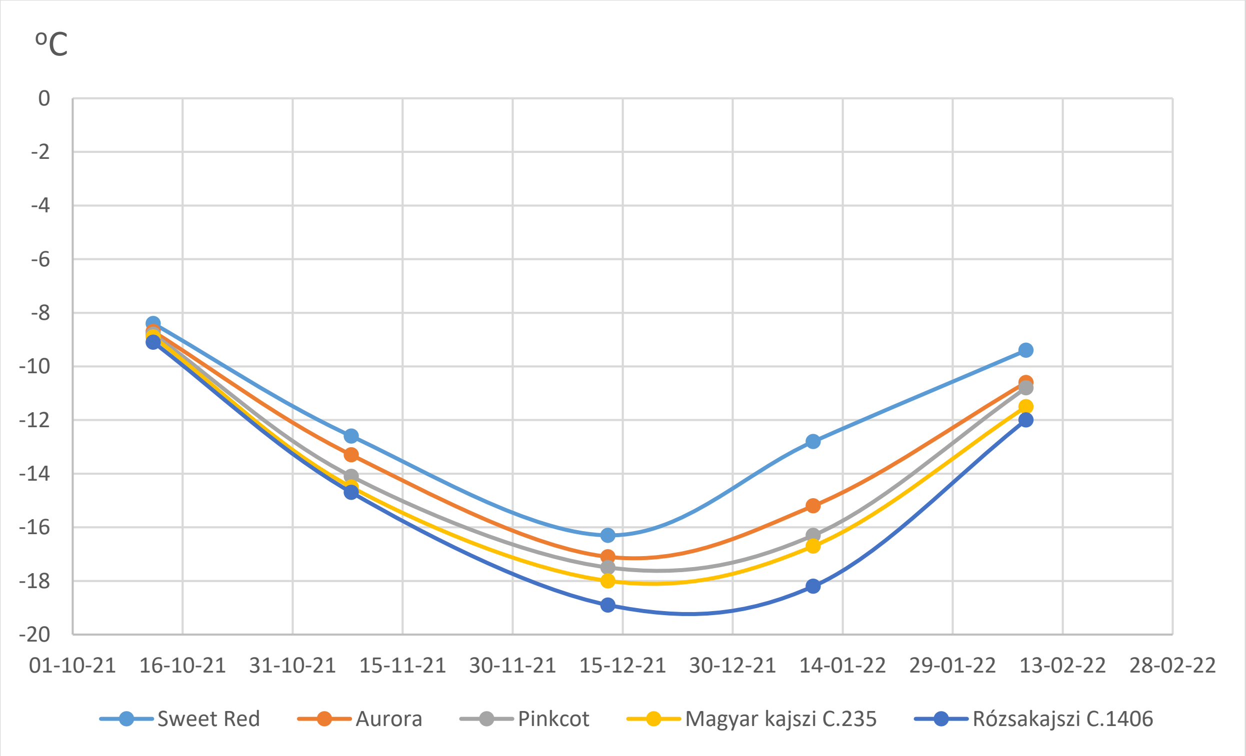


Figure 12: LT50 values of selected cultivars

characteristic of each respective month. As the average temperature of a given month decreases, the frost hardiness of the cultivars under examination demonstrates adaptation. The aforementioned phenomenon is observable during the period spanning from October of 2021 to December of 2021. The frost hardiness of cultivars decreases in January 2022 due to a slight increase in average temperature. This decline is more pronounced in February, likely due to a more drastic increase in monthly average temperatures.

The LT_{50} disparity among cultivars is contingent upon their provenance and the specific planting site. The results depicted in Figure X indicate that the cultivar exhibiting the most favourable LT50 score is Rózsakajszi C.1406, followed by Magyar kajszi C.235. These cultivars are of Hungarian origin and have been acclimatised to the environmental conditions prevailing at the Experimental Station of the Hungarian University of Agriculture and Life Sciences located in Soroksár. The aforementioned phenomenon is observable in the French Sweet Red cultivar as well, which exhibited suboptimal outcomes due to its adaptation and origin in the comparatively warmer Mediterranean climate of France. However, certain cultivars exhibit adaptability to colder climates despite their origins in warmer regions. The Italian Aurora cultivar and the French Pinkcot cultivar serve as exemplary instances of this phenomenon.

Given the established LT_{50} values of the chosen cultivars, various frost protection techniques can be implemented to optimise the overall profitability and safeguard the crop. As delineated in the "Literature Review" section of this thesis, two distinct forms of frost protection exist: active and passive frost protection. Selecting an appropriate cultivar is a crucial passive frost protection strategy, among other methods such as orchard floor care, proper orchard nutrition, and appropriate pruning. Site selection is also a significant factor to consider. By employing pre-planting planning and implementation of various techniques, the likelihood of frost damage in orchards can be significantly reduced. In the event that these measures prove inadequate, additional active protection methods, such as the utilisation of heaters, sprinklers, wind machines, and similar strategies, can be employed. To achieve optimal efficiency, it is recommended to employ a combination of active protection techniques.

To enhance the prospects of this study, it is recommended to expand the scope of cultivars under investigation to encompass a wider range of cultivars, with the aim of mitigating the impact of frost damage on a global scale. By adopting examination methods similar to those described in this thesis and expanding the scope of cultivars studied, orchard owners can obtain sufficient data to minimise crop losses and optimise profits through the implementation of appropriate frost protection measures. This approach can also contribute to the advancement of the fruit growing industry. The prevention of avoidable crop losses has the potential to address global famine and increase the availability of produce, thereby reducing the cost of fruits and making them accessible to all. The compendium of active and passive frost protection techniques and their corresponding data ought to be regularly revised to reflect the emergence of novel and more effective methods.

6. Summary:

In summary, this thesis has accomplished all of its stated goals. Initially a brief explanation of the term "frost" is given, which describes the creation of ice crystals on surfaces [Blanc et al., 1963; Bettencourt, 1980; Mota, 1981; Cunha, 1982]. This can be caused by dew freezing or by a phase transition from vapour to ice, but most typically it refers to a weather event in which crops and other plants are damaged due to freezing temperatures. When the surface temperature falls below zero degrees Celsius, frost sets in [Cunha, 1952]. Even if every step of the agricultural production process is well monitored and managed, a single night of subfreezing temperatures can wipe out an entire harvest [Usha,Thakre, Goswami, and Deepak, 2015]. Night-time temperatures below 0 °C, with daytime temperatures above 0 °C, a clear sky, and wind speeds of less than 5 mph (less than 8km/h) are the conditions for radiation frost [Usha, Thakre, Goswami, and Deepak, 2015] and Advection frost, which happens when the weather changes and cold air flows in and displaces the warmer air that had been there earlier [Snyder, Melo-Abreu, & Matulich, 2005]. The literature review section of this thesis also discusses other elements that influence frost damages on plants. These include relative humidity, air temperature, dew points, inversion layer, cloud covering, and wind speeds.

As a second point, the Literature study discussed several freeze protection strategies. Active and passive frost protection techniques are distinguished here [Kalma et al., 1992]. Methods that are passive are those that are put in place before a frost is expected. Active protective tactics are short-lived and either labour- or energy-intensive, or both; passive measures, on the other hand, include biological and ecological efforts like those taken before a frost night to decrease the chance for injury. According to the literature [Snyder, Melo-Abreu, & Matulich, 2005], "active" refers to methods that require some level of physical exertion. Because of this, preparation work must be done the day or night before frost is expected. Active protection includes a variety of strategies that make up for inherent energy losses during the frost night. Site selection, cold air drainage, plant selection, canopy management, plant nutrition management, cooling to delay bloom, plant covers, soil covers, trunk wraps, etc. are all examples of passive frost protection, while heaters, foam insulation, sprinklers, surface irrigation, wind machines, foggers, and the combination of active methods are all examples of active protection.

Thirdly, the rates of frost damages among the selected cultivars of Sweet Red, Aurora, Pinkcot, Magyar kajszi C.235, and Rózsakajszi C.1406 have been identified via 5 main experiments that consist of 17 micro experiments. These micro experiments were carried out in different temperatures and each of them produced a novel result. Among these micro experiments, the first experiment of October was the lightest with -4.8 degrees Celsius while the while the last experiment of December was the coldest with -20.5 °C. These temperatures subjected a similar result in term of ratios of the damaged flower buds to total flower buds as in the initial survey the results were varying from 2.73% to 5.56% while it was between 90% to total fatality on the third part of the December experiment.

The dates of the experiments were 12.10.2021, 08.11.2021, 13.12.2021, 10.01.2022, 08.02.2022.

Last but not least, LT_{50} values, hence the frost the hardiness of these cultivars were determined by calculating the temperature which would damage 50% of total buds during each month. *The LT_{50} values of selected cultivars can be observed in Table 9:*

Frost tolerance profile of apricot cultivars based on the results of artificial freezing of flower buds (2021-2022)					
Cultivars:	**LT_{50} values of selected cultivars and the dates of experiments**				
	12.10.2021	08.11.2021	13.12.2021	10.01.2022	08.02.2022
Sweet Red	-8.4 °C	-12.6 °C	-16.3 °C	-12.8 °C	-9.4 °C
Aurora	-8.7 °C	-13.3 °C	-17.1 °C	-15.2 °C	-10.6 °C
Pinkcot	-8.8 °C	-14.1 °C	-17.5 °C	-16.3 °C	-10.8 °C
Magyar kajszi C.235	-8.9 °C	-14.5 °C	-18 °C	-16.7 °C	-11.5 °C
Rózsakajszi C.1406	-9.1 °C	-14.7 °C	-18.9 °C	-18.2 °C	-12 °C

Table 9: LT50 values of selected cultivars and the dates of experiments

Table 9 shows that in October 2021, despite some differences in frost resistance, all cultivars performed similarly. Rózsakajszi C.1406 showed the greatest frost tolerance, with a temperature of -14.7 °C in November 2021. Sweet Red had the lowest LT_{50} score (-12.6 degrees Celsius), whereas the values for Magyar kajszi C.235, Pinkcot, and Aurora all fell. Rózsakajszi C.1406 had the highest frost hardiness, at -18.9 degrees Celsius, followed by Magyar kajszi C.235, Pinkcot, Aurora, and Sweet Red, with Sweet Red having the lowest score, at -16.3 degrees Celsius, indicating some variation in performance trends between the January 2022 and December 2021 experiments. Aurora, Pinkcot, and Magyar kajszi C.235 showed similar findings, ranging from -15.2 to -16.7 °C, but Rózsakajszi C.1406 remained on top with a temperature of -18.2 °C in January while the Sweet Red variety underperformed in January, with a score of -12.8 degrees Celsius. With a February record of -12 degrees Celsius, Rózsakajszi C.1406 has maintained its position at the top of the temperature rankings. Pinkcot tied for third place with a temperature of -10.8 °C, while Magyar kajszi C.235 recorded the second-highest score with a reading of -11.5 °C. When exposed to a temperature of -10.6 °C, the Aurora cultivar showed comparatively lower levels of performance, and when exposed to a temperature of -9.4 °C, the Sweet Red variety once again showed the worse outcome.

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Annex 3.

A.) Way of communication of own table

Table 1.: concise and accurate title of the table –must be clear in itself without the main text! (Budapest, 2012)

Apellation	Letterhead1 unit	Letterhead2 unit	Letterhead3 unit
Control	18,45	23,60	3,18
Treatment A	3,70	16,70	4,17

B.) Way of communication of taken over table

Table 2.: The title of the table (result of Smith, 1991)

Apellation	Letterhead1 unit	Letterhead2 unit	Letterhead3 unit

Annex 4.

Notation

place of the figure

Figure 23.: Title of the figure
must be clear in itself without the main text!

Annex 5.

DECLARATION

Me, as the undersigned Elman Gadimov (Code-Neptun: HAAGND) declare, that the Diploma Thesis entitled Frost protection methods and frost hardiness of apricot cultivars submitted on 07.05.2023 is my own intellectual property. I hereby acknowledge that the presentation of my thesis in the Dean's Office according the shedule does not mean at the same time the acceptance of my dissertation from professional and content related aspects.

07.05.2023, Budapest

signature of the student

Annex 6.

STATEMENT
of origin and public access of the thesis

Author's name: Elman Gadimov

Title of the thesis: Frost protection methods and frost hardiness of apricot cultivars.

Year of publication: 2023

Name of the Department: Fruit Growing

I declare that the submitted thesis is the product of my personal, original work.

The submitted thesis is defended. It is a pdf document embossed with the name of the author. I authorise to survey and print thesis but not to compile it.

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Annex 7.

Hungarian University of Agriculture and Life Sciences
Faculty of Horticultural Science
Department of Fruit growing

Elman Gadimov

Frost protection methods and frost hardiness of apricot cultivars.

Fruit growing

Two-sided summary of the thesis based on the formal requirements as described in Chapter IV of this Guide.

Summary:

Due to their extensive genetic diversity, apricots play an outsized role in the global fruit industry [Jiang et al. 2019]. The apricot accounts for 0.49 percent of global fruit production (3.72 million metric tonnes) [FAOSTAT. 2022; Statista. 2022; Uzundumlu et al. 2021], making it the twenty-fifth most produced fruit in the world. Despite this, global apricot production is lower than that of numerous other significant Prunus fruit commodities. The reason for this is that the majority of apricot cultivars have very specific ecological requirements; consequently, cultivars planted in other regions typically produce low yields [Polat and alşkan, 2014].

In conclusion, this thesis has achieved all of its specified objectives. Initially, a concise definition of the term "frost" is provided, which refers to the formation of ice crystals on surfaces [Blanc et al., 1963; Bettencourt, 1980; Mota, 1981; Cunha, 1982]. This can be caused by dew freezing or by a phase transition from vapour to ice, but typically refers to a meteorological event in which freezing temperatures cause injury to crops and other vegetation. Frost develops when the surface temperature descends below zero degrees Celsius [Cunha, 1952]. Even if every stage of agricultural production is carefully monitored and managed, a single night of subfreezing temperatures can destroy an entire crop [Usha, Thakre, Goswami, and Deepak, 2015]. The conditions for radiation frost are nighttime temperatures below 0 °C, daytime temperatures above 0 °C, a clear sky, and wind velocities of less than 5 mph (less than 8km/h) [Usha, Thakre, Goswami, and Deepak, 2015]. , and Advection frost, which occurs when the weather changes and frigid air flows in and displaces the previously milder air [Snyder, Melin-Abreu, & Matulich, 2005]. This thesis's literature review discusses additional factors that influence frost damage to plants. Included are relative humidity, ambient temperature, dew point, inversion layer, cloud cover, and wind velocities.

As a second point, the literature review covered a variety of freeze protection strategies. This article distinguishes between active and passive frost protection techniques [Kalma et al., 1992]. Passive methods are those that are implemented before a frost is anticipated. Active protective tactics are either labour- or energy-intensive, or both; passive measures include biological and ecological efforts such as those taken before a frost night to reduce the likelihood of injury. According to the research [Snyder, Melo-Abreu, & Matulich, 2005], "active" refers to methods requiring some measure of physical effort. Therefore, preparations must be made the day or night before frost is anticipated. Active protection comprises a variety of strategies that compensate for energy losses that occur naturally during frost nights. Site selection, cold air drainage, plant selection, canopy management, plant nutrition management, cooling to delay bloom, plant covers, soil covers, trunk wraps, etc., are examples of passive frost

protection, whereas heaters, foam insulation, sprinklers, surface irrigation, wind machines, foggers, and the combination of active methods are examples of active frost protection.

Thirdly, the rates of frost damage among the selected cultivars of Sweet Red, Aurora, Pinkcot, Magyar kajszi C.235, and Rózsakajszi C.1406 have been determined via 17 micro-experiments comprising 5 main experiments. These micro experiments were conducted at various temperatures, and each produced a unique result. The first experiment of October was the warmest with a temperature of -4.8 degrees Celsius, while the last experiment of December was the coolest with a temperature of -20.5 degrees Celsius. In the initial survey, the ratio of damaged flower buds to total flower buds ranged from 2.73 to 5.56 percent, while in the third and final phase of the December experiment, the ratio ranged from 90 to 100 percent.

The dates of the experiments were 12.10.2021, 08.11.2021, 13.12.2021, 10.01.2022, 08.02.2022.

Last but not least, the LT50 values, and consequently the frost-resistance of these cultivars, were determined by calculating the monthly temperature at which 50% of total blossoms would be damaged. The LT50 values of specific cultivars are shown in Table 10:

Table 10: The LT50 values of selected cultivars

Frost tolerance profile of apricot cultivars based on the results of artificial freezing of flower buds (2021-2022)					
Cultivars:	**LT_{50} values of selected cultivars and the dates of experiments**				
	12.10.2021	08.11.2021	13.12.2021	10.01.2022	08.02.2022
Sweet Red	-8.4 °C	-12.6 °C	-16.3 °C	-12.8 °C	-9.4 °C
Aurora	-8.7 °C	-13.3 °C	-17.1 °C	-15.2 °C	-10.6 °C
Pinkcot	-8.8 °C	-14.1 °C	-17.5 °C	-16.3 °C	-10.8 °C
Magyar kajszi C.235	-8.9 °C	-14.5 °C	-18 °C	-16.7 °C	-11.5 °C
Rózsakajszi C.1406	-9.1 °C	-14.7 °C	-18.9 °C	-18.2 °C	-12 °C

Table 10 shows that in October 2021, despite some differences in frost resistance, all cultivars performed similarly. Rózsakajszi C.1406 showed the greatest frost tolerance, with a temperature of -14.7 °C in November 2021. Sweet Red had the lowest LT_{50} score (-12.6 degrees Celsius), whereas the values for Magyar kajszi C.235, Pinkcot, and Aurora all fell. Rózsakajszi C.1406 had the highest frost hardiness, at -18.9 degrees Celsius, followed by Magyar kajszi C.235, Pinkcot, Aurora, and Sweet Red, with Sweet Red having the lowest score, at -16.3 degrees Celsius, indicating some variation in performance trends between the January 2022 and December 2021 experiments. Aurora, Pinkcot, and Magyar kajszi C.235 showed similar findings, ranging from -15.2 to -16.7 °C, but Rózsakajszi C.1406 remained on top with a temperature of -18.2 °C in January while the Sweet Red variety underperformed in January, with a score of -12.8 degrees Celsius. With a February record of -12 degrees Celsius, Rózsakajszi C.1406 has maintained its position at the top of the temperature rankings. Pinkcot tied for third place with a temperature of -10.8 °C, while Magyar kajszi C.235 recorded the second-highest score with a reading of -11.5 °C. When exposed to a temperature of -10.6 °C, the Aurora cultivar showed comparatively lower levels of performance, and when exposed to a temperature of -9.4 °C, the Sweet Red variety once again showed the worse outcome.

REQUEST FOR CONFIDENTIALITY

I, the undersigned Elman Gadimov (Neptun code: HAAGND) student at Horticultural Science programme request that my thesis / diploma thesis[1] titled Frost protection methods and frost hardiness of apricot cultivars. (name of supervisor(s): Professor László Szalay and Mr József László Bakos) be encrypted by applying point c) of Section 95 (5) of the Study and Examination Regulations of the Hungarian University of Agriculture and Life Sciences (hereinafter referred to as 'SER'). I understand that if my request is approved, the encryption of the thesis / diploma thesis will cover 5 years following the successful defence, in accordance with point c) of Section 95 (5) of SER.

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I APPROVE / REJECT the request for confidentiality.

Reasons for rejection: ____

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Done at: ___________________, _________________

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Programme leader's signature

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STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Elman Gadimov (HAAGND), I here declare that the final essay/thesis/master's thesis/portfolio[4] has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend[5] the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*[6]

Place and date: Budapest, 2023.05.07

Internal supervisor

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