



Universitat de Lleida
Escola Tècnica Superior
d'Enginyeria Agrària



Grau em Enginyeria Agrària i Alimentària

TRABAJO DE FIN DE GRADO (TFG) ESTUDIO TÉCNICO.

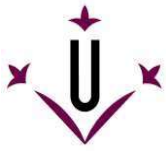
STRAWBERRY (*Fragaria L.*) CONSERVATION PROCESSES IN POSTHARVEST

Name: Cabral, Leticia Daniela da Silva

Tutor: Soria Villalonga, Yolanda Jacinta

Department: Ciència i Enginyeria Forestal i Agrícola

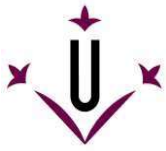
Course: 2022/23



ABSTRACT

The strawberry (*Fragaria L.*) is a perennial herbaceous plant, which is mostly grown as an annual plant and belongs to the *Rosaceae* family. It is a plant with great economic potential, with the possibility of being used in feeding, processing, cosmetics, and even pharmaceutical industries. However, it is a very perishable and delicate fruit, with a high respiratory rate and, therefore, a short postharvest life. This fragility demands care from producers during all stages of production, with product conservation methods being an extremely important stage that will reflect on the quality of the fruit. The fruit must be harvested at the ideal time to maintain its organoleptic qualities, handled with care during harvesting to avoid physical damage and wounds that could allow the entry of deteriorating organisms. The packaging used in conservation must be clean and sanitized, and the fruits must be kept in an environment of low temperature and high relative humidity. Among the packaging most used for conservation are plastic boxes with lids and expanded polystyrene trays, and using the most technological and effective conservation techniques is one of the ways to reduce waste in strawberry production and, therefore, the economic losses of the sector.

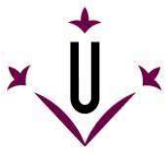
Key Words: Strawberry; Conservation, Postharvest.



RESUMEN

La fresa (*Fragaria L.*) es una planta herbácea perenne, que se cultiva principalmente como planta anual y pertenece a la familia de las rosáceas. Se trata de una planta con un gran potencial económico, con posibilidad de ser utilizada en la industria alimentaria, de transformación, cosmética e incluso farmacéutica. Sin embargo es un fruto muy perecedero y delicado, con una alta tasa respiratoria y, por tanto, una corta vida postcosecha. Esta fragilidad exige un manejo cuidadoso por parte de los productores durante todas las etapas de la producción, siendo los métodos de conservación del producto una etapa sumamente importante que se reflejará en la calidad de la fruta. Los frutos deben ser cosechados en el momento ideal para mantener sus cualidades organolépticas, manipulados con cuidado durante la cosecha para evitar daños físicos y heridas que puedan permitir la entrada de microorganismos. Los envases utilizados para la conservación deben estar limpios y desinfectados y los frutos deben mantenerse en un ambiente con baja temperatura y alta humedad relativa. Entre los envases más utilizados para la conservación se encuentran las cajas de plástico con tapa y las bandejas de poliestireno expandido y el uso de las técnicas de conservación más tecnológicas y eficaces es una de las formas de reducir los residuos en la producción de fresa y, por tanto, las pérdidas económicas del sector.

Palabras Clave: Fresa; Conservación, Postcosecha.



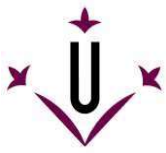
LIST OF ILLUSTRATIONS

Figure 1. Strawberry cultivars.....	10
Figure 2. Stages of fruit development.....	11
Figure 3. Schematic representation of different strawberry ripening-related processes.....	12
Figure 4. Production Technologies: Autumn or summer production cycle.....	15
Figure 5. Cultivation in tunnels and combinations of plastics.	16
Figure 6. Combination of soil coverings (black polyethylene and straw).	17
Figure 7. Contribution of each European country in percentage to the total production volume (tons).....	19
Figure 8. Strawberry flow and marketing channels.....	20
Figure 9. Distribution of strawberry sales volume in the national market by type of establishment..	21
Figure 10. Surface, production, and commercialization of strawberry.	21
Figure 11. Products originated from strawberry processing.	23
Figure 12. Scheme for traditional canned strawberry jam processing.	23
Figure 13. Strawberry quality ratings.....	25
Figure 14. Cold Chamber.	29
Figure 15. Controlled atmosphere CO ₂ treatment in strawberry.....	30
Figure 16. The edible coating on strawberry fruit..	30
Figure 17. Setup for forced air cooling.	31
Figure 18. Packaging with PET box and PVC film covering.	33
Figure 19. Package with a PET box and lid, with a perforated lid.....	34
Figure 20. Packing with individual separation for strawberries.	34
Figure 21. Cardboard boxes for external packaging.....	35
Figure 22. Examples of mechanical damage.....	36
Figure 23. Examples of physiological damage.	37
Figure 24. Field diseases with postharvest evolution.	38
Figure 25. Diseases associated with postharvest wounds.	38



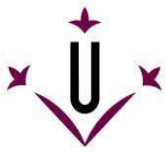
LIST OF CHARTS

Chart 1. Most used cultivars according to each European country.....	10
Chart 2. European Strawberry Yield in the last six years.	19
Chart 3. Monthly evolution of the strawberry production marketed fresh (2010/11). .	22



SUMMARY

1 INTRODUCTION	7
2 GOALS	9
3 LITERATURE REVIEW	9
3.1 THE STRAWBERRY CULTIVATION	9
3.2 PHYSIOLOGICAL CHARACTERIZATION OF THE FRUIT	11
3.3 CLIMATE AND AGRICULTURE	13
3.3.1 Water Requirement	13
3.3.2 Temperature and Photoperiod	13
3.4 PRODUCTION METHODS	14
3.5 MANAGEMENT PRACTICES	16
3.6 STRAWBERRY MARKET	18
3.6.1 Harvesting and Consumption	21
3.6.2 Industry and Processing	22
3.7 STRAWBERRY QUALITY CLASSIFICATION	24
3.8 LOGISTICS AND TRANSPORT	26
3.9 STRAWBERRY CONSERVATION	27
3.9.1 Most Used Methods	28
3.9.2 Packaging and Materials	32
3.10 MAJOR POSTHARVEST DAMAGE	35
3.10.1 Mechanical Damage	35
3.10.2 Physiological Damage	36
3.10.3 Rots	37
3.11 ECONOMIC STUDIES AND WASTE REDUCTION	39
4 CURRENT SITUATION	40
5 STUDY OF ALTERNATIVES	40
6 CONCLUSIONS	42
7 BIBLIOGRAPHIC REFERENCES	43



1 INTRODUCTION

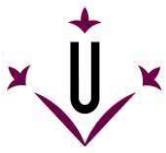
The strawberry (*Fragaria L*) is a dicotyledonous flowering plant that belongs to the botanical family *Rosaceae* and the genus *Fragaria*. The types of strawberry are quite variable in functional and structural terms, therefore, according to CONTI et al. (2002), plants are classified according to the morphological differences of the leaf, plant, and fruit (ANTUNES et al., 2016). It is a perennial herbaceous plant, cultivated annually for physiological, sanitary, and quality reasons, but its roots and stems that are more than a year old are partially lignified (BRAZANTI, 1989). Its size ranges from 15cm to 30cm and can be crawling or erect.

It is estimated that the modernized species of strawberry that we consume today (*Fragaria x ananassa*) emerged 250 years ago. Before that, other species were cultivated and consumed mostly wild (LISTON et al., 2014). Its center of genetic origin is in East Asia, but studies indicate that strawberries have been consumed by humans since the Stone Age (FOLTA et al., 2009; McINTROSH, 2006).

The world's largest producer is China, according to 2021 data gathered by FAOSTAT, while Spain is the sixth largest producer in the world and the largest producer in Europe, with 90% of production carried out in the Huelva region. The main strawberry production systems are open field and protected cultivation (greenhouses or plant factory). The largest consumer of strawberries in the world is the United States, which annually consumes more than 800,000 tons of the fresh fruit and 240,000 tons of the frozen fruit (MADAIL, 2021).

The strawberry plant has a taproot, stolons and trifoliate leaves, these leaves vary in size and shape according to the variety. This plant has indeterminate growth and, due to its stolons, the strawberry can spread and form new plants throughout its life. Regarding reproduction, strawberries produce hermaphrodite flowers, and pollination can occur through wind, insects or even self-pollination, inefficient pollination can compromise the formation of fruits, leaving them deformed (DIAS, 2013). The strawberry is considered an achene-type pseudo fruit.

Strawberry climatic preferences range from subtropical to temperate (CENEVIVA, 2019). According to SANTOS (1993), the strawberry plant needs heat



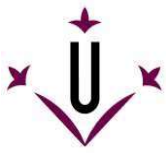
for good vegetative development, but for floral differentiation and fruiting, it prefers colder climates. Fruit production and quality are greatly influenced by temperature (it is very sensitive to climate variations) and photoperiod (DIAS, 2013). Still according to SANTOS (1993), short photoperiods favor fruiting, while long photoperiods stimulate vegetative growth.

Among the various delicacies of the strawberry, the fruit is also very perishable and has a short post-harvest life. Mechanical damage carried out during harvesting, transportation and commercialization leaves the fruit susceptible to microorganism attack, which can cause great losses in the sector and in organoleptic qualities (CANTILLANO, 2009).

In the postharvest, some aspects are important for maintaining fruit quality; CANTILLANO (2009) mentions the following: color, absence of damage and wounds, cleaning of fruits and packaging used. In addition, the management of adequate air temperatures and humidity to stabilize strawberries are also factors that can maintain the quality of the product and increase its lifespan on the market.

The main physiological factors that affect strawberry quality are respiration and transpiration (ANTUNES et al., 2013). Strawberries have a high respiratory rate, which can increase in five times when the temperature reaches 10°C and up to ten times more when the temperature reaches 20°C (MITCHAM et al., 2003). Due to the large surface area exposed, compared to the weight, and because it does not have a protective epidermal layer, the strawberry is at great risk of losing water through transpiration. Strawberry is a fruit with a high-water content (90%), which due to homeostasis with the environment, the large amount of water in the fruit tends to migrate to the environment (CLAYPOOL, 1975; ANTUNES et al., 2013). Both factors can be controlled during postharvest in a chamber with controlled temperatures and air humidity.

This work will present studies on different conservation and packaging techniques, at the time of harvest, in the postharvest, transport and disposal in markets, whether fresh consumption (table) or industrial (processing), making a study of alternatives from comparison between the methods and, finally, indicate the most technically and economically viable.



2 GOALS

The objective of this technical study is to gather the available strawberry conservation techniques and, through the research of these techniques, to consider which one is the best, considering the efficiency, the improvement in the quality and the increase in the lifetime of the product and the possible reduction in waste in the sector.

3 LITERATURE REVIEW

3.1 THE STRAWBERRY CULTIVATION

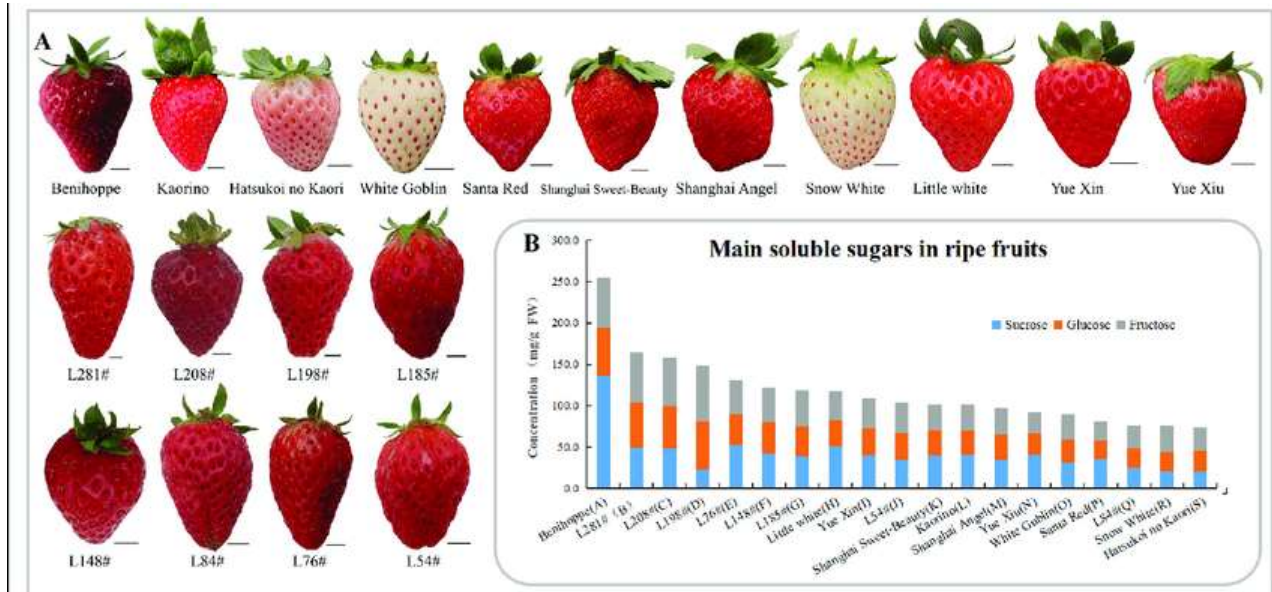
The cultivated strawberry (*Fragaria L.*) originates in East Asia (FOLTA et al., 2009; McINTROSH, 2006), is a member of the *Rosaceae* family and, according to the Garden Museum (2021), it is estimated that there are more than twenty species around the world, with many hybrids and several cultivars of cultivars.

The main cultivated species in the world is *Fragaria x ananassa* and its hybrids, followed by *Fragaria vesca* (GARRETT, 2022). *Fragaria x ananassa* is a hybrid resulting from the American species *F. Chiloensis*, *F. Virginiana* and *F. Ovalis*, and the European *Fragaria vesca* (RONQUE, 1998; RADMANN et al., 2006).

The choice of species and cultivars depends on the characteristics of the production environment, mainly temperature and photoperiod (SANTOS, 1993), other important factors are altitude and type of production required in a particular region (PETRUZZELLO, 2023). The choice of variety should also consider the final use of the fruit (in natura consumption, freezing, processing, among others), as its size, shape and organoleptic quality strongly influence the final product audience (ESPOMA, 2018).

Some examples of cultivars, listed by GARRET (2022), are grouped according to growing seasons: early season, early midseason, midseason, late midseason, late season.

In Figure 1 below we can observe some strawberry cultivars and their respective amounts of soluble sugars.



In Chart 1 it is possible to observe some cultivars of strawberries most cultivated in different European countries.

Region	Popular varieties for cultivation
Netherlands	'Sonata', 'Lambada'
United Kingdom	'Malling Centenary'
Central Europe	'Alba', 'Asia', 'Brilla', 'Joly', 'Romina', 'Sibilla' (early and mid-season production)
Germany, (Poland)	'Cristina', 'Letitia' (late season) 'Malwina' (very late season)
Central Europe & Germany	'Clery' (Patented by Consorzio Italiano Vivaisti-CIV)
Northern & central Europe	'Sonata', 'Elsanta' (old cultivar, no patent, gradually being replaced by various new cultivars)
Scandinavian countries	'Korona'
France	'Gariguette' (old cultivar), 'Darselect'
Southern Europe (central areas of Italy, Spain, Greece)	'Clery', 'Joly', 'Alba', 'Asia', 'Garda', 'Eva', 'Romina', 'Sibilla', 'Cristina', 'Darselect'
Southern Europe (Southern Italy, Spain, Greece)	'Florida-Fortuna', 'Camarosa', 'Monterey', 'Portola' (USA cultivars), 'Sabrosa-Candongra', 'Sabrina', 'Rociera', 'Melissa' (Spanish cultivars), 'Calinda', 'Victory', 'Primavera' (new cultivars)
Huelva (Spain)	'Florida-Fortuna' (Florida University), 'Primoris', 'Rociera' and 'Rabida' (Fresas Nuevos Materiales-FNM)

Chart 1. Most used cultivars according to each European country.
Source: CBI Ministry of Foreign Affairs (2021).

Due to the high perishability of strawberries, the fruit is generally produced close to consumption or processing centers. Also, very sensitive to mechanical damage, the strawberry harvest is hardly mechanical, so it is interesting that the productive zone is close to a place where labor is available (PETRUZZELLO, 2023).

3.2 PHYSIOLOGICAL CHARACTERIZATION OF THE FRUIT

According to DE ASSIS et al. (2015) strawberry is influenced by factors such as temperature and photoperiod. The formation of stolons is favored by long days and high temperatures, whereas floral induction occurs in mild temperatures and short days.

It is said by FILGUEIRA (2002), the plant requires daily thermoperiodicity to maintain its organoleptic standards, with mild daytime temperature and lower nighttime, since under high temperature, the strawberry becomes more acidic, poor in flavor and aroma.

Strawberry ripening involves drastic changes in color, texture, flavor and aroma, and nutritional and palatability qualities strongly depend on the optimal degree of ripeness (ASAO et al, 2019). Figure X below demonstrates the stages of fruit development, with degrees of maturity advancing from left to right (anthocyanin development).

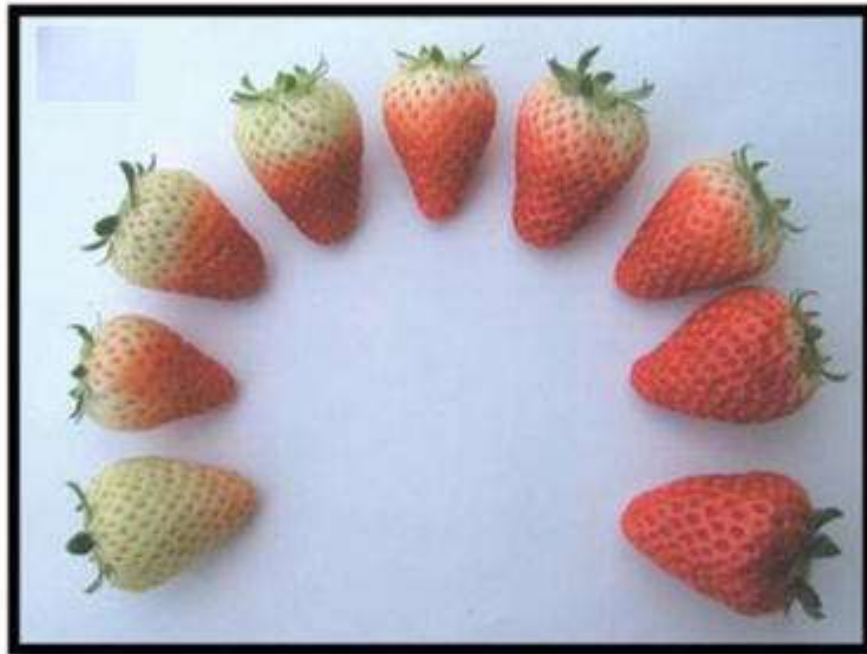


Figure 2. Stages of fruit development. Source: ASAO et al. (2019).

The strawberry has a short post-harvest life and is a nonclimacteric fruit. A nonclimacteric fruit is one that does not show increases in respiratory rate and ethylene production after harvesting (BRON et al. 2007) and, according to

SÁNCHEZ-GÓMEZ et al. (2022), strawberry ripening is largely regulated by abscisic acid (ABA), in addition to other processes such as hormonal balance, flavonoids biosynthesis, carbohydrates metabolism, volatile production and cell wall modifications (GU et al., 2019).

In Figure 3 is the schematic representation of some of the processes mentioned in the paragraph above.

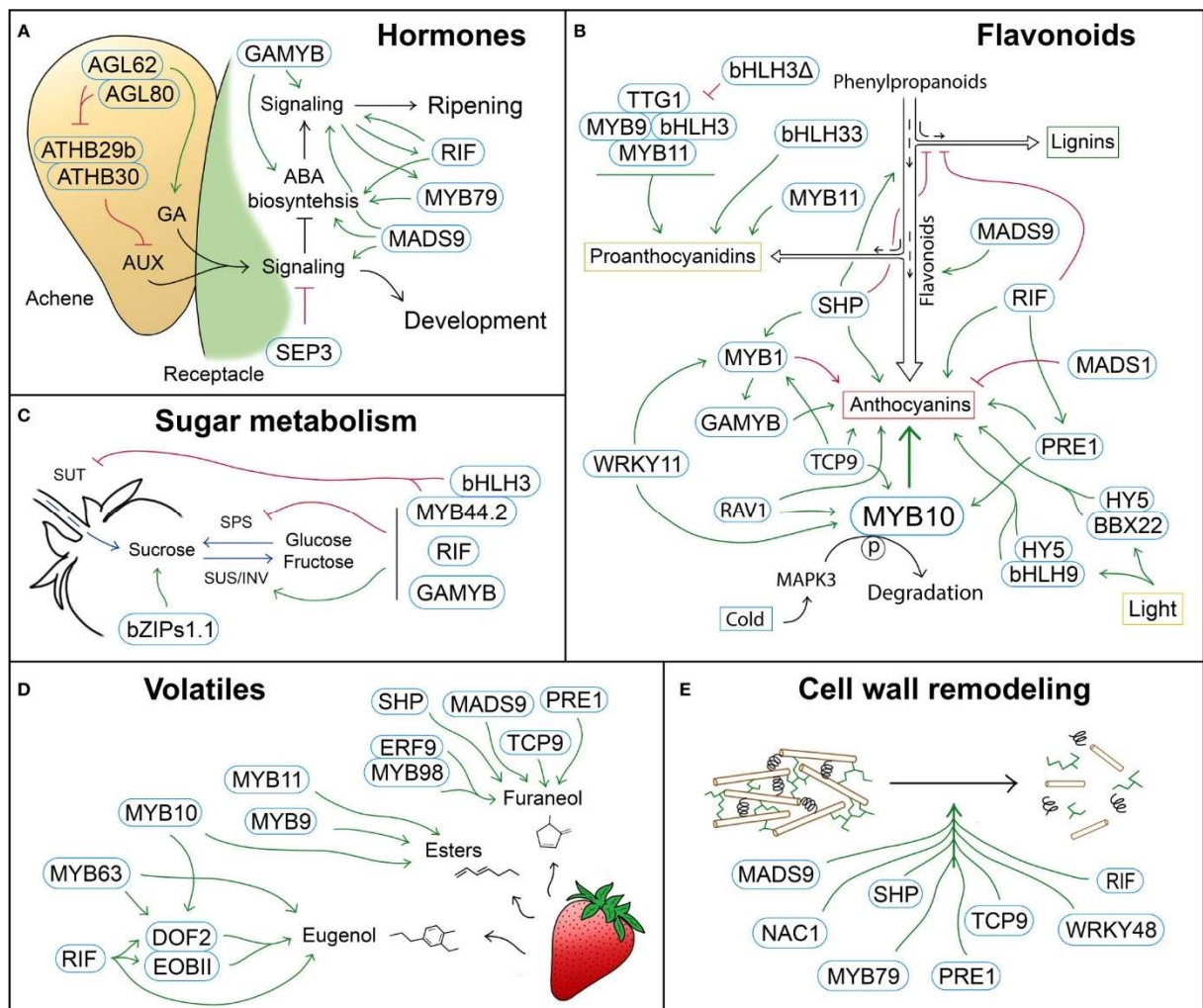
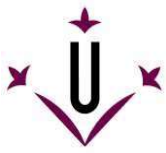


Figure 3. Schematic representation of different strawberry ripening-related processes. Source: Sánchez-Gómez et al., (2022).

Even though the endogenous ethylene production rate is very small in nonclimacteric fruits, the presence of this gaseous phytohormone in the air is undesirable, considered one of the great villains in the transport and storage of fruits, as it can lead to senescence, in addition to being able to activate plant defense mechanisms such as phytoalexin production (SENHOR et al, 2009).



For this reason, controlling ethylene in storage and transport environments is important and one of the alternatives to prolong the shelf life of strawberries.

There are records that treatment with 1-MCP (synthetic ethylene regulator) prolonged the postharvest life of strawberries by delaying decay. This beneficial response occurs only in low concentration treatments, while in high concentration (500 nL/L) of 1-MCP there is an increase in disease problems (SÁ et al., 2008).

3.3 CLIMATE AND AGRICULTURE

As the strawberry originates from regions with temperate and subtropical altitude climates, its cultivation demands certain climatic and growing environment requirements. The same applies to species, hybridizations and cultivars that emerged after genetic improvement (ANTUNES et al., 2013).

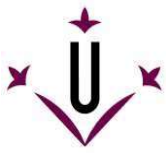
3.3.1 Water Requirement

The amount of water needed can vary according to the stage of development of the plant. According to ANTUNES et al. (2013), the highest concentration of the strawberry root system is found in the first 25 cm of depth, so the crop can be highly sensitive to water deficiency due to the response to evapotranspiration.

The daily water depth of the irrigation system during the crop cycle is around 2mm/day (PIRES et al., 2007), requiring constant availability of water, close to field capacity. However, according to REISSER JÚNIOR et al. (2009), excess water favors the incidence of diseases.

3.3.2 Temperature and Photoperiod

The optimum temperature for root development is between 17 and 30°C, and once the root system is established, temperatures below 15°C are favorable for the accumulation of reserves in the roots and rhizome. On the other hand, the favorable conditions for leaf development are long days and increasing temperatures, with the optimal temperature range being between 18 and 28°C (MEXIA et al., 2005).



About the photoperiod, since strawberry is a plant with thermal amplitude of production, the selection of the plant found several forms of reproduction under different environmental conditions, establishing groups of growth habits influenced by the photoperiod (WREGGE et al., 2007).

The cultivars are as follows:

- a) Short-day cultivars, flowering during the winter, when daylight hours are shorter.
- b) Long-day cultivars, flowering during the summer, when there are more hours of light.
- c) Day-neutral cultivars, indifferent to the total variation of hours between day and night.

WREGGE et al. (2007) say that the variation is proportional to latitude, that is, it increases proportionally to the increase in latitude.

It is of productive and economic interest that the cultivation follows or be as close as possible to the optimal conditions for development, as the world market becomes increasingly demanding in terms of product quality, whether in terms of visual, organoleptic, or even sanitary aspects (ANTUNES et al., 2013).

Also factors such as size, formation, genetic expression of characteristics such as color, relationship between acidity and sugars, are strongly influenced by the climatic conditions of the region (ANTUNES et al., 2013).

3.4 PRODUCTION METHODS

Strawberry production technologies have been constantly evolving in the last decades (ANDRADE et al., 2005), these techniques include genetic improvement, micropropagation, integrated pest management, protected cultivation and the use of day-neutral plants that allowed strawberry production to expand throughout the year, in addition to being a production more sustainable and "cleaner" of pests and diseases.

The election of production techniques will vary according to the requirements of the destination market, the cultivars and the edaphoclimatic conditions of the production area.

ANDRADE et al. (2005) mention some production techniques in countries with subtropical to tropical climates, such as the following:

- I. Outdoor production with planting during autumn: uses improved cultivars selected for production in the Spring/Summer seasons. The most used cultivars are the short-day ones.
- II. Production in protected cultivation planting during summer: strawberry production out of season, from October to December, with semi-forced management. Use of cold-preserved plants, produced for out-of-season cultivation and conditioned until transplantation. The seedlings require storage in refrigerated chambers, with temperatures between -1 to -2°C and relative humidity of 90 to 95% during the months before planting, for seedlings to go into dormancy. This technique uses neutral day cultivars.

In the Figure 4 it is possible to observe the production distribution during the months for both production techniques.



Figure 4. Production Technologies: Autumn or summer production cycle. IF - Floral induction; FL - Flowering; FR - Fruiting. Source: ANDRADE et al., 2005.

ANTUNES et al. (2013) also mention some alternatives to modify the cultivation environment, such as using plastic tunnels to anticipate or prolong the

harvesting period, as can be seen in Figure 5; the use of cultivars and plastic film combination management are efficient techniques to reconcile the low dependence on climatic conditions and still be able to achieve higher yields and fruit quality (ALMEIDA et al., 2009; REISSER JÚNIOR et al., 2011).



Figure 5. Cultivation in tunnels and combinations of plastics.
Source: BALBINO (2019).

3.5 MANAGEMENT PRACTICES

Cultural management practices cited by ANDRADE et al. (2005) in the "strawberry tree manual" include:

- I. Crop rotation: used to reduce the occurrence of weeds, pests, and diseases, and improve soil fertility. It is advisable that no species of the *Solanaceae* family have been cultivated in the area, and some species suggested for rotation are oats (*Avena sativa*), corn (*Zea mays*) or ryegrass (*Lolium multiflorum*) (EMBRAPA, 2010).
- II. Soil disinfection: process carried out in the presence of pathogenic fungi, nematodes, pests, and weeds. Among the disinfection methods, there are physical ones (such as soil solarization); chemical (using chemical control substances); and mixed (solarization together with a chemical substance).

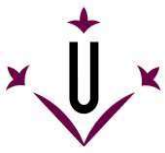
- III. Soil preparation: aiming at and respecting soil conservation and carried out following contour lines. Soil preparation, manual or using machinery, can provide improvements in the heating of the volume of land that touches the rhizosphere, drainage, aeration, ventilation and can facilitate harvesting.
- IV. Soil cover: with plant material and/or plastic. It increases the temperature and maintains the structure and humidity of the soil, benefiting rooting and, consequently, the precocity of the plants. It also helps in reducing water loss. The most recommended materials for covering the soil are black polyethylene, and for cases of production during summer and autumn, the use of white polyethylene on the upper surface and black polyethylene on the lower part, so that the soil temperature does not become too high.

In Figure 6 below, the combination of covering with black polyethylene in the production lines and vegetation cover in the corridors can be seen.



Figure 6. Combination of soil coverings (black polyethylene and straw).
Source: PASSOS et al. (2013).

- V. Choice of plant material: in addition to choosing the appropriate variety for the edaphoclimatic characteristics of the production area and the market of interest, also always should be used certified plants, with guaranteed sanitary and vegetative quality.
- VI. Planting: mostly via seedlings, carried out manually, soil with good moisture content before implantation.



- VII. Planting density: spacing of 0.3m x 0.3m or 0.25m x 0.25m between plants, arranged in a double row, is recommended. Resulting in 60,000 to 72,000 plants per hectare.
- VIII. Organic matter and pH: Strawberry plants prefers soils rich in organic matter, and it is recommended that it be applied to the soil whenever levels are below 1%. The plant prefers slightly acidic pH values, between 6.0 and 6.5.

Other important controls include fertilization, types of fertilization, irrigation systems and frequencies and weed control (insects, diseases, or weeds). These controls depend on the variety of strawberry used, as well as soil conditions, the productive zone, and other variable factors.

3.6 STRAWBERRY MARKET

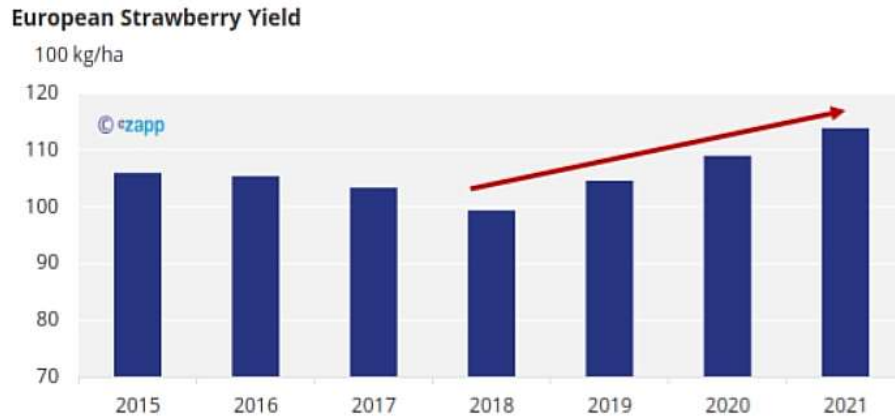
The development of the housing industry underwent rapid expansion in the twentieth century, mainly in places such as California, the Mediterranean region, Central and South America, Australia, and China. In these regions, combinations of short days with high average temperatures are found, making high productions possible through the seasons (SIMPSON, 2018).

In 2013, according to FAOSTAT, the global production of strawberries was greater than 7.7 million tons, reaching an increase of 142% when compared to the last 20 years. According to SOUZA et al. (2022), in 2020 the global strawberry market reached about US\$ 18,370 million, with prospects to reach US\$ 23,210 million in the year 2027. The main names in the global strawberry market are the companies: Dole Food, Driscoll, Berry Gardens, Fresgarrido, Goknur Gida, Grupo Mirak, Quilhas, Fazendas Naturipe and Bel Orta.

The United States, in addition to being the world's largest producer, with 39% of production, is also the largest consumer of strawberries in the world, with an annual consumption of around 800,000 tons of fresh and 240,000 tons of frozen fruit. (MADAIL, 2021).

In Europe, in the last six years, the strawberry harvest has become much more efficient, with around 1.7 million tons for an area of 14 thousand hectares, as can be seen in Chart 2 below (PACHON, 2023).

Chart 2. European Strawberry Yield in the last six years.
Source: PACHON (2023).



The largest European producer and supplier is Spain, which produces about 400,000 tons of strawberries a year (PACHON, 2023). The percentages of the contribution of each country can be seen in Figure 7.

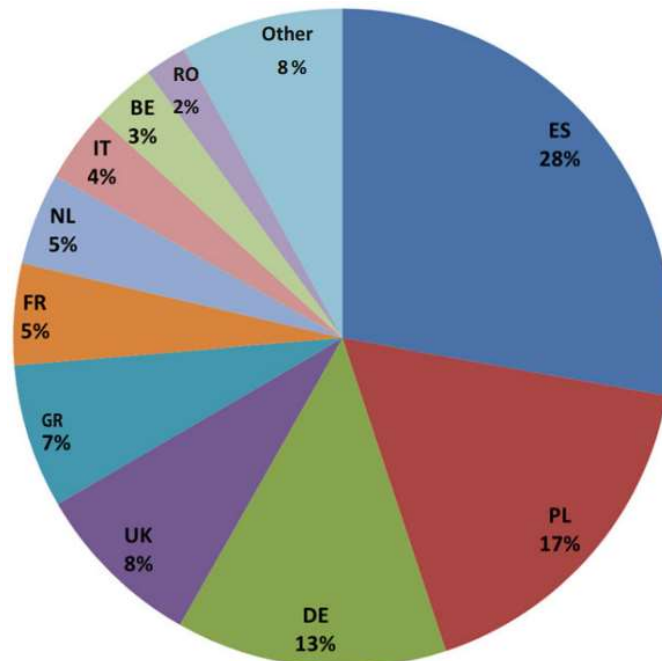


Figure 7. Contribution of each European country in percentage to the total production volume (tons). Source: FAOSTAT (2013).

The consumption of strawberries has also become increasingly popular around the world, as it is considered a healthy, pleasant food that requires little or no preparation to eat, in addition to the versatility of the product, which can be consumed fresh, frozen, in jellies among others (SIMPSON, 2018). The hybridization of species and the creation of new cultivars also helped the development of strawberries in different regions of the world, enabling their production and expanding the adaptability and resistance of the crop.

Strawberry marketing follows a flow according to the type of channel used, traditional or modern. The "Junta de Andalucía" (2011) developed a diagram (Figure 8) in which it demonstrates the paths taken by the product from the field to the end of the commercial chain.



Figure 8. Strawberry flow and marketing channels.
Source: Junta de Andalucía (2011).

Still using the data provided by the "Junta de Andalucía" in 2011, each type of establishment has its percentage of strawberry sales in the Spanish national market, following this degree shown in Figure 9 below:

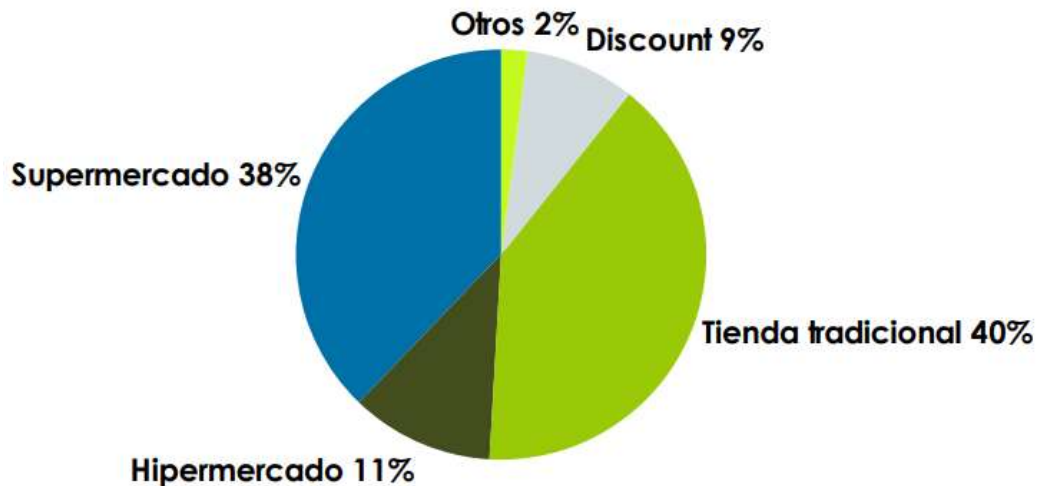


Figure 9. Distribution of strawberry sales volume in the national market by type of establishment. Source: Junta de Andalucía (2011).

3.6.1 Harvesting and Consumption

The "Junta de Andalucía" (2011) disclosed data that showed that 79% of the Spanish production of strawberry is destined for fresh consumption and 21% for industry, as shown in Figure 10.

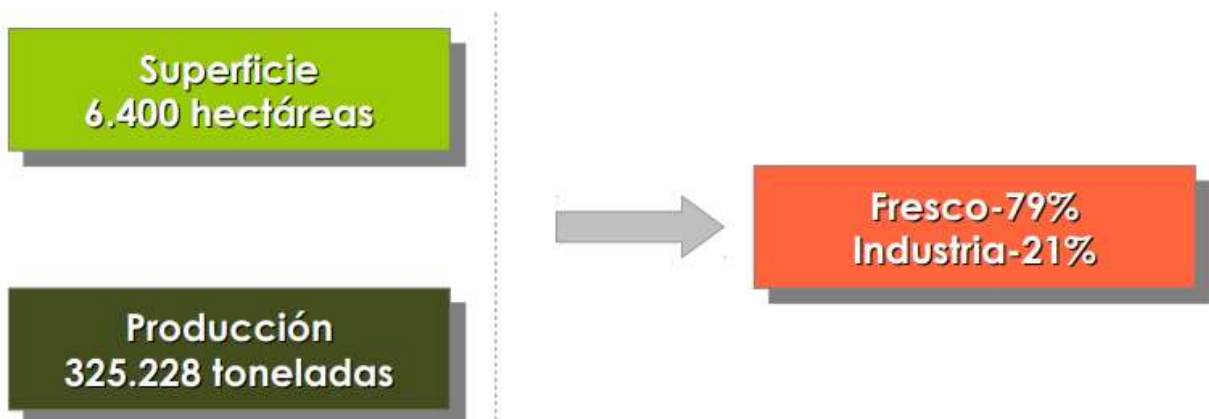


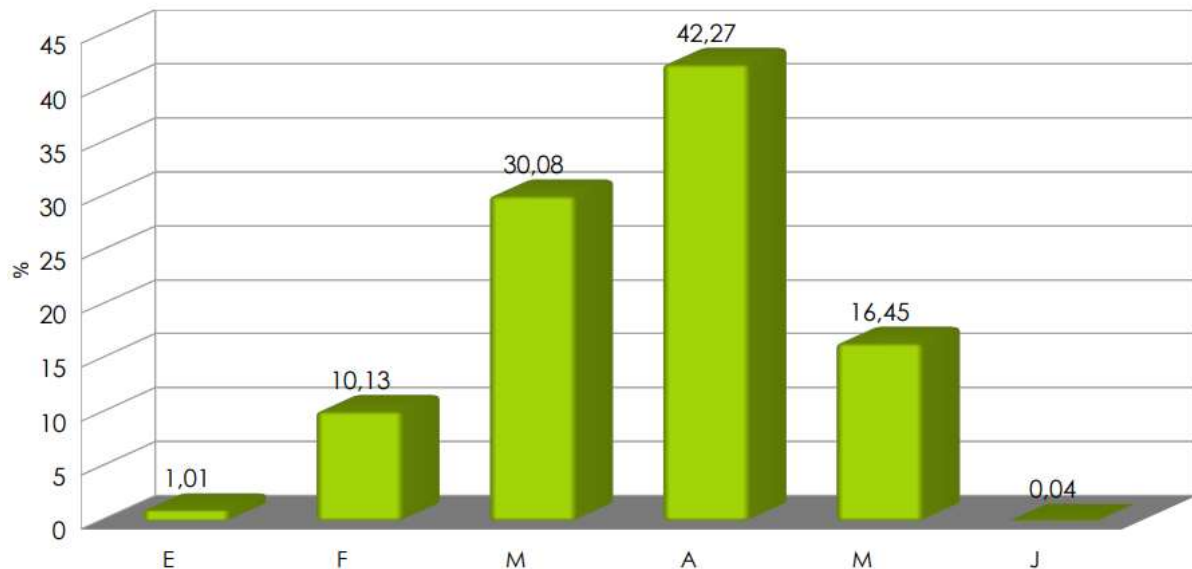
Figure 10. Surface, production, and commercialization of strawberry. Source: Junta de Andalucía, (2011).

The production of strawberries marketed fresh is concentrated in the months of March, April, and May, with its peak in April, expressed in Chart 3. The data are quite old, carried out through a market survey in 2011 by the "Junta de Andalucía", but it is still the most solid survey carried out, as it considers the different markets and forms of consumption, as well as the types of producers and the ways in which

they put their products in the market, covering the entire production chain, from producer to consumer.

Chart 3. Monthly evolution of the strawberry production marketed fresh (2010/11).

Source: Junta de Andalucía, (2011).



For industrial use and processing, the strawberry harvest must be carried out when the fruit is 50% to 75% ripe, expressed through the bright red color, bearing in mind that the acidity of the fruit may be interesting for some types of processed products, and lower amounts of sugars. And the harvesting point can also vary according to the distance and time of transport, the ambient temperature, the cultivar, and the purpose of the product (EMBRAPA, 2004). And for fresh consumption, they can be harvested at the point of full ripeness, since in the case of fresh consumption it is interesting that the amount of sugar is high, and the acidity less accentuated.

3.6.2 Industry and Processing

The use of strawberries in industry can have several purposes, whether in the food, pharmaceutical or even cosmetic industries. Strawberry can be used as a flavor, odor, and pigment in the industries. As a processing, according to BURGGRAAF (2016), strawberries can be preserved by pasteurization in cans (caned strawberries), they can be turned into syrup to preserve the flavor, in addition to the multitude of industrialized products originating from strawberries such as

juices, ice creams, fillings, jellies, jams, syrups, among others. Some products originated from strawberry processing can be seen in Figure 11.

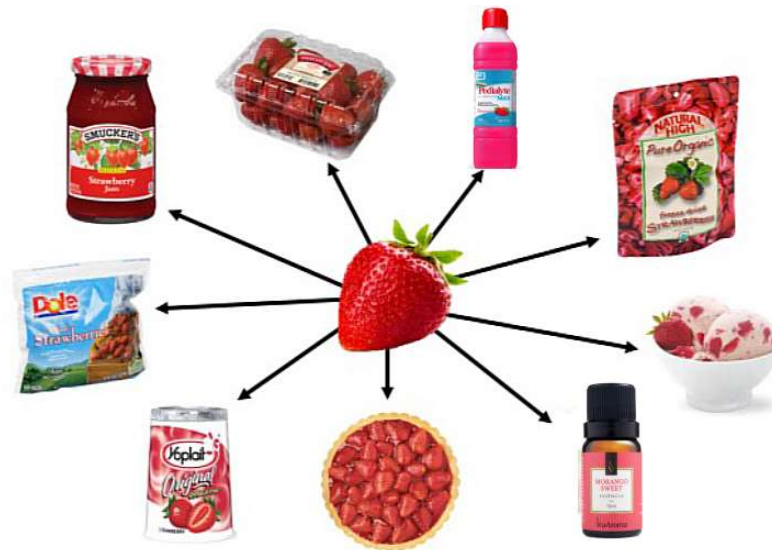


Figure 11. Products originated from strawberry processing.
Source: Minnesota Agriculture in The Classroom (2016), adapted.

The strawberry processing segment has as main limits the technological level and the equipment used, aspects that depend on business management and market relations (AMARO, 2002). And among the activities related to the strawberry production chain, industrial processing is considered the second most economically important activity.

Below, in Figure 12, contains a schematic example of the process of canned strawberry jam.

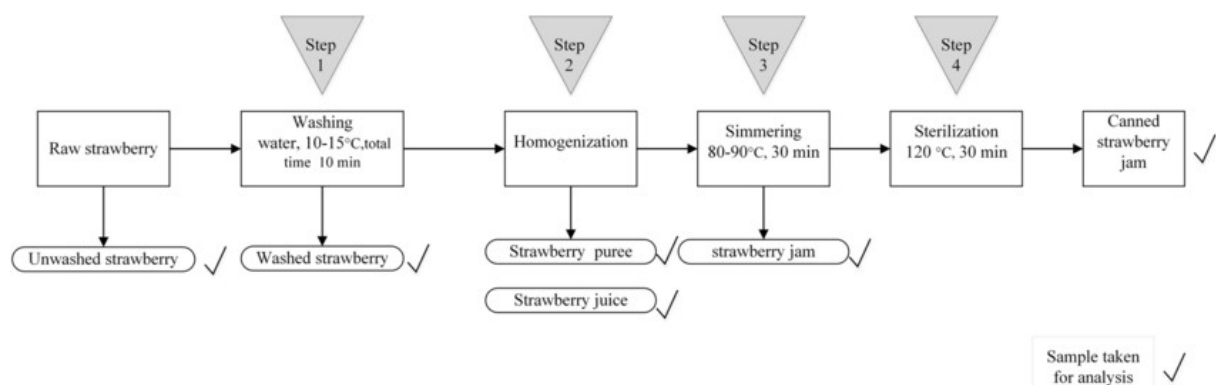
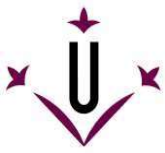


Figure 12. Scheme for traditional canned strawberry jam processing.
Source: LIU et al. (2018).



Still according to AMARO (2002), in strawberry processing no by-products are generated, as practically there is full use of the fruit. And the destination of the fruit in the industrial process is defined by the degree of ripeness, in addition to the choice of variety in the field.

Due to the low conservation capacity of the fruit, with significant losses of color and flavor, the strawberry must be submitted to primary processing, to later manufacture the other secondary products. The loss of quality is directly proportional to the high time and temperature to which the strawberry was exposed during processing (UENO, 2004).

Still according to UENO (2004), the most used primary processing methods are freezing (individual, with nitrogen tunnel, with carbon dioxide, in block, by chemical methods) and preservation by use of heat (pasteurization and aseptic filling).

3.7 STRAWBERRY QUALITY CLASSIFICATION

The definition of fruit quality can vary between products (Figure 13), depending on the use and destination market (storage, fresh consumption, or processing), which may dictate whether the product is accepted by the consumer or not (CHITARRA & CHITARRA, 2005).

Sensory attributes are important aspects of qualities demanded by the consumer, such as color, aroma, texture, sweetness and acidity and the balance between the last two aspects (SANTOS, 2013).






Grade	0	1	2	3	4
Photographs at different stages of visual					
Fruit quality	Excellent	Good	Acceptable	Poor	Very poor
Decay percentages	0%	0%	<10%	10%-40%	>40%
Carpodium	Green	A little withered	Dry and wilt	Dry and wilt	Dry and wilt
Sepal	Green	Green	A little withered	Dry and wilt	Dry and wilt
Fruit	Fresh	little shrunken	Began to decay	Decay area become larger	Extensive decay

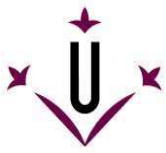
Figure 13. Strawberry quality ratings. Source: WANG et al. (2021).

Tests are performed to determine these factors. In the case of the soluble solids (SS) content, which indicates the amount of all substances dissolved in the fruit pulp (mostly sugars of the sucrose, fructose, and glucose type), it is determined with the aid of a refractometer, and the results are expressed in °Brix (CHITARRA & CHITARRA, 2005).

Acidity is commonly measured by titratable acidity (TA) and pH. The TA method presents all acid groups found (free organic acids, salts, or phenolic compounds) while the pH method determines the hydrogen ion concentration of the solution (LUCENA, 2006).

The SS/TA ratio is one of the most representative variables in the evaluation of fruit flavor, demonstrating the balance between the sugar and acidity levels present in the fruit. The higher the SS/AT ratio, the greater the degree of sweetness (CHITARRA & CHITARRA, 2005; SANTOS, 2013).

Quality factors such as color, size, shape, turgor, and absence of external defects are used as criteria that the consumer uses to decide whether to buy the product or not, therefore the presentation and appearance of the product is decisive in the market and in the decision of its value commercial.



According to CHITARRA et al. (2005), quality characteristics are expressed by product integrity, freshness, aroma, nutritional value, and flavor combined with physical and aesthetic properties. It is also a relationship between the chemical composition with the sensory and nutritional attributes.

Strawberries with acceptable flavors must have a minimum of 7.0 °Brix of soluble solids and a maximum of 0.8% of titratable acidity (KADER, 1991).

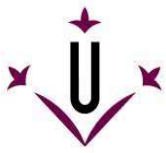
3.8 LOGISTICS AND TRANSPORT

With the change in eating habits and the demand from consumers for greater quality, there was a greater need for postharvest care, with great emphasis on transport, making use of refrigeration not only to improve quality, but also to reduce losses (MALGARIM et al., 2006).

Strawberry requires careful handling, and it is always of productive and economic interest that the supply chain be optimized so that high quality products are delivered in the shortest possible time to national or international consumption zones. The most recommended method of transporting strawberries is under low temperature conditions so that their shelf life is extended (SILVA, 2022).

It is estimated that the loss of raw material until it is received by the final consumer is 15 to 25%, the acceptable level is that it reaches a maximum of 6% of losses, according to CANTILLANO (2010). One of the factors causing waste is improper handling before and during transport (AMARO, 2002). Mismanagement of transport and packaging results in low-quality and low-yield strawberries.

According to Embrapa Temperate Climate (2010), land transport conditions for strawberries must contain suspensions that reduce transport vibrations, which consequently reduce the potential for mechanical damage to the fruit. Before loading, the refrigerated transport chamber must be acclimatized to a temperature not exceeding 3°C, keeping the fruits between 0° and 3°C and with forced air circulation. For air transport, in addition to the low temperature, the strawberry must be previously cooled and undergo a CO₂ application treatment.



The fruit also must be transported immediately after harvesting if there are no cold chamber structures close to the production area that can ensure greater durability and quality of the strawberry.

3.9 STRAWBERRY CONSERVATION

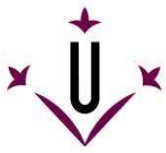
Several studies are focused on fruit processing, focusing on the conservation of raw materials and with the aim of extending the useful life of these materials. Because strawberry is a fruit with a short shelf life and some added value, there are techniques that must be employed in the post-harvest to ensure that the product reaches markets, industries and consumers with high quality and high value.

The delicacy of the strawberry, due to its thin epidermis, high percentage of water and high metabolism, requires a lot of care during and after harvesting.

If the fruits are harvested too ripe, there is a risk of reaching the market with Rots and decomposition, otherwise, if they are harvested in an immature state, as they are nonclimacteric fruits, they will have high acidity, astringency, and lack of aroma. In both cases, the product reaches the market with low quality and, therefore, with low commercial value (CANTILLANO, 2021).

Still according to Cantillano (2021), some precautions must also be taken during harvesting, such as: taking place in the coolest hours of the day, avoiding leaving the fruits directly under the sun, harvesting on rainy days or days with a lot of dew. It is important to deposit them in a clean place and, if the fruits are to be consumed "*in natura*", they must be picked with the chalice to help with conservation.

The main physiological factors that affect strawberry quality and conservation are respiration and transpiration. Strawberries have a respiratory rate of approximately 6 mg to 10 mg of CO₂/kg.hr at 0 °C (MITCHAM et al., 2003), and the fruit's respiration rate increases by 50% when it goes from immature to mature, also increasing when there is mechanical damage to the "body" of the strawberry.



As previously mentioned, strawberry is a nonclimacteric fruit, that is, it does not respond to ethylene to stimulate the ripening process (the ethylene production rate is less than $0.1 \mu\text{L}/\text{C}_2\text{H}_4/\text{kg}\cdot\text{hr}$ at 20°C), but even so, ethylene must be removed from the storage location to avoid the increase of Rots, according to Mitcham et al., (2003).

In the case of transpiration, which is the physical process characterized by the loss of water in the form of steam, it can cause weight loss, wrinkling, drying, and softening of the fruit (ANTUNES et al., 2016), all factors are negative for the consumer market. The maximum acceptable percentage of water loss is 6%.

3.9.1 Most Used Methods

According to EMBRAPA (2016), the most used conservation processes that strawberries go through are: rapid cooling, cold storage, controlled atmosphere and CO_2 treatments, transport under special conditions. However, it is also worth mentioning the methods: forced air cooling and use of coatings.

Rapid cooling: Also called "pre-cooling", according to EMBRAPA (2016), it consists of immediately removing the heat that the fruit brings from the field, before reaching its definitive conservation temperature, changing from more or less 25°C to 5°C in two or three hours. With this, the respiratory rate is reduced, prolonging the conservation of the product.

Cold storage: Cold chambers that can keep the temperature and relative humidity in optimal conditions for strawberry conservation, which are, respectively, 0° and 90-95%. The strawberries are organized and stacked in boxes on pallets until they are collected by the appropriate transport, which can maintain the cold chain (EMBRAPA, 2016). Figure 14 is an example of an empty cold chamber.



Figure 14. Cold Chamber. Source: Eletrofrigor (2006).

Controlled atmosphere: The controlled atmosphere in the storage of fruits and vegetables decisively delays respiratory activity, softening, color changes and quality (CUNHA JUNIOR, 2011). In the controlled atmosphere there is a mixture of gases (chosen according to the specific needs of the product) which is generally a combination of carbon dioxide, oxygen, and nitrogen (JUNQUEIRA & LUENGO, 1999).

In the case of strawberry, which is relatively tolerant to CO₂ (KADER et al., 1991), it is possible to use atmospheres enriched with CO₂ to increase postharvest life. The optimal levels of gas concentrations are 10% of O₂ and 15% to 20% of CO₂, at 0°C (ALMENAR et al., 2006). Results observed in the study by BRACKMANN et al. (2001), pointed out that the use of 20% CO₂ associated with refrigeration (0°C) maintained fruit quality for up to 20 days. In Figure 15 there is an example of controlled atmosphere treatment in strawberry.

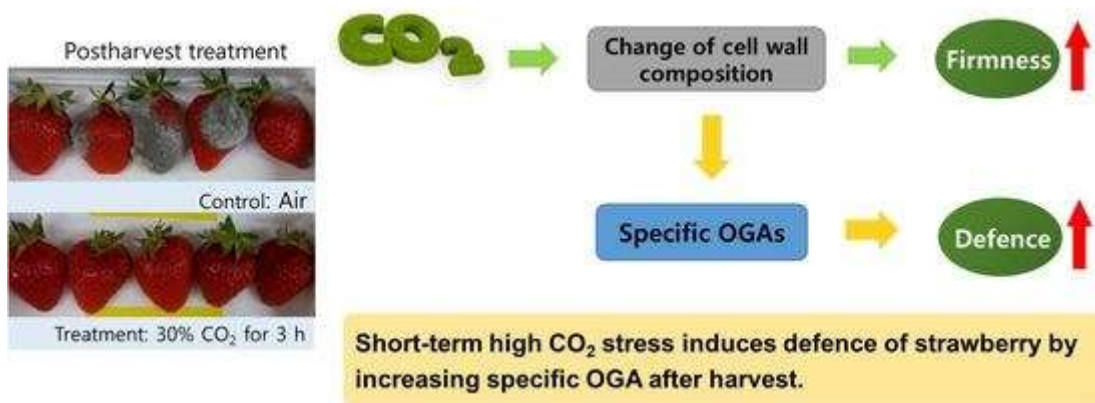


Figure 15. Controlled atmosphere CO₂ treatment in strawberry.
Source: EUM et al. (2021).

Coatings: Very perishable and expensive fruits, such as strawberries, compensate for products being protected with coatings, which can act as semi-permeable moisture and gas barriers, controlling microorganisms, preserving color and texture. Several studies and tests of coatings are launched every day, some examples being: edible silk fibroin (MARELLI et al., 2016), calcium and nano-chitosan (NGUYEN et al., 2021), starch-based coatings, botanical coatings (like Aloe vera) (ASAO et al., 2019), chitosan-based edible films, glycerol, and acetic acid (PAVINATTO et al., 2019) and among others. The outline of the role of coatings on the strawberry fruit is exemplified in Figure 16.

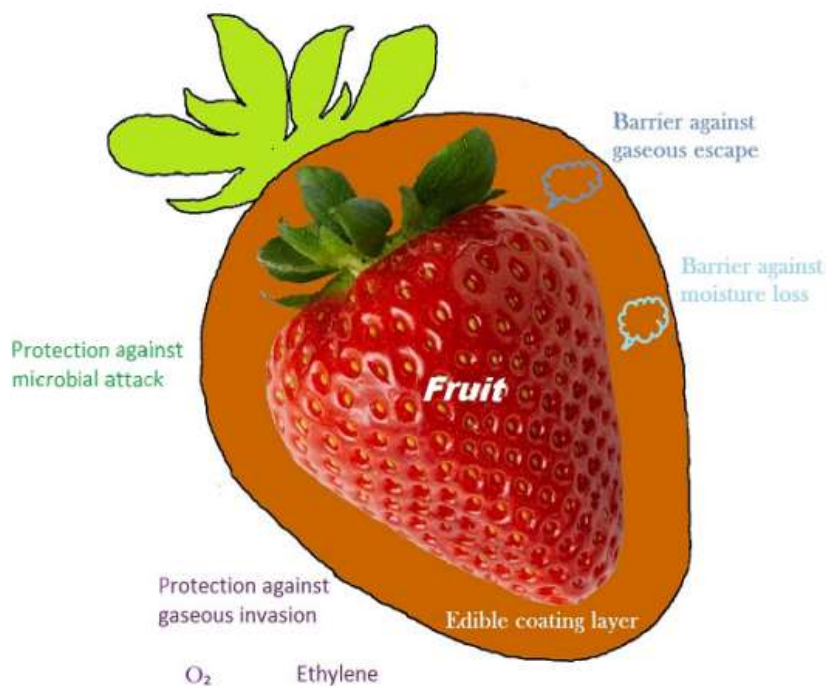


Figure 16. The edible coating on strawberry fruit. Source: KAUR et al. (2022).

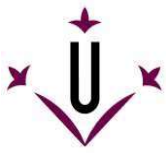
Forced air cooling: As stated by ANDERSON et al. (2004): "In a common setup for forced air cooling, two rows of palletized strawberry containers are lined up against an open cooler wall, through which a suction fan stands equidistant from either row. The top of the center aisle and the end opposite to the fan are sealed with atarp, and the fan is turned on. This creates a negative pressure in the aisle between the pallets. Air is pulled from the refrigerated room, through the vents in the containers, and then through the suction fan. The air removes heat from the strawberries as it is pulled through the vents and cools the fruit". An example of this setup can be seen in the Figure 17 below.



Figure 17. Setup for forced air cooling. Source: Polter's Berry Farm (2019).

Sanitization: Several sanitizing products can be used, such as hypochlorite (NaOCl , $\text{Ca}[\text{OCl}]_2$), chlorine dioxides (ClO_2), quaternary ammonium, formaldehyde, peracetic acid, acetic acid, hydrogen peroxide (H_2O_2), benzalkonium chloride, ethanol and ozone (O_3) (TERAO et al. 2012). According to CENCI (2008), a widely used and highly efficient method is the immersion of the fruits in cold water (5°C to 8°C) with 150ppm (part per million) of active color for 10 minutes. This specific treatment is the most effective in inhibiting fungal growth without altering the sensory characteristics of the strawberry.

Methods such as hydrocooling or vacuum cooling are not indicated because, with them, the fruits may run the risk of physical damage and/or for increasing the humidity on the surface of the strawberry, which can promote microbial development (ANDERSON et al., 2004).



3.9.2 Packaging and Materials

Packaging acts in the conservation of products that, in addition to protecting against biotic and abiotic damage, also serves to maintain visual quality attributes (appearance and color) that are limiting at the time of purchase (LOPES VIEITES et al., 2006).

The ability to regulate the atmosphere inside the package depends on the respiration of the fruit and the permeability of the package (CIA, 2002). These factors depend on the temperature, and its elevation promotes the respiratory rate of the products, therefore the use of packaging does not reduce or eliminate the need for refrigeration (MANTILLA et al., 2010).

According to KADER et al. (1989), the most suitable materials for making packaging are polyolefin films due to their good water vapor barrier properties and relatively high permeability to O₂ and CO₂.

The most used packages are small polyethylene terephthalate (PET) boxes coated with polyvinyl chloride (PCV) film or with a perforated PET lid, which partially prevent fruit dehydration and contamination, but do not contribute much to increase the strawberry shelf life (DE FARIAS et al., 2022).

Perforated PET lids have a better result of gas alteration inside when compared to PVC film. PVC, on the other hand, prevents mass loss during a storage period, as the film acts as a barrier to water vapor (CUNHA JUNIOR et al., 2017). They are also expanded polystyrene trays (styrofoam). The dimensions of the trays normally support between 250 and 500 grams of strawberries.

A study directed by SCALON et al. (1996) showed results that strawberries stored at 4°C in PVC packaging had their shelf life extended by 14 days, maintaining quality with the ideal rate of pH, soluble solids, titratable acidity, and total sugar.

In the studies by DE FARIAS et al. (2022), pectin biofilm packaging, an edible coating, was also tested, but it was proven that biofilms made from polysaccharides are not considered effective against fruit weight loss due to their hydrophilic nature (GUERREIRO et al., 2015; CHU et al., 2020).

Tests performed by CUNHA JUNIOR et al. (2017) tested packaging with PET boxes, varying the films that covered the product and their thickness (in millimeters). Polypropylene (PP), D955 and polyvinyl chloride (PVC) films were used. The best alternative proved to be PET packaging with PVC film with a thickness of 0.020mm.

Figure 18 represents the packaging with PET box and PVC film covering. Figure 19 shows a package with a PET box and lid, with a perforated lid. Figure 20, on the other hand, is a less common packaging alternative, which had the fruit format in its configuration for individual placement in each space. Although promising for promoting less contact between the fruits and for making them more fixed during transport and handling, it is a package that requires more time and labor to fill, in addition to being more expensive when compared to previous packages.



Figure 18. Packaging with PET box and PVC film covering.
Source: Solução Hidroponia (2020).



Figure 19. Package with a PET box and lid, with a perforated lid.
Source: Serraplast (2017).



Figure 20. Packing with individual separation for strawberries.
Source: Serraplast (2017).

For external packaging, for transport and handling, PEREIRA (2004) suggests corrugated cardboard boxes (Figure 21) which, given the padding characteristics of the material, resistance to stacking and lightness, can be a great alternative in the strawberry distribution cycle. However, he also warns about the sensitivity of

cardboard to water, which can break down and retain water, which is a major structural disadvantage and poses a great risk of the proliferation of diseases that can contaminate the strawberries, such as fungi.



Figure 21. Cardboard boxes for external packaging.
Source: Inbrapel Embalagens (2018).

3.10 MAJOR POSTHARVEST DAMAGE

3.10.1 Mechanical Damage

Mechanical damages are those that occur at the time of harvesting, transport and marketing carried out incorrectly, not respecting the delicacy of the strawberry. The damage takes the form of wounds and bumps, which leave the fruit susceptible to attack by microorganisms, causing nutritional, qualitative, and economic losses for the strawberry production chain (CANTILLANO et al., 2010).

In Figure 22 it is possible to observe examples of mechanical damage registered by a collection of authors.

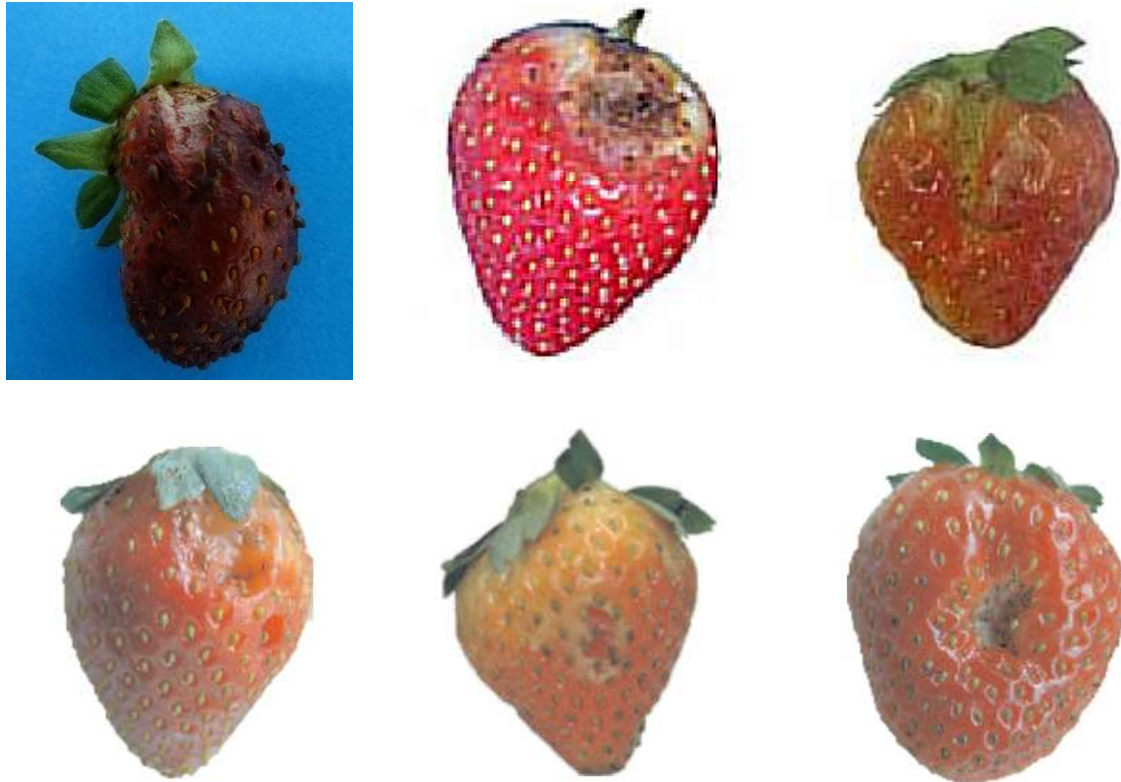


Figure 22. Examples of mechanical damage.
Source: CANTILLANO et al. (2010); CALEGARIO (2009).

3.10.2 Physiological Damage

In the physiological damages in strawberries there is occurrence of formation of deformed fruits, being a quite common phenomenon, according to UENO (2004), which can be caused by several biotic and abiotic factors. The deformations affect the size and shape of the fruit and, consequently, its visual quality, reducing or nullifying the chances of commercialization. The occurrence of deformation in strawberry may vary according to the season, production system and cultivar.

The main factor related to physiological damage is poor pollination, which can be influenced by temperature, humidity, lack of ventilation and pollinating insects, attack by pests and diseases. In addition, edaphoclimatic factors, by dictating the growth and development of strawberry plants, can interfere with nutritional imbalances, irrigation deficiency, attack by pests and diseases, lack of light, among others.

Below are some examples of physiological damage with images by different authors (Figure 23).



Figure 23. Examples of physiological damage.
Source: CALEGARIO (2009); UENO (2018).

3.10.3 Rots

Strawberry cultivation is commonly affected by diseases that lead to rot when growing and storage conditions are not adequate.

CALEGARIO (2009) points out some postharvest strawberry diseases, whether they are field diseases that evolved in the postharvest period, or diseases associated with postharvest injuries.

The field diseases that evolved in the postharvest period (Figure 24) are Anthracnose (*Colletotrichum spp.*), Gray Mold (*Botrytis cinerea*), White Rot (*Sclerotinia sclerotiorum*), *Hainesia* Rot, *Pestalotia* Rot and *Phytophthora* Rot.



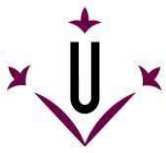
Figure 24. Field diseases with postharvest evolution. Source: CALEGARIO, (2009).

Diseases associated with postharvest mechanical damage (Figure 25) are *Alternaria* Rot, Bacterial Rot, *Cladosporium* Rot, Yeast Rot, *Rhizopus* Rot (*Rhizopus* spp.) and *Penicillium* Rot.



Figure 25. Diseases associated with postharvest wounds.
Source: CALEGARIO (2009).

HARRIS et al. (2007) also mention that in addition to taking care of the strawberry production chain, consumers should also keep in mind that strawberries are highly perishable, and suggest various techniques such as homemade



conservation maneuvers, such as washing the fruit, separate the fruit from parts that show damage, remove the top part with the leaves, freeze the fruits, preserve in syrup, dry the fruit and make jellies. All maneuvers require previously cleaned packaging for storage.

3.11 ECONOMIC STUDIES AND WASTE REDUCTION

In 2020, the world production of strawberries was 8,861,381 tons, showing a growth of 39% in the last ten years. The cultivated area has also increased by 18.7% in the last ten years, as shown by the FAO data (2022).

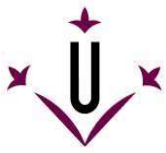
In terms of value generated by consumption, in 2019 strawberries grossed \$2,693 million in the American market (PRODUCEPAY, 2021). In the year 2022, the average price per kilogram of strawberries in Europe was around 2.1EUR/kg, but on special occasions such as holidays, such as Valentine's Day, the average price rose to 4.35EUR/kg (Procurement Resource, 2022).

The data prove that the strawberry crop has a high commercial value, with losses due to waste and poor management being quite expressive for the sector. Waste data are not robust enough to be presented, as they vary greatly, especially for highly perishable products such as strawberries, but it is estimated that along the supply chain, waste losses reach 30% of production (SANTOS, 2022).

A UK report by the Waste and Resources Action Program (WRAP, 2015) announced that £31 million worth of strawberries and lettuce were discarded on farms, the main cause being that produce did not meet market requirements.

According to SANTOS (2022), the main factors that lead to losses due to waste are inadequate harvesting, poorly managed storage, transport and logistics, and the use of inefficient packaging.

Another major problem is that companies treat losses and waste as inevitable and many ways to reduce food waste are neglected (MURIANA, 2017). Thus, understanding the causes of losses in an integrated perspective of the production chain is the way to create solutions and prioritize practices to prevent and/or reduce this waste (GARRONE et al., 2014).



Some strawberry by-products used in industry can be reused to make pomace, food additive used in industrial production due to its high Dietary Fiber (DF) content, other forms of recycling are composting, biogas formation, oil extraction, among others (HASSAN et al., 2023; VILLAMIL-GALINDO et al., 2022; NAWIRSKA AGNIESKA et al. 2008).

4 CURRENT SITUATION

The current situation of losses in the field and in the strawberry distribution cycle can be reversed if we use a set of practices and techniques throughout the production process: in the field, at harvest, during storage, transport, and disposal in markets.

This work focuses mainly on postharvest techniques and processes during strawberry conservation, but this does not exclude the fact that good practices in the field, industries and markets are extremely important to extend the shelf life of products.

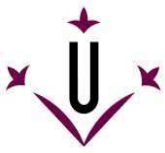
Currently, the losses of the agricultural sectors are high, around 30% of all production, which, in addition to the economic loss of the sector, also contributed to the increase in prices in the markets and the increase in hunger.

To solve this problem, several researches, tests, and essays are carried out. In the case of strawberries and their postharvest conservation, the focus is on storage in controlled environments, with conditions of temperature, relative humidity, wind, light and atmospheric gases, but another very important part of strawberry conservation is the materials used for packaging and transport and distribution management conditions for the entire production chain.

5 STUDY OF ALTERNATIVES

Considering that before the alternatives mentioned below, the whole harvesting process was done in an adequate and delicate way and the fruits were protected from direct sunlight, the alternatives differ with different foci.

1) Treatments



- Use or not of edible coatings.
- Sanitize the strawberry or not.
- Carry out pre-cooling or not.

II) Storage.

- Shade storage at room temperature.
- Storage in a cold chamber (0°C and 90-95% relative humidity).
- Storage in controlled atmosphere (0°C, 90-95% relative humidity, control of carbon dioxide, oxygen, and nitrogen).

III) Films.

- Polypropylene (PP).
- D955.
- Polyvinyl chloride (PVC).

Packaging:

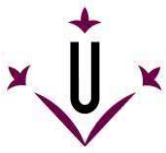
- Polyethylene terephthalate (PET).
- Expanded polystyrene trays (Styrofoam).
- Cardboard boxes.

IV) Transportation

- Transport without thermal control.
- Transport in a cold room (maintenance of the cold chain).

The alternatives can be mixed between them, choosing to follow an option from each scope (storage, transport, packaging, and treatments), using the methods and processes mentioned above in this work as a collection of possibilities to be used in your production process.

In addition, with the diverse cultivars of strawberries around the world, along with the range of different climatic conditions in the productive zones, each condition and alternative must be meticulously studied so that the ideal sequence of practices



can be put together for the best conservation of the strawberry, aiming at a longer useful life while maintaining the quality characteristics demanded by the consumer market.

It must be considered that the conditions of low temperatures, high relative humidity and ventilation are constant for the good conservation of strawberries, which must be maintained, respectively, at 0°C, 90-95% and good aeration.

It should also be borne in mind that with each process added to the production chain, as is the case with treatments, the process requires more and more labor and other raw materials, resulting in more conservation costs and, consequently, in a product with higher commercial value.

6 CONCLUSIONS

The ideal strawberry conservation process would be, first, to go through pre-cooling at 5°C to remove the heat that the fruit comes from the field, then sanitizing with immersion of the fruits in cooled water (5°C to 8°C) with 150 ppm (part per million) of active chlorine for 10 minutes and, after rinsing, storage in a controlled environment, with concentrations of 10% of O₂ and 15% to 20% of CO₂, all at 0°C and 95% humidity relative air, resulting in a storage of up to 20 days. Once this is done, the transport must be refrigerated and, preferably, the place of sale must be close to the producing property. For packaging, the most efficient are PET boxes covered with a 0.02 mm PCV film. These conditions show the best results.

In a more realistic scenario, aiming for the maximum savings possible, it is sufficient that the process is shorter, without employing sanitization or pre-cooling. The storage chamber can be a cold chamber or forced air cooling, without atmospheric control, under the same conditions of 0°C and 90-95% relative humidity. Transport must be carried out in a cold chamber and the packaging must be sanitized.



7 BIBLIOGRAPHIC REFERENCES

ALMEIDA, I. R. de; ANTUNES, L. E. C.; REISSER JÚNIOR, C.; STEINMETZ, S.; CARVALHO, F. L. C. Potenciais regiões produtoras de morango durante a primavera e verão e riscos de ocorrência de geada na produção de inverno no estado do Rio Grande do Sul. Pelotas: Embrapa Clima Temperado, 2009. 5 p. (Embrapa Clima Temperado. Comunicado técnico, 229).

ALMENAR, E.; FERNANDEZ-MUÑOZ, P.; LAGARÓN, J.M.; CATALA, R.; GAVARA, R. Controlled atmosphere storage of wild strawberry fruit (*Fragaria vesca* L.). *Journal of Agricultural and Food Chemistry*, Washington, v 54, p. 86-91, 2006.

AMARO, MIRIAN CRISTINA CHAVES. A cadeia produtiva agroindustrial do morango nos municípios de Pelotas, Turuçu e São Lourenço. 2002.

ANDERSON, B. A., SARKAR, A., THOMPSON, J. F., & SINGH, R. P. (2004). Commercial-scale forced-air cooling of packaged strawberries. *Transactions of the ASAE*, 47(1), 183.

ANDRADE JÚNIOR, V. C., GUIMARÃES, A. G., AZEVEDO, A. M., PINTO, N. A., & FERREIRA, M. A. (2005). Conservação pós-colheita de frutos de morangueiro em diferentes condições de armazenamento. *Horticultura Brasileira*, 34, 405-411.

ANTUNES, L. E. C., CALEGARI, F., COSTA, H., & DUARTE FILHO, J. (2014, January). Produção integrada de morango (PIMo) no Brasil. In: CONGRESSO BRASILEIRO DE FRUTICULTURA, 20.; ANNUAL MEETING OF THE INTERAMERICAN SOCIETY FOR TROPICAL HORTICULTURE, 54., 2008, Vitória. Minicurso. Frutas para todos: estratégias, tecnologias e visão sustentável: anais. Vitória: INCAPER: Sociedade Brasileira de Fruticultura, 2008. 5p. CD-ROM.

ANTUNES, L. E. C.; REISSER JUNIOR, C.; SCHWENGBER, J. E. Morangueiro. Embrapa Clima Temperado, Brasília/DF, 2016.

ASAO, Toshiki; ASADUZZAMAN, Md (Ed.). Strawberry: Pre-and Post-Harvest Management Techniques for Higher Fruit Quality. BoD–Books on Demand, 2019.

BRACKMANN, A.; HUNSCHE, M.; WACLAVOWSKY, A.J; DONAZZOLO, J. Armazenamento de morangos cv. Oso Grande (*Fragaria Ananassa* L.) sob elevadas pressões parciais de CO₂. *Revista Brasileira de Agrociência*, Pelotas, v.7, n.1, p. 10-14, 2001.

BRON, I. U., & JACOMINO, P. (2007). Classificação de frutos por “climatério” é conceito em extinção. *Visão Agrícola*, 7, 8-10.

BURGGRAAF, W. Strawberries. Safe Food Factory, Netherlands, Noord-Holland - Amsterdam. 14/12/2016. Access via: <<https://www.safefoodfactory.com/en/knowledge/34-strawberries/>> on 05/05/2023.

CALEGARIO, F. F. PBMH & PIMo - PROGRAMA BRASILEIRO PARA A MODERNIZAÇÃO DA HORTICULTURA & PRODUÇÃO INTEGRADA DE MORANGO. Normas de Classificação de Morango. São Paulo: CEAGESP, 2009. (Documentos, 33).



CANTILLANO, F. F. Cuidados na conservação do morango. Portal Agronegócio, Embrapa Clima Temperado. 31 de dezembro de 2009. Access via: <<https://www.portaldoagronegocio.com.br/agricultura/fruticultura/artigos/cuidados-na-conservacao-do-morango>> on 01/05/2023.

CBI, 2021. The European market potential for strawberries. Ministry of Foreign Affairs, 29 September 2021. Accessed via: <<https://www.cbi.eu/market-information/fresh-fruit-vegetables/strawberries/market-potential#:~:text=Spain%20is%20the%20largest%20producer%20and%20supplier%20of%20strawberries%20in%20Europe.>> on 01/05/2023.

CBI. The European market potential for strawberries. CBI Ministry of Foreign Affairs. Netherlands, Amsterdam. 29/09/2021. Access via: <<https://www.cbi.eu/market-information/fresh-fruit-vegetables/strawberries/market-potential>> on 03/05/2023.

CENCI, S. A. Para reduzir perdas com o morango. Embrapa Agroindústria de Alimentos. Revista Frutas e derivados (IBRAF – Instituto Brasileiro de Frutas) Ano 3. Edição 11, Setembro de 2008. Access via: <https://www.frutas.radar-rs.com.br/frutas/morango/reduzir_perdas_com_o_morango.htm> on 07/05/2023.

CHU, Y.; GAO, C.; LIU, X.; ZHANG, N.; XU, T.; FENG, X.; YANG, Y.; SHEN, X.; TANG, X. Improvement of storage quality of strawberries by pullulan coatings incorporated with cinnamon essential oil nanoemulsion. LWT-Food Scien. Technol., v. 122, n. 109054, mar. 2020. DOI: <https://doi.org/10.1016/j.lwt.2020.109054>.

CIA, P. Efeito da atmosfera modificada no controle de podridões pós-colheita e na qualidade de caqui cv. Fuyu. 2002. 122f. Dissertação (Mestrado em Agronomia/Horticultura) – Faculdade de Ciências Agrônômicas, Universidade Estadual Paulista, Botucatu, 2002.

CLAYPOOL, L. L. Factores que influncian la calidad. In: SIMPOSIO SOBRE MANEJO, COSECHA Y POST-COSECHA DE FRUTAS Y HORTALIZAS, 9., 1975, Santiago, Anais... Santiago: Universidad de Chile, 1975. p. 1-5.

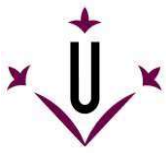
CONTI, J. H.; MINAMI, K.; TAVARES, F. C. A. Comparação de caracteres morfológicos e agrônômicos com moleculares em morangueiros cultivados no Brasil. Horticultura Brasileira, v. 20, n. 3, p. 419-423, 2002.

CUNHA JÚNIOR, L. C.; MORGADO, C. M. A.; JACOMINO, A. P.; TREVISAN, M. J.; PARISI, M. C. M.; NASCIMENTO, A. R. Embalagem alternativa para cadeia produtiva de morango. Rev. de Ciências Agrárias, Lisboa, v. 40, n. 2, p. 42-51, jun. 2017. DOI: <http://dx.doi.org/10.19084/RCA16155>.

CUNHA JÚNIOR, Luis Carlos. Atmosfera controlada na conservação de morango. 2011. Tese de Doutorado. Universidade de São Paulo.

DE ASSIS, Thiago Leonel; CANESIN, Regina Célia Faria Simão. Características fisiológicas de cultivares de morangueiro em ambiente protegido em Cassilândia/MS. Revista Cultura Agrônômica, v. 24, n. 3, p. 235-244, 2015.

DE FARIAS, M. R., SATEL, N. M., ROSSET, M., & DOS SANTOS, C. M. E. (2022). Avaliação de diferentes embalagens na manutenção de características físico-químicas de morangos. Revista em Agronegócio e Meio Ambiente, 15(2), 321-332.



DIAS, M. S. C. FISILOGIA E FENOLOGIA DO MORANGUEIRO. Núcleo Tecnológico Epamig Batata e Morango, Governo de Minas - Pouso Alegre, MG. Accessed via: <https://www.cnpma.embrapa.br/eventos/2011/pimo/palestras/20111109/fisiologia_fenologia.pdf> on 01/05/2023.

ELETROFRIGOR. Câmara Fria - o que é, como trabalhar com ela e quais suas vantagens? Brasil, Niteroi, RJ (2006). Access via: <<https://www.eletrofrigor.com.br/blog/post/camara-fria-o-que-e>> on 03/05/2023.

EMBRAPA. Sistema de Produção do Morango. Colheita e pós-colheita. Embrapa Clima Temperado, Brasília, DF - Brasil. 31/07/2004. Access via: <https://www.spo.cnptia.embrapa.br/conteudo?p_p_id=conteudoportlet_WAR_sistemasdeproducao6_1ga1ceportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&p_r_p_-76293187_sistemaProducaoId=4201&p_r_p_-996514994_topicId=1316> on 04/05/2023.

EUM, HYANG-LAN; HAN, SEUNG-HYUN; LEE, EUN-JIN. High-CO₂ treatment prolongs the postharvest shelf life of strawberry fruits by reducing decay and cell wall degradation. *Foods*, v. 10, n. 7, p. 1649, 2021.

FAOSTAT (2013). Food and agriculture data. Access via: <<http://faostat.fao.org/beta/en>> on 03/05/2023.

FAOSTAT, 2021. Production of Strawberries: top ten producers 2019. Accessed via: <<https://www.fao.org/faostat/en/#data/QCL/visualize>> on 01/05/2023.

FEADER. Cadena de Valor de la Fresa. Campaña 2010/11. Junta de Andalucía, Europa invierte en las zonas rurales. Programa de Desarrollo Rural de Andalucía. Junio/2012.

FILGUEIRA, F. A. R. Novo manual de olericultura: agrotecnologia moderna na produção e comercialização de hortaliças. Viçosa: UFV, 2002. 402 p.

FLORES CANTILLANO, R. F.; DA SILVA, Médelin Marques. Manuseio pós-colheita de morangos. Embrapa ClimaTemperado, 2010.

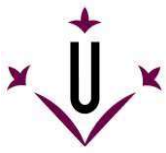
FOLTA, K.M.; GARDINER, S.E. (2009) Genetics and Genomics of Rosaceae. Part IV Strawberry (Ch 20–23), Springer.

GARRETT, K. Strawberry Cultivars, Strawberryplants.org, California, San Francisco - USA. 14/02/2022. Access via: <<https://strawberryplants.org/strawberry-cultivars/>>. on 02/05/2023.

GARRONE, P.; MELACINI, M.; PEREGO, A. Opening the black box of food waste reduction. *Food Policy*, v. 46, 129–139, 2014. Access via: <<http://dx.doi.org/10.1016/j.foodpol.2014.03.014>> on 06/05/2023.

GU, T., JIA, S., HUANG, X., WANG, L., FU, W., HUO, G. (2019). Transcriptome and hormone analyses provide insights into hormonal regulation in strawberry ripening. *Planta* 250, 145–162. doi: 10.1007/s00425-019-03155-w

GUERREIRO, A. C.; GAGO, C. M. L.; FALEIRO, M. L.; MIGUEL, M. G. C.; ANTUNES, M. D. C. The effect of alginate-based edible coatings enriched with essential oils constituents



on *Arbutus unedo* L. fresh fruit storage. *Postharvest Biol. Technol.*, v. 100, p. 226-233, fev. 2015. DOI: <http://10.1016/j.postharvbio.2014.09.002>.

HARRIS, LINDA J. *Strawberries: Safe Methods to Store, Preserve, and Enjoy*. UCANR Publications, 2007.

HASSAN, A., SHAHBAZ, H. M., NAEEM, M., & AADIL, R. M. (2023). Food and non-food applications of berries' by-products. In *Berry Bioactive Compound By-Products* (pp. 135-157). Academic Press.

HOW TO CHOOSE THE RIGHT STRAWBERRY VARIETY TO GROW. Espoma Organic, Fruits & Vegetables, Millville, NJ. 31/05/2018. Access via: <https://www.espoma.com/fruits-vegetables/how-to-choose-the-right-strawberry-variety-to-grow/>. on 02/05/2023.

INBRAPEL. *Caixa Para Morangos Em Papelão Ondulado*. Embalagens de Papelão Ondulado, Brazil, Toledo-PR, 2018. Access via: <https://inbrapel.com.br/produtos/caixa-em-papelao-ondulado-para-morangos/> on 03/05/2023.

JUNIOR, L. C. C., MORGADO, C. M. A., JACOMINO, A. P., TREVISAN, M. J., PARISI, M. C. M., & DOS REIS NASCIMENTO, A. (2017). Embalagem alternativa para cadeia produtiva de morango. *Revista de Ciências Agrárias*, 40(2), 342-352.

JUNQUEIRA, A.H.; LUENGO, R. de F.A. *Mercados diferenciados de hortaliças*. Brasília, DF: EMBRAPA Hortaliças, 1999. 7 p. (Circular Técnica, 17).

KADER, A. A. Quality and its maintenance in relation to postharvest physiology of Strawberry. In: LUBY, A., (ed.), *The strawberry into the 21st century*, Timber Press, Portland, Oregon, EUA. 1991, p. 145-152.

KADER, A.A.; ZAGORY, D.; KERBEL, E.L. Modified atmosphere packaging of fruits and vegetables. *Critical Reviews in Food Science and Nutrition*. West Palm Beach, v. 28, n. 1, p. 1-30, 1989.

KAUR, Komalpreet; KUMAR, Anil. Enhancement of strawberry shelf life with coating: A review. *Modern Phytomorphology*, v. 16, n. 2, 2022.

LISTON, A., CRONN, R., & ASHMAN, T. L. (2014). *Fragaria*: a genus with deep historical roots and ripe for evolutionary and ecological insights. *American journal of botany*, 101(10), 1686-1699.

LIU, H. T., JI, Y., LIU, Y., TIAN, S. H., GAO, Q. H., ZOU, X. H., ... & DUAN, K. (2020). The sugar transporter system of strawberry: genome-wide identification and expression correlation with fruit soluble sugar-related traits in a *Fragaria* × *Ananassa* germplasm collection. *Horticulture research*, 7.

LIU, N., PAN, X., YANG, Q., JI, M., & ZHANG, Z. (2018). The dissipation of thiamethoxam and its main metabolite clothianidin during strawberry growth and jam-making process. *Scientific Reports*, 8(1), 15242.

LOPES VIEITES, R., MARTA EVANGELISTA, R., DE SOUZA SILVA, C., & LUIS MARTINS, M. (2006). Strawberries storage conservation in modified atmosphere. *Semina Ci. agr.*, 243-252.



LUCENA, E. M. P. de. Desenvolvimento e maturidade fisiológica de manga “Tommy Atkins” no vale do São Francisco, 2006. 152f. Tese (Doutorado em Agronomia) – Univerisidade Federal do Ceará, Fortaleza, 2006.

MADAIL, J. C. M. Mercado de Morango. Empresa Brasileira de Pesquisa Agropecuária (Embrapa), Brasília/DF. 20 de dezembro de 2021. Accessed via: <<https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/morango/pre-producao/socioeconomia/mercado#:~:text=Autor&text=Os%20Estados%20Unidos%2C%20a%20fora%20ser,consumidor%20da%20fruta%20no%20mundo.>> on 01/05/2023.

MALGARIM, MARCELO BARBOSA; CANTILLANO, RUFINO FERNANDO FLORES; COUTINHO, ENILTONFICK. Sistemas e condições de colheita e armazenamento na qualidade de morangos cv. Camarosa. Revista Brasileira de Fruticultura, v. 28, p. 185-189, 2006.

MANTILLA, S. P. S., MANO, S. B., DE CARVALHO VITAL, H., & FRANCO, R. M. (2010). Atmosfera modificada na conservação de alimentos. Revista Acadêmica Ciência Animal, 8(4), 437-448.

MARELLI, B., BRENCKLE, M. A., KAPLAN, D. L., & OMENETTO, F. G. (2016). Silk fibroin as edible coating for perishable food preservation. Scientific reports, 6(1), 25263.

MCINTOSH, J. (2006) Handbook to Life in Prehistoric Europe, Oxford University Press.

Minnesota Agriculture in The Classroom. Strawberry Breeding and Genetics. Minnesota, USA (2016). Access via: <<https://minnesota.agclassroom.org/matrix/lesson/519/>> on 03/05/2023.

MITCHAM, E. J.; CRISOSTO, C. H.; KADER, A. A. Strawberry: recommendations for maintaining postharvest quality. Davis: UC Davis Postharvest Technology, 2003. 3 p. Access via: <<http://postharvest.ucdavis.edu/PFfruits/Strawberry>> on 01/05/2023.

MURIANA, C. A focus on the state of the art of food waste/losses issue and 214 suggestions for future researches. Waste Management, v. 68, 557–570, 2017. Access via: <<https://doi.org/10.1016/j.wasman.2017.06.047>> on 06/05/2023.

NAWIRSKA AGNIESKA., UKLANSKA CECYLIA. (2008). Waste Products from Fruit and Vegetable Processing as Potential Sources for Food Enrichment in Dietary Fibre. Access via: < <http://jml.indexcopernicus.com/fulltxt.php?ICID=883304>> on 07/05/2023.

NGUYEN, Van TB; NGUYEN, Ha VH. Postharvest quality of strawberry (Fragaria x ananassaduch.) coated with calcium and nano-chitosan as affected by different storage temperatures. Journal of Horticulture and Postharvest Research, v. 4, n. 4, p. 413-426, 2021.

PACHON, J. Strawberry Market Update: Ripe for the Picking. Czarnikow - Czapp. London, UK. 08/05/2023. Access via: <<https://www.czapp.com/analyst-insights/strawberry-market-update-ripe-for-the-picking/#:~:text=In%20the%20past%20six%20years,such%20as%20the%20GoodBerry%20project.>> on 10/05/2023.

PALHA, M. D., MEXIA, A., NUNES, A., CECILIO, A., MATEUS, C., ANDRADE, C. S., & CURADO, T. (2005). Manual do morangueiro. Belgráfica, Lda.



PASSOS, Francisco A.; TRANI, Paulo E. Calagem e adubação do morangueiro. Campinas: Instituto Agrônomo de Campinas. 16p, 2013.

PAVINATTO, A., DE ALMEIDA MATTOS, A. V., MALPASS, A. C. G., OKURA, M. H., BALOGH, D. T., & SANFELICE, R. C. (2020). Coating with chitosan-based edible films for mechanical/biological protection of strawberries. *International journal of biological macromolecules*, 151, 1004-1011.

PETRUZZELLO, M. Strawberry, plant and fruit. *Britannica*, The Editors of Encyclopaedia. "strawberry". *Encyclopedia Britannica*. Access via: <<https://www.britannica.com/plant/strawberry>> on 02/05/2023.

PIRES, R. C. de M.; FOLEGATTI, M. V.; PASSOS, F. A.; SAKAI, E.; SILVA, T. J. A.; ARRUDA, F. B. Produção de morangueiro em diferentes níveis de água, coberturas do solo e ambientes de cultivo. *Irriga*, v. 12, n. 3, p. 338-353, 2007.

Polter's Berry Farm. Strawberries. Fremont, OH (2019). Access via: <<http://poltersberryfarm.com/strawberries/>> on 03/05/2023.

RADMANN, E. B., BIANCHI, V. J., OLIVEIRA, R. P. D., & FACHINELLO, J. C. (2006). Caracterização e diversidade genética de cultivares de morangueiro. *Horticultura Brasileira*, 24, 84-87.

REISSER JÚNIOR, C.; ANTUNES, L. E. C.; STEINMETZ, S.; ALMEIDA, I. R. de; RADIN, B. Strawberry production under different plastic mulches and tunnels in nonfumigated fields in south Brazil. In: NORTH AMERICAN STRAWBERRY SYMPOSIUM, 7.; NORTH AMERICAN STRAWBERRY GROWERS ASSOCIATION, 35., 2011, Tampa. *StrawberryConference: resumos*. Tampa: NASGA, 2011. p. 17.

SÁ, C. R. L., SILVA, E. D. O., TERAQ, D., & SARAIVA, A. C. M. (2008). Métodos de controle do etileno na qualidade e conservação pós-colheita de frutas.

SÁNCHEZ-GÓMEZ, C., POSÉ, D., & MARTÍN-PIZARRO, C. (2022). Insights into transcription factors controlling strawberry fruit development and ripening. *Frontiers in Plant Science*, 13.

SANTOS, IURI BENEDITO DA SILVA. Estudo de campo da pós-colheita de morangos para redução de desperdícios. 2022.

SCALON, S. D. P., CHITARRA, A., CHITARRA, M., & ABREU, M. D. (1996). Conservação de morangos (*Fragaria ananassa* Duch) cv. Sequóia em atmosfera modificada. *Revista Brasileira de Fruticultura*, 18(3), 431-436.

SENHOR, R. F., DE SOUZA, P. A., NETO, R. C. A., & PINTO, A. C. (2009). Controle através de bloqueadores de etileno. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, 4(2), 3.

Serraplast. Embalagem de Morango. Durham, North Caroline (USA), 2017. Access via: <<https://www.serraplastembalagem.com.br/embalagem-de-morango>> on 03/05/2023.

SILVA, F. P. The strawberry chain. Wageningen University & Research, Netherlands, Utrecht. 27/05/2022. Access via: <<https://www.freshknowledge.eu/en/knowledge-database/crops/strawberry-1/the-strawberry-chain.htm>> on 05/05/2023.



SIMPSON, DAVID. The economic importance of strawberry crops. The genomes of rosaceous berries and their wild relatives, p. 1-7, 2018.

Solução Hidroponia. Filme Extensível Darnel Wrap 30cm X 1000 Mts (9 micras). São Paulo, Brazil-SP (2020). Access via: <<https://www.solucaohidroponia.com.br/produto/211/filme-extensivel-35-300-mm-1000-mts/>> on 03/05/2023.

TERAO, D., FORNER, C., & BETTIOL, W. (2012). Importância da sanitização no controle de doenças pós-colheita.

UENO, BERNARDO. Manejo integrado de doenças do morango. 2º Simpósio Nacional do Morango 1º Encontro de Pequenas Frutas e Frutas Nativas, p. 70, 2004.

VILLAMIL-GALINDO, E., ANTUNES-RICARDO, M., PIAGENTINI, A. M., & JACOBO-VELÁZQUEZ, D. A. (2022). Adding value to strawberry agro-industrial by-products through ultraviolet A-induced biofortification of antioxidant and anti-inflammatory phenolic compounds. *Frontiers in Nutrition*, 9.

WANG, Y., YAN, Z., TANG, W., ZHANG, Q., LU, B., LI, Q., & ZHANG, G. (2021). Impact of chitosan, sucrose, glucose, and fructose on the postharvest decay, quality, enzyme activity, and defense-related gene expression of strawberries. *Horticulturae*, 7(12), 518.

WREGGE, M. S.; REISSER JÚNIOR, C.; ANTUNES, L. E. C.; OLIVEIRA, R. P. de.; HERTER, F. G.; STEINMETZ, S.; GARRASTAZU, M. C.; MATZENAUER, R.; JOÃO, P. L.; SANTOS, A. M. dos. Zoneamento agroclimático para produção de mudas de morangueiro no Rio Grande do Sul. Pelotas: Embrapa Clima Temperado, 2007. 27 p. (Embrapa Clima Temperado. Documentos, 187).