Algerian People's Democratic Republic

Ministry of Higher Education and Scientific Research

Faculty of Sciences

Department of Agronomic Sciences

Course materials: Harvesting and Preservation of Fruits and Forage.

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For use by second-year Master's students in Plant Improvement.

Academic Year: 2025-2026

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Master's Program Title: Plant Improvement

Semester: 3 Course

Title: UEF2 Subject

Title: Harvesting and Conservation of Fruits and Forage

Credits: 4

Coefficients: 2

Teaching Objectives:

- The first part of the module aims to master several factors that determine the fruit's quality from harvesting to its preservation in a fresh state.
- The second part aims to raise awareness among students about the aspects of forage harvesting and conservation.

Recommended Prerequisite Knowledge: Modules from Master's Year 1 **Classroom Activities:** Lectures, Visits to a Fruit Packaging and Conservation Station Others

This module requires conducting bibliographic research and assignments to facilitate the understanding of the subject matter.

Assessment Method: Course: Written Exam (fruits and forage), Tutorials + Presentations (Written Exam + Tutorials) 60% + 40%

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Course 1: Fruit harvesting

1. Definition

Harvesting refers to the process of gathering plants or plant products that hold commercial value, such as fruits, vegetables, or grains.

This crucial step occurs at the culmination of the cultivation period when the crops have reached maturity and are ready for use or sale.

Following the harvest, a series of post-harvest activities takes place, including cleaning, sorting, packaging, and preparing the products for either market distribution or industrial processing.

2. Harvesting Systems

Harvesting methods can be broadly classified into two systems: **manual or hand harvesting** and **mechanical harvesting**.

2.1. Manual or hand Harvesting:

Hand harvesting is the practice of manually collecting crops, often with the assistance of simple tools such as knives, scissors, or sickles.

This method relies heavily on human labor to gather produce, and it is particularly beneficial for crops that are delicate or intended for fresh markets.

For these types of crops, hand harvesting ensures careful handling, which minimizes the risk of damage and preserves the appearance and quality of the produce.

Hand harvesting is also well-suited for crops that have a longer or staggered harvesting period. Unlike mechanical harvesting, which typically collects crops all at once, hand harvesting allows workers to selectively pick products at different stages of maturity.

This selective process is crucial for ensuring that only the most mature or optimal fruits or vegetables are harvested at the right time, enhancing both the quality and yield of the crop.

Despite being labor-intensive, hand harvesting remains widely utilized in agriculture due to its flexibility and adaptability.

It is effective in various conditions, whether on small-scale farms or in challenging environments where machinery might be less practical.

Furthermore, this method can be adjusted to suit specific harvesting conditions, such as different crop types, field sizes, or terrain types.

Moreover, hand harvesting plays an essential role in maintaining product quality. By allowing workers to handle each item with care, it helps prevent bruising, over-ripening, or other forms of damage that might occur with more aggressive harvesting methods.

This is particularly important for high-value crops, where consumer satisfaction depends on the visual and physical condition of the produce.

Additionally, hand harvesting facilitates better sorting of the produce directly in the field, further improving the efficiency and quality of the post-harvest process.

2.1.1. Advantages

One of the primary advantages of hand harvesting is that it does not require a significant initial investment in machinery, making it a more accessible method, especially for small-scale farmers or those operating on a limited budget.

Unlike mechanical harvesting, which often necessitates the purchase of expensive equipment, hand harvesting relies on human labor and simple tools, which makes it economically feasible for a wide range of agricultural operations.

This accessibility ensures that even farmers with limited resources can still participate in large-scale agricultural production.

In addition to its cost-effectiveness, hand harvesting is particularly beneficial for crops with extended harvesting periods.

Unlike crops that are ready for harvest all at once, such as grains, some fruits and vegetables require careful and selective harvesting over an extended period.

With hand harvesting, workers can pick only the mature products at various stages, ensuring that the crop is gathered at its peak quality.

This method allows for precision and careful timing, especially for crops that ripen gradually, reducing the risk of harvesting immature or overripe produce.

During peak harvesting periods, such as when rapid ripening occurs due to favorable weather conditions, hand harvesting provides the flexibility to deploy a large number of workers to speed up the process.

The ability to adjust the workforce size allows for a more efficient harvest, especially when conditions like heat or rain trigger a sudden surge in ripening.

This responsiveness ensures that crops are gathered at their optimal ripeness, reducing waste and maximizing yield. In such circumstances, the workforce can adapt quickly, ensuring that produce is collected before it deteriorates or is overripe.

Another significant benefit of hand harvesting is the human ability to assess the maturity and quality of each individual product.

Workers are able to examine the produce closely, evaluating its texture, color, and firmness to determine whether it is ready for harvest.

This careful selection process is especially important for fragile crops, such as berries, cherries, or soft fruits, which can be easily damaged if mishandled.

By using their judgment and experience, workers ensure that only the best-quality products are harvested, minimizing damage and preserving the integrity of the produce.

This delicate approach not only helps maintain the physical appearance of the fruits and vegetables but also contributes significantly to the overall market value of the harvested products.

Because the produce remains in optimal condition, it is more likely to meet consumer expectations and command a higher price.

Furthermore, consumers are more likely to be satisfied with the quality of the products, leading to improved sales and a stronger reputation for the farmer.

The attention to detail in hand harvesting thus supports both the immediate goal of preserving product quality and the long-term goal of sustaining profitable and consumer-friendly agricultural practices.

2.1.2.Disadvantages

Despite its numerous advantages, hand harvesting does come with several disadvantages that can affect both the efficiency of the process and the quality of the harvested produce.

One of the most significant challenges is the need for adequate training and close supervision of the harvesting teams.

Workers must be trained to identify crops at the correct stage of maturity and to use proper separation techniques to ensure that both the products and the plants are not damaged. Without proper training and oversight, the risk of bruising, mishandling, or picking immature or overripe produce increases, which can compromise the quality of the harvest and reduce its market value.

The type of contract and compensation structure for the workers also plays a crucial role in the success of hand harvesting.

When workers are paid based on time such as hourly, weekly, or monthly rates the emphasis tends to be on careful, thorough harvesting, but this can slow down the process.

While the quality of the produce may be higher due to the slower, more deliberate pace, it may take longer to collect the entire crop, which can be problematic during peak harvesting periods or when dealing with large-scale operations.

On the other hand, when workers are paid based on output, such as the number of boxes filled, furrow meters completed, or plants harvested, there is often a drive to work faster to maximize earnings.

While this can increase productivity, it can also lead to rougher handling of the crops, increasing the likelihood of damage, such as bruising or breaking delicate produce, and ultimately affecting the overall quality of the harvest.

In addition to these labor-related factors, the working conditions themselves such as the division of labor, work hours, and exposure to environmental elements can have a significant impact on both worker well-being and the quality of the harvested crops.

Long working hours without adequate breaks can lead to fatigue, which may result in carelessness or poor handling of the produce.

Additionally, exposure to extreme weather conditions, whether excessive heat or cold, can cause physical discomfort or stress for workers, further affecting their ability to handle the crops properly.

These factors not only impact the health and safety of the workers but can also negatively affect the produce, as tired or uncomfortable workers are more likely to make mistakes that lead to damage or suboptimal harvesting practices.

2.2.Mechanical Harvesting:

Mechanical harvesting uses machinery such as harvesters, combines, or specialized picking equipment to efficiently collect crops.

This method is often employed for large-scale operations or crops intended for industrial processing.

The choice of a harvesting system, however, depends on several factors.

The type of crop plays a significant role, as fragile fruits like strawberries are better suited for manual harvesting, while grains like wheat are typically harvested mechanically.

The destination of the produce also matters; products intended for direct consumption require careful handling, whereas those for processing can tolerate rougher treatment.

Additionally, the layout and accessibility of the field can influence the selection of harvesting equipment, as certain machinery may require specific field conditions for optimal performance.

2.2.1.Advantages:

Mechanical harvesting offers several distinct advantages, especially in terms of speed and cost efficiency, making it a highly favorable option for large-scale farming operations.

One of the most significant benefits of mechanical harvesting is its ability to drastically reduce the time needed to gather crops.

Unlike traditional hand harvesting, which is a labor-intensive and time-consuming process, mechanical harvesting can cover vast areas of farmland in a relatively short period.

This speed is crucial, especially for crops that have a narrow window of optimal harvest time, such as grains, corn, and certain fruits, where delays can result in significant crop losses due to over-ripening or spoilage.

By enabling farmers to harvest crops quickly, mechanical harvesting helps to maximize the yield and quality of the produce.

Another key advantage of mechanical harvesting is its impact on the overall cost structure of farming operations.

When implemented on a large scale, mechanical harvesting can significantly reduce the cost per ton of produce by minimizing the dependence on human labor.

Labor is often one of the most significant expenses in traditional farming methods, and by automating the harvesting process, farmers can reduce labor costs substantially.

While the upfront cost of purchasing and maintaining harvesting machinery may be high, the long-term savings in labor and operational efficiency make it a cost-effective solution for many agricultural activities.

The reduction in labor costs can be particularly advantageous in regions where labor shortages or high wages make manual harvesting financially unfeasible.

Additionally, mechanical harvesting allows for greater consistency and efficiency across large farms. Since machines can operate continuously for extended hours, they ensure a steady and timely harvest, which is essential for large-scale operations.

This efficiency minimizes delays and ensures that crops are gathered at their peak maturity, which can help preserve both the quantity and quality of the produce.

Consistency in harvesting also reduces the risk of crop wastage, as it enables farmers to collect produce more reliably and avoid over-ripening or harvesting too early, both of which can negatively affect product quality.

Mechanical harvesting also provides significant advantages in terms of scalability.

For farms that grow large quantities of crops, particularly those with vast acreage, mechanized systems allow for efficient and rapid harvests that would otherwise be impossible or highly impractical to achieve with human labor alone.

This scalability enables farmers to manage their operations more effectively, increasing their output while reducing the need for additional workers.

Moreover, mechanized systems can be used not only for harvesting but also for other tasks such as sorting, cleaning, and packing, further optimizing farm productivity.

In conclusion, mechanical harvesting offers significant benefits in terms of speed, cost efficiency, and scalability, making it an ideal choice for large-scale farming operations.

By reducing the time required to harvest crops and minimizing labor costs, it enables farmers to increase productivity and profitability.

Although the initial investment in machinery can be substantial, the long-term savings and operational advantages make mechanical harvesting a valuable tool for modern agriculture, particularly for farms dealing with large volumes of produce.

2.2.2.Disadvantages:

Mechanical harvesting, while undoubtedly efficient, also presents several challenges and limitations that must be carefully considered when adopting this technology in agricultural operations.

One of the primary drawbacks of mechanical harvesting is the high initial investment required to purchase and maintain the necessary equipment.

This upfront cost can be a significant burden for smaller farms or operations with limited financial resources.

The purchase of harvesting machinery, along with ongoing maintenance and repairs, can strain the budgets of smaller-scale farmers, making it difficult for them to access the advantages that mechanical harvesting offers.

Furthermore, the economic feasibility of mechanical harvesting may not always be viable for farms producing smaller quantities of crops or those with highly variable harvest seasons.

Another challenge is that the use of machinery may result in damage to the harvested produce, particularly fragile crops that require careful handling.

While mechanical harvesting is highly efficient for robust crops like cereals or grains, it can cause bruising, crushing, or other forms of physical damage to delicate products such as berries, soft fruits, or vegetables.

The rough handling of these crops by machines can lead to a decrease in their market value and consumer appeal.

For such crops, the potential loss in product quality due to mechanical harvesting might outweigh the benefits of increased efficiency, making manual harvesting the preferred method for those particular products.

In addition to crop sensitivity, mechanical harvesting is limited in its applicability. It is particularly well-suited for crops that are harvested only once per season, such as cereals or certain root vegetables.

However, it is less effective for crops that require multiple harvests, such as fruit trees or vegetables that continue to grow throughout the season. Crops with staggered harvest times or those requiring selective harvesting at different stages of maturity may not be easily adapted to mechanical harvesting systems.

For these types of crops, the precision and selectivity of hand harvesting remain more suitable.

To maximize the benefits of mechanical harvesting, effective operational planning is essential.

The entire agricultural process must be carefully adapted to meet the specific requirements of the machinery.

For example, plowing, planting, and field preparation must account for the dimensions of the harvesting equipment.

This includes ensuring the proper row spacing, field leveling, and the overall layout of the crop to accommodate machinery.

Additionally, crop varieties should be selected for their resilience and ability to withstand the rough handling that mechanical harvesting entails.

Crops that are too fragile or sensitive to mechanical damage will not be ideal candidates for this harvesting method.

Moreover, post-harvest logistics need to be optimized to handle the large volumes of produce typically associated with mechanical harvesting.

Once the crops are collected, efficient systems for cleaning, sorting, and packaging must be in place to process the produce quickly and effectively.

This is particularly important when dealing with large-scale operations where the volume of harvested crops can overwhelm traditional post-harvest systems.

The integration of machinery into the post-harvest process, such as automated sorting lines or packing systems, can help streamline operations and ensure that the harvested produce reaches the market in optimal condition.

3. Harvest Maturity (Fruit Ripening)

Harvest maturity refers to the stage at which fruits are ready to be consumed, following certain changes in their color, texture, and taste.

It is a critical point in fruit production, as it directly affects the quality, shelf life, and market value of the product.

Determining the maturity stage accurately is essential for ensuring that fruits meet market standards and consumer expectations.

To assess maturity, producers often rely on color scales, which measure the percentage of desired color on the fruit's surface.

In addition, objective tools like colorimeters are used to obtain precise measurements of color changes, offering a scientific basis for determining harvest readiness.

There are two main types of maturity based on the degree of fruit growth:

3.1. Physiological Maturity

Physiological maturity is a crucial stage in the growth and development of fruits, marking the point at which the fruit has completed its growth and is ready to transition towards ripening. This stage is characterized by the completion of internal processes necessary for the fruit's final development, including the accumulation of nutrients and the formation of various compounds that influence its color, texture, and taste.

One of the most visible signs of physiological maturity is a change in the color of the fruit.

This often involves the degradation of chlorophyll, the pigment responsible for the green color in the fruit, leading to the appearance of other pigments such as carotenoids (which give yellow and orange hues) or anthocyanins (which provide red, purple, or blue tones).

As the fruit reaches physiological maturity, specific pigments and enzymes are synthesized that indicate its progression toward ripening.

These include the activation of enzymes responsible for softening the fruit's texture, converting starches into sugars, and modifying the acid content. The formation of these pigments and compounds signals the fruit’s readiness to enter the ripening phase, although this is not always an immediate or automatic process.

Physiological maturity may not always coincide with full ripening, and in some cases, the fruit may remain in this stage until external conditions, such as temperature or light, trigger the ripening process.

For fruits destined for market consumption, physiological maturity is a critical threshold, as it defines when the fruit has reached a stage where it can develop into the desired ripened form, whether through continued ripening or controlled storage techniques. The point at which the fruit achieves **commercial maturity** the stage at which it is ideally ready for harvest and transport to the market may or may not align with the moment of physiological maturity. Depending on the fruit type, the commercial maturity stage could involve further changes in flavor, texture, and nutritional content, influenced by the ripening process that follows physiological maturity.

3.2. Commercial Maturity

Commercial maturity is the stage at which a fruit is deemed ready for sale or consumption, making it a key factor in determining the optimal time for harvesting.

This stage may coincide with physiological maturity, but it does not always align perfectly with it.

While physiological maturity marks the completion of the fruit's growth, commercial maturity is more concerned with the fruit's readiness for market and consumer preferences, which are often dictated by factors such as color, texture, and taste. In many instances, commercial maturity is reached after the fruit has completed its growth, but it can also occur before the fruit has fully developed in terms of size, ripeness, or other internal factors.

The timing of commercial maturity is influenced by various factors including market demand, storage requirements, and transport considerations. For example, fruits intended for long-distance transport may be harvested just before they reach full ripeness to ensure they do not spoil during the journey.

Similarly, certain fruits may be harvested at an earlier stage of ripening to extend their shelf life or to meet specific commercial requirements for consistent quality.

For some fruits, such as bananas, tomatoes, or avocados, commercial maturity might involve a balance between the fruit's readiness to ripen fully once harvested and its ability to withstand handling, storage, and distribution without damage.

In contrast to physiological maturity, which is driven by the internal biological processes of the plant, commercial maturity is heavily influenced by external factors such as consumer expectations and the logistical needs of the supply chain.

This distinction underscores the importance of not only understanding the biological growth stages of fruits but also being attuned to the practical considerations that guide their harvest, marketing, and distribution.

Therefore, the concept of commercial maturity is both a scientific and a commercial decision, aiming to ensure the fruit reaches the market in its best possible condition while meeting consumer demands for taste, appearance, and freshness.

Fruits are further categorized based on their ripening behavior and autonomy in reaching maturity:

3.2.1. Fruits with Natural Hormonal Growth (Climacteric Fruits)

Climacteric fruits are those that possess the ability to ripen autonomously, meaning their ripening process can continue even after they have been detached from the mother plant. These fruits undergo significant changes in taste, aroma, color, and texture as they ripen, all of which are closely linked to a transient peak in respiration.

This peak in respiration is associated with the auto-catalytic production of ethylene, a plant hormone that plays a pivotal role in initiating and driving the ripening process.

The production of ethylene accelerates the biochemical changes within the fruit, such as the breakdown of starches into sugars, the softening of the flesh, and the conversion of pigments, which results in the typical color changes seen in ripe fruit.

Climacteric fruits, such as bananas, apples, and tomatoes, are especially noteworthy because they can continue their ripening process after being harvested.

This ability is in contrast to non-climacteric fruits, which must remain attached to the plant in order to ripen properly.

The presence of ethylene allows climacteric fruits to ripen off the plant, which is a key factor for their commercial handling.

For example, bananas are often harvested while still green and unripe, as they can continue to ripen during transport and in storage under controlled conditions, eventually reaching a state where they are suitable for consumption.

Similarly, tomatoes and apples are typically picked before they have reached full ripeness, allowing them to ripen during shipping and storage, which ensures they arrive at their destination in optimal condition for sale.

This unique feature of climacteric fruits, where ripening can proceed independently of the plant, has profound implications for their harvesting, storage, and transportation strategies.

It also allows for a more flexible market window, as these fruits can be harvested at slightly earlier stages of ripeness, reducing the risk of over-ripening or spoilage before reaching consumers.

Additionally, the ability to control the ripening process through ethylene management is a valuable tool in the fruit industry, enabling growers and distributors to meet demand and supply at the ideal stage of ripeness.

3.2.2. Fruits with Direct Vegetative Growth (Non-Climacteric Fruits)

Non-climacteric fruits are those that rely on the plant for the completion of their ripening process, meaning they achieve full commercial maturity only while still attached to the mother plant. Unlike climacteric fruits, non-climacteric fruits do not continue to ripen or undergo significant changes in color, texture, or flavor after being harvested.

Fruits such as grapes, strawberries, and citrus are prime examples of this category. These fruits typically show minimal changes once they are picked, and their ripening process is largely confined to the time they remain on the plant.

Full ripening in non-climacteric fruits occurs only while they are still attached to the plant, where they undergo the necessary biochemical processes to develop their final color, flavor, and texture.

For instance, grapes and strawberries will only achieve their characteristic sweetness and desirable color as they mature on the vine.

Once detached, these fruits do not continue to accumulate sugars or undergo the enzymatic changes that produce the full array of sensory attributes associated with ripeness.

Similarly, citrus fruits such as oranges and lemons require the sun and the plant's physiological systems to develop their full flavor and coloration, and this process halts once they are harvested.

This characteristic of non-climacteric fruits means that their harvest must be timed very carefully to ensure they are picked at the optimal stage of ripeness.

Once removed from the plant, non-climacteric fruits cannot be “forced” to ripen further through external factors such as ethylene exposure, as is the case with climacteric fruits. As a result, these fruits are typically harvested when they have reached their peak of flavor, color, and texture, making the timing of the harvest crucial for quality control.

Additionally, because their ripening process is so closely linked to the plant, these fruits have a much shorter post-harvest shelf life, often requiring immediate consumption or prompt transportation to maintain freshness.

3.3. Overmaturity or Excessive Ripeness

Overmaturity refers to the stage that follows commercial maturity.

At this point, the fruit becomes overly soft, loses its characteristic flavor, and often becomes unappealing to consumers.

However, overripe fruits are not without value; they are ideal for processing into jams, sauces, and other value-added products.

Recognizing and utilizing fruits at this stage can help reduce waste and enhance profitability.

Table 1. Fruits with natural hormonal growth and fruits with direct vegetative growth.

Direct Vegetative Growth		**Natural Hormonal Growth**	
Bell Pepper	Olive	Apple	Melon
Blackberry	Orange	Apricot	Nectarine
Blueberry	Pineapple	Avocado	Papaya
Cacao	Pomegranate	Banana	Passion Fruit
Cashew Apple	Pumpkin	Breadfruit	Peach
Cherry	Raspberry	Cherimoya	Pear
Cucumber	Strawberry	Feijoa	Persimmon
Eggplant	Squash	Fig	Plantain
Grape	Sour Cherry	Soursop	Plum
Grapefruit	Ground Cherry	Guava	Quince
Lemon	Japanese Peach	Jackfruit	Sapodilla
Lime	Lychee	Kiwi	Sapote
		Mamey	Tomato
		Mango	Watermelon

4.Harvest handling

Harvest handling involves a series of essential operations that are carried out in the field to prepare harvested produce for market sale, ensuring that the products maintain their best possible condition for consumers.

The process begins with pre-sorting, where non-edible parts such as leaves, stems, or damaged fruits are carefully removed.

This step is crucial for preventing contamination and ensuring that only market-ready items proceed to further processing. In some cases, the produce is fully prepared for sale directly in the field.

This can involve washing, sorting, and packing the items right after they are harvested, making them ready for transport and sale without any further processing.

However, in most situations, harvested fruits and vegetables are placed in containers and transported to a warehouse or processing facility.

At this stage, the produce may undergo additional processing, such as drying, immersion in water, or other treatments designed to preserve quality and extend shelf life.

Following these treatments, the produce is moved to sorting lines where it undergoes final preparation before being packaged for sale.

This stage often includes the removal of any remaining imperfections and the categorization of the produce based on size, color, and quality.

While these handling stages are vital for preparing the produce for the market, they also expose the product to various types of physical damage.

This can range from minor bruises caused by rough handling or collisions with other produce, to more severe injuries that might occur during the harvesting, sorting, or transportation processes.

Such damage can compromise the overall quality and shelf life of the product, reducing its marketability and making it less attractive to consumers.

It is therefore essential for the entire handling process to be carried out with care and efficiency, minimizing any potential harm to the produce to ensure it reaches the consumer in optimal condition.

4.1. Types of lesions

There are several types of lesions or damage commonly encountered during the harvesting and post-harvest handling processes.

4.1.1.Injuries (cuts and punctures) are one of the most common types of damage.

These injuries are typically caused by harvesting tools such as pruning shears, knives, or even by pickers' fingernails or stems of other fruits.

When a fruit is cut or punctured, the fruit's tissue is damaged, creating an entry point for fungi and bacteria, which can lead to spoilage.

While such injuries are generally visible and can be detected during sorting, they can still significantly affect the quality of the produce if not properly addressed.

4.1.2.Bruises, on the other hand, are more common and can be more insidious because they may not be immediately visible.

Bruises often become evident several days after the product has been harvested and distributed to consumers.

There are three primary causes of bruises:

4.1.2.1. Impact :

Impact bruising occurs when fruits or packaged produce fall onto hard surfaces or collide with each other.

During harvesting or packaging, fruits may fall or be jostled, leading to bruises.

These types of injuries can be especially prevalent when the fruits are not handled carefully or when they are dropped during transport or sorting.

4.1.2.2. Compression :

Compression bruising happens when fruits are subjected to pressure, typically during storage and transport.

When fruits are stacked in large quantities or improperly packaged, the weight of the produce can press down on the lower layers, causing deformation.

This can also occur if the packaging material is not strong enough to support the weight of the produce or if fruits are crammed into containers that are too small.

The pressure causes bruising that may not be immediately visible but can lead to significant deterioration over time.

4.1.2.3. Abrasion :

Abrasion refers to superficial damage caused by friction, particularly with fruits that have thin skins, such as pears or apples.

These bruises occur when the produce comes into contact with other fruits, packaging materials, or ropes used for handling and transport.

Abrasions are usually shallow but can lead to the breakdown of the fruit's skin, making it more vulnerable to decay and reducing its shelf life.

Each of these types of damage, whether from cuts, bruises, or abrasions, can have a detrimental effect on the harvested produce.

In particular, bruised or cut fruits are more prone to bacterial and fungal growth, which can reduce their marketability.

Even minor damages can lead to consumer dissatisfaction, as these imperfections affect the visual appeal and overall quality of the product.

To mitigate these risks, it is essential to handle the produce carefully throughout the harvesting, transportation, and post-harvest processing stages.

Moreover, proper packaging, appropriate transport methods, and efficient sorting and handling processes can help minimize the occurrence of such damage, ensuring that produce reaches consumers in optimal condition.

4.2. Symptoms of lesions

The symptoms of lesions on harvested fruits depend on several factors, including the affected tissue, the degree of fruit maturity, the type of bruise, and the severity of the damage. These symptoms can vary widely, from minor cosmetic damage to more severe internal deterioration, but they always reflect the physical impact the fruit has undergone.

One of the key characteristics of lesions is that they are cumulative.

As the fruit sustains damage, it triggers a series of stress responses that, while part of the natural healing process, can lead to further degradation of the product's quality.

Physiologically, the fruit responds to injury by increasing its respiration rate.

This temporary rise in respiration is a direct result of the stress caused by the lesion and is associated with the fruit's deterioration.

As the fruit continues to metabolize its stored reserves, it accelerates its ripening process, often leading to an undesired increase in softness.

This process is also accompanied by a transient production of ethylene, a natural hormone involved in ripening.

While ethylene plays a role in the fruit's normal maturation, its production is amplified following injury, causing the fruit to ripen more quickly and further contribute to its softening.

This accelerated ripening process can significantly shorten the shelf life of the fruit, making it less appealing to consumers.

In some instances, the physical damage caused by the lesion, particularly mechanical tearing of the fruit's membranes, can have even more profound effects.

When membranes are torn or ruptured, enzymes that were previously contained within the cells come into contact with various substrates.

This interaction can lead to the synthesis of secondary metabolic products that alter the texture, taste, appearance, aroma, or nutritional value of the fruit.

For example, some enzymes may lead to the breakdown of starches into sugars, altering the sweetness of the fruit, while others might impact the color or flavor profile.

At the site of impact, the fruit's firmness rapidly decreases due to cell death and the subsequent loss of tissue integrity.

The more mature the fruit, the more susceptible it becomes to damage, and the more severe the effects of bruising and injury.

As fruit ripens, its cell walls weaken, making it more prone to mechanical damage. Furthermore, high temperatures and prolonged storage periods exacerbate the effects of these lesions.

The longer the fruit is stored after injury, the more pronounced the damage becomes, often leading to a significant loss in quality.

To mitigate these negative effects, various strategies can be employed, such as controlling or modifying the atmospheric conditions during storage.

By reducing or eliminating the presence of ethylene in the storage environment, the fruit's healing rate can be slowed, minimizing the stress response mechanisms that accelerate deterioration.

Similarly, modifying the atmosphere to reduce the fruit's exposure to oxygen can help limit the production of ethylene and delay ripening.

These techniques can be particularly useful for prolonging the shelf life of fruit and reducing the impact of mechanical damage.

5.Recommendations for Harvesting:

Harvesting plays a crucial role in determining the quality of the final product. To ensure optimal outcomes, several best practices should be followed throughout the harvesting process.

First, it is highly recommended to carry out harvesting during the cooler morning hours. During this time, the fruits and other products are typically more swollen due to the cool temperatures, and they will require less energy for refrigeration after being harvested.

This helps maintain the product's freshness and reduces energy costs for storage.

The degree of maturity required for harvesting is an important factor that should be determined based on the distance to the final market.

If the market is nearby, the products can be left on the plant to ripen further, thus enhancing their flavor and market value.

However, for longer distances, it is best to harvest the produce at the appropriate level of ripeness to avoid over-ripening or degradation during transportation.

Once harvested, it is essential to keep the products in the shade until transport. Exposure to direct sunlight can lead to the fruits overheating, which can affect their texture, flavor, and overall quality.

Proper care must be taken to prevent any damage during this stage of handling.

To avoid damaging the produce during the actual harvesting process, pruning shears or knives with rounded tips should be used.

Sharp tools help reduce the risk of tearing or bruising the fruits, ensuring they are not roughly handled.

Ensuring that these tools are well-maintained and sharp will also make the harvesting process smoother and more efficient.

Furthermore, the containers used for transporting harvested products should be padded and smooth, with no sharp edges that could cause abrasion.

They should not be overloaded, as excessive weight can lead to compression or crushing of the produce.

Handling the containers with care is essential to prevent any accidental damage.

When transferring the products to different containers, care should be taken to reduce drop heights.

A gentle transition between containers minimizes the risk of bruising or other types of physical damage.

In addition, proper training of personnel is essential.

Workers should be trained to handle the products delicately and should be educated on recognizing the optimal harvest maturity.

It is also highly recommended that personnel wear gloves during harvesting and handling to avoid transferring oils, dirt, or other contaminants to the fruits and to further reduce the risk of accidental damage.

By following these recommendations, the harvested products will be less prone to injury and degradation, ensuring that they reach the market in the best possible condition, enhancing their shelf life and market appeal.

Course 2: Fruit preparation for the market

Once fruits and vegetables are harvested, the next critical phase involves preparing them for sale, whether directly at the farm, through retailers, wholesalers, or within supermarket chains.

Proper preparation ensures that the products are market-ready and can be sold at the highest possible quality.

Regardless of the final destination, the preparation process typically involves several essential steps.

1.Field Selection:

The initial step in preparing harvested produce for market begins with field selection. This is a crucial phase in reducing costs and minimizing the risk of product spoilage. Handling fruits as little as possible during the preparation process helps preserve their quality and ensures that they reach the market in optimal condition.

Ideally, the preparation should take place at the production field level, as this minimizes unnecessary transportation and handling, which can result in bruising or other forms of damage.

Field selection involves the careful inspection and sorting of the harvested products to eliminate any that have visible defects, lesions, or signs of disease. This step helps prevent damaged or spoiled produce from entering the supply chain, ensuring that only the best quality products are sent to market.

It is particularly important for delicate or perishable products, which may require more careful handling to maintain their integrity.

For such crops, field selection is especially vital as they may be more susceptible to deterioration if not immediately processed or sorted.

Moreover, field selection is an essential step for limited volumes of products destined for nearby markets.

For these products, where rapid distribution is crucial, it is especially important to address any imperfections right away to avoid unnecessary waste.

By eliminating subpar produce at the field level, farmers can focus their resources on preparing the highest quality products for the market, thereby reducing costs and improving efficiency.

Overall, field selection serves as a preventive measure to reduce handling, preserve freshness, and ensure that only the best products make it to the market, which ultimately enhances customer satisfaction and reduces waste.

2.Transport to packing facility or warehouse:

After the initial field preparation, the harvested product is transported to the packing facility or warehouse, where it undergoes further processing to prepare it for market distribution.

For large-scale operations or products destined for distant or demanding markets, this step becomes crucial. Products that require specialized treatments such as washing, brushing, waxing, controlled ripening, refrigeration, or other specific processing or packaging techniques are typically sent to a dedicated packing facility.

Transporting the product to a packing facility is necessary for maintaining quality and ensuring that special operations are performed properly.

In cases where mobile packaging units are available, these can serve as an alternative for processing larger volumes in less time, reducing the need for transport and streamlining the packaging process directly on-site.

This is especially useful for operations where efficiency and speed are critical.

A packing facility offers several advantages over field preparation, notably the ability to prepare products within 24 hours, regardless of weather conditions.

This capability ensures that produce is promptly processed, reducing the risk of spoilage and maintaining its freshness.

Furthermore, the centralized operations of a packing facility provide better control over the quality and consistency of the final product, which is particularly important for meeting market standards.

Due to its capacity to handle larger volumes of produce, packing facilities are often utilized by farmers' associations, cooperatives, or even community organizations.

The size and complexity of the facility can vary depending on factors such as the type of crops being processed, the volume of produce, the available capital for investment, and whether the operation is handling only its own production or providing services to third-party growers.

For example, packing facilities can range from simple structures, such as shelters with basic equipment, to highly automated and sophisticated buildings designed for large-scale production.

In some cases, packing facilities may also include storage units and commercial transaction offices, enabling smoother operations from the packing stage to product sale.

These facilities are typically well-organized, protecting both the product and the personnel working there from external weather conditions.

The facility is structured to allow for centralized handling operations, and in many ways, it operates similarly to an assembly line factory, where raw agricultural products undergo a series of sequential operations from washing and sorting to packaging before reaching the final market-ready product.

2.1. General Conditions Regarding the Location and Necessary Facilities for the Smooth Operation of a Packing Facility

The location of a packing facility plays a crucial role in its efficiency and overall operation. Ideally, the facility should be positioned close to the production fields, minimizing the time between harvesting and processing.

This proximity ensures that the products are handled as quickly as possible, preserving their quality and freshness.

Additionally, the facility should have convenient access to main roads or highways to facilitate transportation of goods to and from the packing site, making it easier for both suppliers and distributors to deliver and collect products efficiently.

The facility must be designed with optimal traffic flow in mind, having a single entry point to streamline the management of incoming and outgoing deliveries.

This controlled access helps to reduce congestion and delays, ensuring smoother operations. The layout should also be spacious enough to allow for future expansions or additions, such as the inclusion of new processing units or storage areas.

With sufficient space, the facility can grow in line with production demands without being hindered by limited space.

When it comes to the building design itself, careful consideration should be given to the positioning of the structures.

For instance, loading and unloading areas should be positioned so that they benefit from natural shade for most of the day, protecting the products from excessive heat, which can accelerate deterioration. Additionally, these areas should be well-ventilated during the summer months to prevent overheating, while also being protected during winter to ensure that the internal temperature remains stable and suitable for product handling.

Although packing facilities are often constructed using cost-effective materials to minimize initial investment, it is important to prioritize the comfort and safety of both the products and the workers.

The facility should be adequately insulated and protected from extreme weather conditions, which could negatively impact the quality of the products.

Similarly, the workers' comfort is essential to reduce errors in product handling and ensure that operations run smoothly.

If the facility is uncomfortable, it can lead to distractions or mistakes, which could affect the quality of the product being processed.

To facilitate the smooth flow of operations, the packing facility should have enough space for efficient movement.

This includes ensuring that pathways are wide enough for easy circulation of workers, equipment, and products.

Access ramps should be incorporated to enable the loading and unloading of goods, and the facility's doors and openings should be large enough to accommodate heavy machinery, such as forklifts.

This ensures that goods can be moved quickly and efficiently, and in case of emergencies, such as fires, the design should allow for quick evacuation routes.

The receiving area, where the harvested products are first delivered, should be spacious enough to hold a volume equivalent to one day's worth of production.

This capacity is important because it ensures that the facility can continue to function smoothly, even if there are delays in the flow of goods from the field due to weather issues or mechanical problems.

A buffer stock in the receiving area helps maintain the operation's momentum.

Electricity is essential for powering the facility's equipment, refrigeration systems, and lighting.

Given that packing facilities often operate around the clock, especially during the harvest season, an uninterrupted supply of electricity is vital.

Proper lighting is especially important in the sorting areas, where workers inspect the products for defects.

The lighting should be positioned to minimize glare and eye strain, and its intensity should be adjusted based on the type of product being processed.

For colored products, a light intensity of 2,000 to 2,500 lux is ideal, while darker products require a higher light intensity of 4,000 to 5,000 lux.

Proper lighting not only enhances product inspection but also ensures the workers' comfort and reduces the risk of accidents.

In addition to lighting, a reliable water supply is essential for a range of activities within the packing facility, such as washing the products, cleaning the equipment, and in some cases, cooling the products.

Water is also necessary for cleaning trucks, bins, and any other equipment involved in the process.

Along with a steady water supply, an effective wastewater drainage system is equally important to maintain cleanliness and hygiene in the facility.

The administrative offices of the packing facility should be located in a quiet, clean area, away from the bustle of the production zones.

These offices should have clear visibility of the entire operation, allowing for efficient monitoring and management.

In addition to administrative tasks, it is important for packing facilities to be equipped with infrastructure, such as laboratories, to analyze product quality and ensure that the products meet the required standards before they reach the market.

Once the design of the packing facility is finalized, a flow diagram should be developed to map out the product's journey through the facility.

This diagram helps visualize the flow of goods and operations, ensuring that the process is as direct and efficient as possible.

The flow should be streamlined, with minimal detours to avoid delays and ensure that products are handled within a short timeframe.

The packing facility should be organized in a way that allows for parallel operations, such as simultaneously processing different sizes or stages of ripeness, which improves overall efficiency.

3.Reception

The reception of harvested products at a packing facility is a critical stage in the overall post-harvest process, and the organization of preparation and packaging operations plays a key role in minimizing the time between harvest and the delivery of the final packaged product. Efficient handling during this phase ensures the preservation of product quality, reducing losses and preventing spoilage.

However, delays in the reception process are common, often due to logistical challenges or congestion in handling.

If delays are inevitable, it is crucial to protect the products from exposure to direct sunlight, as prolonged heat can accelerate deterioration and reduce their marketability.

Typically, upon arrival at the packing facility, the products are weighed and counted to ensure the correct quantity is received.

This process is essential for inventory management and for tracking the flow of goods. In some cases, samples are taken from the batch for quality control purposes, allowing for an analysis of the product's condition, including the detection of any potential contamination or defects.

Once the products have been received and registered, the next step is to prepare them for the market.

The preparation begins with depositing the products onto the packing facility's supply lines, which may involve transporting the products either dry or immersed in water. Each method has its benefits, but in either case, it is crucial to control the speed of the operation to minimize any potential damage to the products and to better manage the flow of goods through the facility.

A slower speed ensures that products are handled more carefully, reducing the likelihood of bruising or other damage during the transition from reception to processing.

In cases where products are immersed in water, the process offers several advantages. Firstly, it helps reduce the incidence of collisions between fruits, which could otherwise result in mechanical damage or bruising.

The water acts as a buffer, guiding the floating products along a current and easing their transport through the system.

However, this method is not suitable for all products, as some fruits and vegetables may not withstand being submerged.

Products with lower densities than water, such as certain fruits, will naturally float, while others might need assistance in floating by introducing diluted salts, such as sodium sulfate, into the water to improve buoyancy.

This modification helps maintain the movement of all products, regardless of their natural density.

The immersion process also serves as a preliminary washing operation, removing a significant portion of the dirt, field debris, and other contaminants that might have adhered to the surface of the produce during harvesting.

While this initial wash helps in reducing the load of dirt, it is often not sufficient for thorough cleaning.

Therefore, additional washing and brushing procedures may be required for more delicate or heavily soiled products. These further cleaning steps ensure that the fruits and vegetables meet hygiene standards before they are packaged and sent to market.

To maintain the cleanliness of the water used in the transport and washing stages, it is important to regularly renew the water.

This helps remove accumulated soil, pesticides, plant debris, and any rotting fruit or vegetable parts that may have been discarded during the washing process.

Water renewal not only prevents contamination but also ensures that the water remains effective in cleaning the products.

However, in some situations, such as in regions with limited access to water or in cases where large volumes of water cannot be easily evacuated, this step may be difficult to implement.

If water is recirculated in the system, it must be adequately filtered to remove any particles that might accumulate.

Contaminants such as dirt, bacteria, or fungal spores can negatively impact the quality of the produce and pose a risk of contamination to healthy products.

In addition, it is recommended to add chlorine to the washing and transport water at a concentration level of 50-200 ppm of active chlorine.

This addition helps eliminate fungal spores, bacteria, and other harmful microorganisms on the surface of the produce, further reducing the potential for contamination and ensuring the fruits remain safe for consumption. Chlorine treatment also contributes to extending shelf life by preventing the growth of spoilage organisms during transport and storage.

In addition to maintaining clean water and using appropriate chemicals, it is vital to minimize the impact of collisions between fruits during the washing and transport process. Collisions can lead to bruising and provide points of entry for pathogens, increasing the risk of contamination.

The movement of the fruits should be as gentle as possible to avoid mechanical damage and to reduce the possibility of infection from the damaged areas.

Water temperature also plays an important role in the reception process. If water is applied too forcefully or at an incorrect temperature, there is a risk of water infiltration into the fruit, which can damage its texture, affect its taste, and accelerate the deterioration process.

To minimize this risk, it is recommended that the temperature of the fruit be, on average, 5°C lower than that of the water used for washing and transportation.

This temperature differential helps prevent the fruit from absorbing water and undergoing unwanted changes in quality.

Proper temperature control during the washing process also helps to maintain the integrity of the products, ensuring they remain fresh and marketable.

4.Removal of Unwanted Plant Parts

The removal of unwanted plant parts is a crucial step that typically follows the soaking process in the post-harvest handling sequence.

This operation is essential for improving the overall quality of the product, as processing non-marketable materials can be both costly and inefficient.

The goal is to eliminate elements that do not meet market standards, ensuring that the final product is as uniform and appealing as possible.

This operation is performed before sizing and sorting, as it significantly facilitates these subsequent steps by reducing the number of unwanted components and contributing to the overall uniformity of the product.

This step complements the initial selection made in the field and focuses on removing non-marketable parts, such as those that are overripe, too small, deformed, seriously damaged, or rotten.

This is important because it ensures that only the best products are sent for further processing, packaging, and eventual sale, thereby reducing waste and improving the efficiency of the handling process.

The removal of such unwanted parts contributes to a higher-quality end product that meets market requirements.

In the case of smaller elements, mechanical methods are often used to eliminate them. For example, nets or mesh screens, along with belts, can help separate the smaller, non-marketable items from the desirable produce.

For items that are visibly damaged or rotten, pre-calibration chains are employed to remove them before they can enter the next stage of processing.

On the other hand, elements that do not conform to size standards or those exhibiting non-standard shapes, dried leaves, or yellowed plant parts are usually removed by hand. This manual sorting ensures that only the best-quality produce proceeds to the next stage.

For many crops, brushing is used as an additional step to remove dirt and debris. Brushing helps clean the fruits or vegetables and makes them more presentable for market, further enhancing their appeal.

For products that can tolerate immersion in water, a differential flotation system is often used to separate the undesirable plant parts.

This system takes advantage of the fact that certain plant parts have different densities, allowing the non-marketable items to float while the better-quality produce sinks. The flotation method can be combined with the use of detergents and brushes to thoroughly remove dirt, latex, insects, pesticides, and other contaminants.

This multi-step cleaning approach ensures that the produce is as clean and free from impurities as possible.

Once cleaned, fresh fruits and vegetables must be dried to prevent excess moisture from compromising their quality and shelf life. For drying, sponges or hot air are typically used to absorb or evaporate the remaining water, depending on the type of product.

Drying is an essential step, particularly for fruits that are sensitive to moisture, as it helps to maintain their texture, flavor, and overall quality.

The materials that are removed during this operation, such as discarded fruits, plant residues, and spoiled items, do not go to waste.

These by-products can be repurposed for various uses, the most common of which is animal feed.

Despite being flavorful and a good source of energy, the high water content of these discarded materials makes them bulky and difficult to transport, adding to their cost.

Moreover, their relatively low protein and dry matter content means their nutritional value is not as high as other types of feed, so their integration into an animal's diet must be carefully managed to avoid digestive issues.

Another challenge with discarded plant materials is their perishability. Since many of these residues are highly perishable, they cannot be stored for long periods, which complicates their use as animal feed.

They must be integrated into the animal diet soon after removal, and careful planning is necessary to ensure they do not spoil before use.

However, if these discarded materials are not utilized as animal feed, they can serve other purposes.

For instance, they may be used as sanitary bedding for animals, particularly when they are clean and free from harmful chemicals.

Alternatively, they can be composted and turned into organic fertilizer, providing valuable nutrients for future crops.

In some cases, these by-products are even burned to generate energy in the form of biogas or alcohol, making them an eco-friendly resource.

5.Sizing by Size and Weight

Sizing by size and weight is a critical operation in packing facilities, conducted before or after the sorting process based on the product's color.

This step ensures that products are grouped according to their uniformity, which plays a vital role in the efficiency of later stages of processing and packaging. It is often recommended to carry out the sizing before the final sorting to allow for easier identification and removal of defective elements.

Uniformity in size or color allows for better handling and improved presentation, which is essential for market acceptance.

The two main methods for sizing are based on either the product's weight or its dimensions, such as diameter, length, or both.

These approaches ensure that the produce meets the specific market standards for presentation and packaging.

For example, spherical or nearly spherical products like grapefruits, oranges, and other citrus fruits are typically easier to size, as their round shape allows for the use of a variety of specialized tools and mechanisms.

One common approach to size these fruits involves using mesh screens or nets, which can separate products by their size and weight.

These nets allow the fruits to be passed through varying gaps or spaces, progressively separating them into different categories based on their dimensions.

Another tool frequently used for sizing spherical fruits is diverging belts.

These belts are designed to gradually increase the space between the belts as the products move along the conveyor system, allowing for the sorting of fruits by size as they pass through.

Progressive gap rollers are also employed in some packing facilities, providing a similar function to the diverging belts.

These rollers increase the gaps between them as the products move forward, effectively sorting them by size.

Additionally, some facilities may use manual methods for sizing. One such method is the use of diameter rings, which are used to measure the diameter of individual fruits. This method is often employed when the mechanical systems are not available or when the desired precision is difficult to achieve with automated machinery.

For many crops, particularly those that vary in weight rather than shape, weight-based selection is preferred. In this case, packing facilities use weighing trays to automatically weigh each product as it passes through the system. These trays are typically linked to automated mechanisms that sort the products based on their weight, depositing them onto different belts according to their weight category.

This method allows for precise grouping of items, ensuring that each batch meets the weight standards set by the market.

Both size and weight-based sorting systems are designed to ensure that the produce is handled efficiently, with minimal damage and waste.

They also help to streamline the packing process, as uniform products are easier to package and display in an appealing manner.

When these operations are properly executed, they enhance the marketability of the products by ensuring consistent quality and appearance.

The end result is a more efficient packing operation, reduced waste, and improved customer satisfaction, as the produce reaches the market in optimal condition.

6. Final Sizing

Final sizing is a crucial stage in the post-harvest process where harvested products are sorted and categorized based on specific criteria such as size, quality, and market requirements.

This step plays a key role in ensuring that only those products which meet the predefined standards are distributed to consumers or sent for further processing.

By separating the produce into distinct categories, producers are able to maximize profitability, optimize the use of resources, and minimize waste.

It is particularly important for maintaining market competitiveness, especially in industries where product quality is a major factor in consumer choice.

The final sizing process helps ensure that products are consistent in appearance and meet the expectations of consumers, retailers, or processors, thus enhancing the overall marketability of the harvest.

In industries such as fresh produce, where appearance and size are often prioritized, effective sizing can be the difference between a product that successfully reaches the consumer and one that is rejected due to non-compliance with market standards.

There are two primary systems used for final sizing: mechanical sizing and manual sizing. Mechanical sizing is typically employed in larger-scale operations and is well-suited for crops with uniform characteristics.

It uses machines that sort the produce based on size, weight, or other factors, which increases efficiency and consistency.

On the other hand, manual sizing is often used for crops that require more careful handling or for operations where precision is key.

It allows for closer inspection of each individual product, ensuring that it meets the specific quality standards expected in the market. Both systems have their advantages and are selected based on the scale of the operation, the specific crop, and the quality requirements of the target market.

6.1. Static System

The static sizing system is tailored for handling delicate and high-value crops that require careful treatment to avoid damage. In this method, products are placed on a stationary selection table, where trained sorters meticulously inspect each item.

Items that fail to meet the size or quality standards whether due to imperfections, irregular sizes, or other defects are manually removed.

This system offers several advantages:

- **Precision and Care**: Since the process is manual, sorters can carefully assess each product, making it ideal for fragile items such as berries, premium-grade fruits, or high-value vegetables.
- **Minimal Damage**: The absence of mechanical movement reduces the risk of bruising or other forms of damage during the sorting process.

However, the static system also comes with notable limitations:

- **Labor-Intensive**: Sorting by hand requires significant human effort, making it a time-consuming process.
- **Limited Volume**: Due to its slow pace, this system is best suited for smaller batches of produce.

Despite these drawbacks, the static system remains indispensable in situations where maintaining the integrity of the product is of utmost importance, such as for high-end markets or export-quality goods.

6.2. Dynamic System

The dynamic sizing system is designed to handle larger volumes with greater efficiency. Products are transported on a conveyor belt, moving in a continuous flow past trained workers who rapidly sort and remove defective items.

This system is widely used in industrial-scale operations where speed and efficiency are critical.

Several key aspects define the dynamic system:

- **Main Flow and Sorting**:

The conveyor's primary flow contains the highest-quality items, which meet all the required standards. Lower-quality items, such as second and third grades, are diverted onto separate belts for alternative uses.

- **Efficiency Through Automation**:

The integration of conveyor belts significantly increases the speed of sorting, allowing producers to handle large volumes of produce in a short period.

While the dynamic system excels in processing capacity, it presents unique challenges:

- **Worker Training and Speed**:

Workers must be highly trained to make accurate sorting decisions, as each item remains in their field of vision for only a few seconds. This demands sharp focus and quick reflexes to identify and remove defective products.

- **Error Risks**:

Two types of errors are common in this system:

  - **False Rejection**: High-quality products are mistakenly removed, reducing the overall yield of premium items.
  - **Missed Defects**: Defective items may not be identified and removed, compromising the quality of the final batch.

Rejected items, often downgraded for cosmetic reasons, are typically categorized as second- or third-choice products. These can still have value through:

- **Alternative Markets**:

They can be sold to retailers or consumers who are less concerned about appearance.

- **Processing Uses**:

These items can serve as raw materials for juices, purees, or other processed goods, extending their shelf life and adding economic value.

Challenges in Processing Low-Quality Products

Despite the potential to repurpose lower-grade products, small-scale processing operations face significant challenges.

Unlike large industrial processors, smaller operations often struggle to maintain quality, consistency, and profitability due to several factors:

- **Inconsistent Raw Materials**:

Products from secondary markets, such as unsold or defective produce, often lack uniformity in size, shape, and quality. This variability makes it difficult to achieve consistent processing outcomes.

- **Limited Technology**:

  Small-scale processors may lack access to advanced machinery and techniques used in industrial settings, resulting in lower yields and reduced product quality.
- **Stringent Health Standards**:

  Processed goods must comply with strict health and safety regulations, which can be difficult to achieve without the specialized tools and expertise available to large-scale producers.

To remain competitive, small-scale processors must aim to produce goods of equal or superior quality compared to industrially processed items.

Achieving this often requires innovative approaches to processing, careful selection of raw materials, and an emphasis on quality control.

Quality Considerations

The quality of a processed product is determined by two critical factors:

- **Raw Material Quality**: High-quality raw materials provide a strong foundation for processing. Freshness, uniformity, and lack of defects are essential to producing premium goods.
- **Transformation Process**: The methods used to process the raw materials must preserve or enhance their inherent qualities. This includes maintaining nutritional value, texture, and flavor.

By focusing on these two factors, producers can optimize the value of all product categories. High-quality items meet the demands of discerning markets, while lower-grade products can be repurposed effectively to minimize waste and increase profitability.

In conclusion, final sizing is an essential step in post-harvest management. Whether using static or dynamic systems, the goal is to ensure that products are categorized and utilized to their fullest potential.

With the right strategies and technologies, producers can achieve a balance between efficiency, quality, and sustainability, meeting market demands while maximizing economic returns.

7. Special Operations

Special operations refer to post-harvest procedures tailored to products that require packaging, differing from basic operations that apply universally to all crops regardless of the packing facility's complexity.

These operations are critical for maintaining quality, extending shelf life, and ensuring products meet market expectations.

7.1. Color Sorting

Color sorting is a common practice for fruits and involves standardizing the degree of ripeness to create a consistent appearance for sale.
This operation can be performed manually or electronically, depending on the scale of the operation and the level of technological investment.

- **Ripeness Management**: Fruits are often harvested at varying stages of ripeness, which necessitates sorting to ensure uniformity. For large-scale operations, electronic color sorters use advanced imaging technology to detect and sort fruits based on color variations, ensuring precision and efficiency.
- **Impact of Harvest Timing**: Harvesting fruits at a less ripe stage simplifies the color sorting process as fewer variations in color exist. However, this practice is only feasible for small volumes of produce because it may require multiple harvest cycles, increasing labor and operational costs.
- **Consumer Perception**: Consistently colored fruits enhance visual appeal and consumer confidence, making this operation crucial for marketability, especially for premium and export products.

7.2. Waxing After Harvesting

Waxing is a specialized operation aimed at reducing dehydration and extending the shelf life of certain fruits and vegetables, such as apples, cucumbers, citrus fruits, peaches, and nectarines.
This process not only preserves the product's freshness but also improves its aesthetic appeal.

- **Purpose of Waxing**:
  Washing during post-harvest handling often removes natural waxes that protect fruits from moisture loss.
  Artificial wax coatings replace these, sealing minor injuries and serving as a barrier against dehydration.
- **Enhanced Functions**:
  Wax formulations can act as carriers for fungicides, preventing fungal growth during storage and transportation.
  Additionally, waxes improve shine, making the products more visually attractive to consumers.
- **Application Methods**: Waxes can be applied through various methods, including spraying, foaming, or immersion.
  To ensure uniform application, soft brushes or rollers are used to spread the wax evenly across the fruit's surface.

- **Precautions**: Over-application of wax can hinder the fruit's ability to "breathe" by obstructing gas exchange, leading to tissue asphyxiation, internal darkening, and the development of unpleasant odors and flavors.

  To prevent such issues, precise application techniques and the use of food-safe waxes are essential.

7.3. De-Greening

De-greening is a process designed to enhance the visual appeal of citrus fruits by breaking down chlorophyll, allowing natural pigments to become more visible.

This operation is particularly important when climatic conditions during the growing season result in fruits with greenish skin despite being fully mature.

- **Consumer Expectations**:

  Even though green-tinged fruits are as ripe and flavorful as fully colored ones, consumers often associate green skin with immaturity and inferior taste, making de-greening essential for market acceptance.
- **Process Details**: De-greening is conducted in specialized chambers where fruits are exposed to ethylene gas (5–10 ppm) for 24 to 72 hours under controlled conditions. Key parameters include:
  - **Temperature**: Optimal temperatures vary by fruit type, such as 25–26 °C for oranges, 22–24 °C for grapefruits and lemons, and 20–23 °C for mandarins.
  - **Humidity**: High relative humidity (90–95%) prevents dehydration during the process.
  - **Ventilation**:

Proper air circulation ensures even exposure to ethylene and prevents gas accumulation.

- **Regional Variations**:

  De-greening conditions may be adjusted based on local production practices and fruit varieties to achieve the best results.

7.4. Controlled Ripening

Controlled ripening ensures that fruits reach the desired level of maturity and quality before being distributed to markets. This operation is especially crucial for climacteric fruits, which continue to ripen after being harvested.

- **Harvesting for Transport**:

  To withstand the rigors of transportation to distant markets, fruits like bananas, tomatoes, melons, avocados, and mangoes are often harvested slightly unripe.

  This reduces damage and spoilage during transit.

- **Ripening Process**:

  Before sale, these fruits are subjected to controlled ripening to achieve uniform maturity and enhance their flavor, texture, and color.

  This process is carried out in specialized ripening rooms equipped with systems for temperature, humidity, and ethylene control.

  - **Heating and Ethylene Application**:

    Fruits are initially heated to the desired temperature, after which ethylene is introduced at a higher concentration compared to de-greening.

    This accelerates the natural ripening process.
  - **Ventilation**:

    Once the ripening process is complete, the chamber is ventilated to remove accumulated ethylene and other gases.
  - **Final Cooling**:

    The temperature is then lowered to prepare the fruits for transportation or storage, ensuring they remain fresh until they reach consumers.
- **Key Variables**:

The ethylene concentration, exposure time, and temperature are carefully calibrated to achieve optimal ripening without compromising the fruit’s quality.

Higher temperatures expedite the process but require precise monitoring to avoid over-ripening.

Importance of Special Operations

Special operations like color sorting, waxing, de-greening, and controlled ripening are integral to modern agricultural supply chains.

They address consumer preferences, enhance product shelf life, and enable efficient distribution across global markets.

By implementing these operations, producers can:

- Meet market demands for visually appealing, high-quality products.
- Reduce post-harvest losses through improved preservation techniques.
- Add value to products, enabling them to compete in premium and export markets.

However, these operations require significant investment in technology, infrastructure, and training. Producers must also adhere to food safety regulations and ensure the use of safe materials and methods throughout the process.

When executed correctly, these special operations not only enhance product quality but also contribute to the sustainability and profitability of agricultural enterprises.

Table 2. Conditions for Controlling the Ripening of Certain Fruits

Fruit	Concentration of ethylene (ppm)	Température de mûrissement °C	Duration of exposure at these conditions (in hours)
Avocado	10-100	15-18	12-48
Banana	100-150	15-18	24
Winter Melon	100-150	20-25	18-24
Kiwi	10-100	0-20	12-24
Mango	100-150	20-22	12-24
Stone Fruits	10-100	13-25	12-72
Tomato	100-150	20-25	24-48

7.5. Pest and Disease Control

Post-harvest pest and disease control is vital to ensuring the quality, safety, and marketability of fresh produce.

Various treatments are applied to prevent or manage the risks associated with pests and diseases that can develop after harvest. These methods, which include fungicides, fumigation, and other chemical applications, are tailored to the specific needs of different fruits and vegetables.

7.5.1.Fungicide Applications

Fungicides play a critical role in reducing post-harvest losses due to fungal infections.

They are commonly used on citrus fruits, apples, bananas, stone fruits, and other fresh produce.

- **Fungistatic Properties**: Most fungicides have fungistatic action, which inhibits or reduces spore germination and fungal growth without completely eradicating the disease.
- **Antifungal Agents**: True antifungal chemicals are rare and are typically reserved for specific, severe infections.

- **Common Chemicals**:
  - **Chlorine**: Widely used as a disinfectant in water, chlorine is effective at concentrations of 50–200 ppm for reducing microorganisms on fruit surfaces. However, it does not prevent the growth of pathogens already established within the fruit.
  - **Sulfur Dioxide**: In table grape production, sulfur dioxide is used to control fungal growth. Grapes are fumigated with a concentrated solution (0.5%) for 20 minutes, followed by ventilation. To maintain quality during storage, periodic fumigations (every 7–10 days) at 0.25% are conducted. Sodium metabisulfite pads placed in cartons during transport gradually release sulfur dioxide, offering continued protection.

7.5.2.Fumigation Techniques

Fumigation is a highly effective method for eradicating insects, including adults, eggs, larvae, and pupae, which can infest produce.

- **Methyl Bromide**: Previously a widely used fumigant, methyl bromide was effective but has been banned in many countries due to its harmful environmental impact.
- **Alternatives to Methyl Bromide**:
  - **Temperature Treatments**: Using heat or cold to eliminate pests.
  - **Controlled Atmosphere Storage**: Modifying oxygen and carbon dioxide levels in storage environments to suppress pests.
  - **Other Fumigants**: Newer chemical options are being developed to replace methyl bromide.
  - **Irradiation**: The use of ionizing radiation to kill pests is gaining acceptance as an environmentally friendly alternative.

7.5.3.Preventing Physiological Disorders

Post-harvest physiological issues, such as bruising and internal breakdown, can also be managed through chemical treatments.

- **Calcium Chloride Baths**: Immersing fruits in calcium chloride solutions (4–6%) strengthens cell walls, making them less susceptible to damage.
- **Heat Damage Prevention**: Chemical dips can protect fruits from damage caused by prolonged storage at high temperatures.
- **Targeted Sprays**: Specific sprays, such as those targeting apple worms, provide additional protection against pests.

7.6. Temperature Treatments

Temperature treatments are a versatile and effective method for pest control and quality preservation.

Both heat and cold are used, depending on the product and its tolerance levels.

7.6.1.Cold Treatments

Cold treatments are particularly effective for fruits that can tolerate low temperatures, such as apples, pears, kiwis, and table grapes. Cold storage helps manage pests like insects and larvae while extending shelf life.

7.6.2.Heat Treatments

Heat treatments are used for fruits and vegetables to eliminate pests, including harmful insects and fungi. The process involves exposing the produce to hot water, hot air, or steam.

- **Hot Water Immersion**: Fruits are immersed in water at a temperature of 43–46.7 °C for 35–90 minutes. This helps reduce microbial mass and control pests in products such as plums, peaches, papayas, melons, and tomatoes.
- **Hot Air and Steam**: Tropical fruits like mangoes, grapefruits, and papayas are often exposed to hot air (40–50 °C) or steam for extended periods. This effectively destroys pests while maintaining fruit quality.

Precautions

Temperature treatments must be applied carefully to avoid damage, such as heat bruising, especially in perishable products. After treatment, temperatures must be reduced promptly to levels suitable for storage and transportation.

7.7. Gas Treatments for Preservation

Gas treatments are another innovative method for preserving produce and managing pests. By manipulating atmospheric composition, it is possible to extend shelf life and control insects without relying on chemical fumigants.

7.7.1.Carbon Dioxide-Rich Atmospheres

Studies show that exposure to carbon dioxide-rich atmospheres (10–40%) for up to a week can preserve the quality of grapefruits, clementines, avocados, nectarines, and peaches.

- **Insect Control**:

  At higher concentrations (60–100%), carbon dioxide is effective against pests at all life stages.
- **Metabolic Effects**:

  Carbon dioxide inhibits respiration and ethylene action, slowing down ripening and decay. It also suppresses spore germination and the growth of microorganisms.

7.7.2.Low-Oxygen Atmospheres

Reducing oxygen levels to less than 1% helps maintain the quality of oranges, nectarines, papayas, apples, cherries, and peaches.

- **Respiration Suppression**:
  Low oxygen slows down metabolic processes, including ethylene synthesis, which delays ripening and extends shelf life.
- **Enzyme Activity**:
  Reduced oxygen also lowers the rate of enzymatic reactions, helping to preserve texture and flavor.

8. Packaging Material Requirements

Effective packaging plays a crucial role in preserving product quality, ensuring safety, and maintaining marketability.

To achieve these goals, packaging must be meticulously designed to address the specific needs of the product and the conditions it will face during its lifecycle.

Several essential factors guide the selection and design of packaging materials:

8.1. Adaptability to Product Characteristics

- **Moisture Resistance**

For products that require cooling with water or ice during storage or transportation, packaging materials must be able to resist moisture without compromising their protective properties. Materials that degrade or weaken when exposed to moisture can lead to product spoilage or damage.

- **Gas Exchange**

Fresh produce, particularly fruits and vegetables with high respiration rates, requires packaging that allows for adequate ventilation.

Proper gas exchange prevents the accumulation of gases such as carbon dioxide and reduces the risk of anaerobic conditions, which can lead to rapid quality degradation or unpleasant odors.

- **Water Retention**

Products prone to dehydration need packaging designed to minimize moisture loss. Effective water barriers help maintain freshness, weight, and visual appeal, ensuring the product reaches the consumer in optimal condition.

- **Atmosphere Modification**

Advanced packaging materials, such as semi-permeable films, enable the creation of a **modified atmosphere** within the package.

This specialized environment serves multiple purposes :

- **Respiration Control**:

Reducing oxygen levels slows down the respiration and metabolic processes of the product, extending its freshness.

- **Ripening and Senescence Delay**:

Controlled levels of gases, like oxygen and carbon dioxide, help delay ripening and reduce the onset of senescence.

- **Extended Shelf Life**:

By maintaining a balanced atmosphere, these materials contribute to preserving the product's freshness, texture, and nutritional value for longer periods.

8.2..Durability and Strength

Packaging materials must be robust and resilient to withstand the challenges of handling, stacking, and transportation.

This includes:

- **Crush Resistance**:

Ensuring the packaging can endure stacking during storage or transit without collapsing or damaging the product.

- **Impact Resistance**:

Protecting the product from damage caused by drops, vibrations, or rough handling.

Well-designed packaging minimizes product loss, enhances safety, and ensures that goods arrive intact at their final destination.

Sustainability Considerations

The global shift towards environmental responsibility has placed sustainability at the forefront of packaging design. Modern packaging solutions increasingly focus on:

- **Biodegradable Materials**:

Utilizing materials that break down naturally, reducing long-term environmental impact.

- **Recyclable Options**:

Encouraging reuse and recycling to reduce waste and support circular economies.

- **Reusable Packaging**:

Designing durable containers that can be used multiple times, reducing overall material consumption.

Sustainable packaging not only minimizes ecological harm but also resonates with environmentally conscious consumers, offering producers a competitive advantage in the marketplace.

8.3. Categories of Packaging

Packaging is a critical component in the post-harvest handling and distribution of agricultural products.

It serves to protect, contain, and present the product while facilitating its transport and storage.

The various types of packaging are categorized based on their intended use and functionality.

8.3.1. Consumer Units or Pre-Packaging

Consumer units, also referred to as pre-packaging, are designed for products that are weighed, packaged, and delivered directly to the consumer in the same container.

Typically, these packages are intended to hold quantities that suit household consumption over a given period, ranging from 300 grams to 1.5 kilograms, depending on the product.

- **Materials Used**:

  Common materials include molded paper pulp, polystyrene trays coated with shrink-wrap film, plastic or paper bags, thermoformed PVC trays, and clamshell containers.
- **Visual Appeal**:

  The choice of material's color, shape, and texture plays a vital role in enhancing the product's visual appeal, making it more attractive to consumers.
- **Convenience**:

  These packages are lightweight, easy to handle, and provide essential product information, such as weight, variety, and nutritional details, directly to the consumer.

8.3.2. Transportation Packaging

Transportation packaging is primarily designed for bulk handling, storage, and shipping, ensuring that the products remain protected throughout the distribution chain.

- **Typical Containers**:

  Commonly used materials include fiberboard or wooden boxes, large sacks, and crates capable of holding 5 to 20 kilograms or more.
- **Handling Features**:

  These packages are designed for ease of handling, stacking, and transport by a single person or machinery.
- **Durability**:

  They must withstand the stresses of transportation and handling while securely containing the products without risk of overflow.
- **Immobilization and Insulation**:

- **Dividers**:

  Vertical dividers are often included to reinforce the container and protect larger items like melons and watermelons.
- **Trays**:

  Used for separating layers of smaller fruits such as apples, peaches, and plums.
- **Individual Protection**:

  Products like mangoes, papayas, and watermelons may be wrapped in foam nets for additional cushioning. Wool, paper, or other flexible materials are also employed for this purpose.

- **Sustainability Considerations**:
  - Reusable packaging should be easy to clean and disassemble for compact return transport.
  - Materials should be biodegradable, recyclable, and non-contaminating to minimize environmental impact.

8.3.3. Packaging by Measurement Units or Pallets

Palletization is the most efficient and widely adopted method for unitizing loads in both domestic and international markets.

It facilitates seamless integration across transport, storage, and distribution systems.

- **Standardized Dimensions**:
  - The most commonly used pallet size is 120 x 100 cm, compatible with shipping containers, trucks, forklifts, and warehouses.
  - Packaging dimensions are standardized to optimize pallet surface usage. ISO standards specify base dimensions of 60 x 40 cm, further divided into subunits of 40 x 30 cm and 30 x 20 cm.
- **Capacity and Stability**:
  - Pallets can hold 20 to 100 individual packages, depending on their size and arrangement.
  - Stability is ensured using plastic nets, protective corner systems, horizontal and vertical straps, or weak adhesives that prevent packages from slipping but allow easy separation. Packages are often arranged diagonally or nested to maximize load stability.
- **Height and Weight Considerations**:
  - While there are no strict rules for individual package height, the total pallet load height should not exceed 2.05 meters to facilitate handling and storage.
- **Environmental Impact**:
  - Non-returnable containers pose significant environmental challenges. To address these, packaging design should aim for recyclability and reusability.

- Materials must balance durability with sustainability, ensuring they can be effectively recovered and reused after their initial lifecycle.

Course 3: Fruit storage

1.The Need for Storage

In temperate regions, a significant portion of the annual fruit and vegetable production is seasonal, with peak harvests during certain times of the year.

However, consumer demand for fresh produce remains constant throughout the year. To address this imbalance, storage becomes an essential practice to ensure a consistent supply of fresh products, even when they are not in season.

- **Strategic Importance**:

  Storage is also employed as a strategy to achieve better profits.

  By storing products until there is a temporary or partial shortage, producers can take advantage of higher prices when supply is low.

- **Product Perishability**:

  The storage period depends largely on the intrinsic characteristics of each product and its level of perishability.

  Some products, like raspberries and other berries, have a very short shelf life and require immediate consumption or processing.

  On the other hand, certain fruits and vegetables, such as pumpkins and root vegetables, are naturally more suited for longer-term storage.

- **Optimal Storage Conditions**:

  The optimal storage conditions vary significantly depending on the product. For instance, most tropical fruits, such as bananas and mangos, are sensitive to cold and should not be exposed to temperatures below 10°C.

  Proper temperature regulation is crucial to prevent spoilage, and certain products may require higher humidity or specific atmospheric conditions for optimal storage.

- **Storage Space Considerations**:

  To maintain the integrity of the product, it is recommended to store only one type of product in the same storage room unless the storage duration is very short.

  Storing multiple types of products together can result in incompatibilities in temperature and relative humidity levels.

  Additionally, this can lead to exposure to ethylene from certain fruits, causing premature ripening in sensitive items.

  Furthermore, odors from one product can contaminate another, further diminishing product quality and shelf life.

2. General Requirements for Storage Warehouses

Storage warehouses are often located in conjunction with packaging facilities or centralized distribution points where products are collected.

In some cases, especially in remote or rural areas, storage may occur at the production site itself, either naturally or in purpose-built sheds designed for short-term preservation.

The efficiency of storage operations depends on several factors, including the physical characteristics of the warehouse, its location, and the environmental conditions surrounding it.

- **Impact of Location**:

The geographic location of the warehouse significantly influences its efficiency. For example, altitude plays a vital role in temperature regulation.

For every 1,000 meters of elevation, the temperature drops by approximately 10°C, which provides a cooler environment for the storage of perishables.

This helps reduce the energy consumption required for refrigeration by improving the heat exchange between the interior of the warehouse and the ambient temperature.

- **Shading and Temperature Control**:

Shading, particularly in areas used for loading and unloading, helps mitigate temperature fluctuations inside the warehouse.

This minimizes the stress on refrigeration systems, maintaining a more stable internal environment and reducing energy consumption.

- **Warehouse Design and Efficiency**:

The design of the storage facility is crucial to maximizing its efficiency. For example, a warehouse with a square-shaped floor plan has better thermal efficiency than a rectangular one, as it allows for more uniform temperature distribution.

The roof is one of the most important aspects of the warehouse structure as it protects the stored products from exposure to rain, extreme heat, and UV rays.

The roof's slope should facilitate easy drainage of rainwater, and its dimensions should extend beyond the building's perimeter to shield the walls from the sun and provide a dry environment during rainfall.

- **Floor and Wall Construction**:

Floors in storage warehouses should be made of cement or another durable material that isolates the products from ground moisture.

The floors should be elevated slightly to prevent water ingress, which can lead to product deterioration. Additionally, the walls of the warehouse must be strong enough to support the weight of stacked products without compromising the structural integrity of the building.

- **Door Design**:

  The doors of the warehouse must be large enough to accommodate mechanical handling equipment and allow for easy movement of products in and out of the facility.

  These doors should also be sealed properly to prevent the entry of pests such as rodents, insects, birds, or pets, which can introduce contamination and diseases into the stored products.

- **Cleaning and Maintenance**:

  Prior to the arrival of new shipments, the warehouse must be thoroughly cleaned to remove dust, organic debris, and potential contaminants that could encourage the proliferation of pests and diseases.

  This process involves scrubbing the walls and floors and ensuring that the entire space is free from any harmful residues.

- **Product Inspection and Sorting**:

  Before entering storage, products should undergo a pre-sorting process to eliminate any damaged or spoiled items, preventing contamination of healthy products.

  A detailed inspection should be performed to ensure that only products that meet quality standards are stored.

- **Product Organization**:

  Proper stacking techniques are essential for maintaining air circulation around the stored products.

  This ensures that each product is kept at an optimal temperature and humidity level, which is critical for preserving its freshness and quality.

  During long harvest periods when the warehouse may be filled with multiple batches of products, the "first in, first out" (FIFO) principle should be implemented.

  This ensures that older products are used or sold first to minimize the risk of spoilage or waste.

Table 3. Recommended temperature and humidity for fruits and storage time based on these conditions

Product	Temperature (°C)	Humidity Rate (%)	Storage Period (Days)
Apricot	-0,5-0	90-95	7-21
Pineapple	7-13	85-90	14-28
Avocado	3-13	85-90	14-56
Banana	13-15	90-95	7-28
Cantaloupe (half)	2-5	95	15
Cantaloupe (whole)	0-2	85-90	5-14
Cherry	1-0,5	85-90	14-21
Lemon	10-13	85-90	30-180
Pumpkin	10-15	50-70	60-160
Date	-18-0	75	180-360
Fig	-0,5-0	85-90	7-10
Prickly pear	2-4	90-95	21
Strawberry	0-0,5	90-95	5-7
Raspberry	-0,5-0	90-95	2-3
Pomegranate	5	90-95	60-90
Persimmon	-1	90	90-120
Lime	9-10	85-90	42-56
Mandarin	4-7	90-95	14-28
Melon (other types)	7-10	90-95	12-21
Blackberry	-0,5-0	90-95	2-3
Nectarine	-0,5-0	90-95	14-28
Japanese Medlar	0	90	21
Olives	5-10	85-90	28-42
Orange	0-9	85-90	56-84
Grapefruit	10-15	85-90	42-56
Watermelon	10-15	90	14-21
Peach	-0,5-0	90-95	14-28
Pear	-1,5-0,5	90-95	60-210

Apple	-1-4	90-95	30-180
Plum	-0,5-0	90-95	14-35
Grape	-0,5-0	90-95	14-56
Tomato (Green)	12,5-15	90-95	14-21
Tomato (Red)	8-10	90-95	8-10
Cherry Tomato	3-4	85-90	21-28

3. Storage systems

Storage systems are critical for preserving the quality and extending the shelf life of harvested agricultural products.

Each product can be stored using different methods, with the storage duration being significantly extended when specific structures are used, especially when refrigeration or controlled atmosphere systems are incorporated.

3.1. Natural or "field" storage

is one of the most basic and traditional methods of preserving agricultural products. It is commonly employed for root vegetables like carrots, sweet potatoes, and cassava, as well as tubers such as potatoes.

In this system, these products are often left in the ground until they are ready for the market. Similarly, some fruits, such as citrus, are left to ripen on the tree.

While this storage method is economical, it exposes the produce to the risk of pests, diseases, and adverse weather conditions, all of which can significantly degrade the quality of the stored goods.

A variation of this system involves stacking products in piles, isolating them from moisture by using tarps, straw, or plastic coverings to protect them from the elements.

This technique is especially useful for bulky crops like potatoes, onions, and pumpkins, reducing handling costs.

A more recent approach involves using crates for storage in the field. In this case, two crates are stacked one on top of the other, with the upper crate being shielded from the weather, which not only provides protection but also simplifies handling when it is time for harvesting or transportation.

3.2. Natural ventilation systems

are another commonly used method for storing agricultural products.

This system leverages the natural circulation of air to remove the heat and moisture produced by the respiration of the stored items.

Any structure that offers protection from external elements and allows for the free flow of air can be used for this type of storage.

The products can be stored in bulk, in bags, boxes, crates, or pallets, depending on the specific needs of the product and storage space.

While simple, natural ventilation systems require careful consideration to ensure effective operation.

The internal temperature and humidity of the storage area are often similar to those outside, making this method suitable only for crops that can thrive in the natural environmental conditions.

Additionally, the storage area must be designed with large openings for proper airflow while preventing the entry of animals, rodents, and harmful insects.

Efficient airflow is essential for removing the heat and gases produced by respiration; however, if the products are stored too compactly, air circulation will be insufficient, which can lead to overheating and moisture buildup.

To mitigate this, periodic adjustments to the ventilation can be made based on external conditions.

For example, the building can be opened when the outside temperature is cooler, typically in the early morning or late evening, and closed when the temperature rises during the day. Proper management of these conditions requires the use of electronic temperature and humidity detectors to monitor and adjust the storage environment, ensuring that the products are kept in optimal conditions. In some cases, additional ventilation may be necessary outside of the regular ventilation schedule to maintain the desired environment.

While this system works well for products with low respiration rates, its effectiveness depends on careful management and the ability to respond quickly to changing external conditions.

3.3. Forced Air Ventilation

Forced air ventilation is an important technique used to enhance the exchange of heat and gases within storage environments.

By circulating air around and among stored products, this system offers a significant advantage over relying solely on natural temperature variations.

Forced air systems allow for more controlled and uniform temperature distribution, ensuring that stored products maintain their quality over a longer period.

- **Improved Space Utilization**:

  One of the key benefits of forced air ventilation is its ability to optimize space for bulk storage.

  This is achieved by using air ducts that circulate beneath a perforated floor, which forces air through the stored products.

  The uniform air distribution depends on careful consideration of factors such as the arrangement of the products, ventilation capacity, and the dimensions of the ducts.

  If the air follows the shortest or least resistant path, certain areas of the storage may not receive adequate airflow, which can lead to inconsistent temperature control and potential spoilage of goods.

- **Adjustable Ducts for Maximized Efficiency**:

  Removable perforated ducts can be employed in the ventilation system to further enhance the efficient use of storage space.

  When the storage area is not in use, these ducts can be removed or adjusted to accommodate changes in storage needs.

- **Fan Selection**:

  The selection of fans plays a pivotal role in ensuring the effectiveness of forced air ventilation.

  This task requires specialized knowledge, as the fan system must be designed based on factors such as the volume of air needed, the number of air exchanges required per unit of time, and the respiration rates of the products being stored.

  Air resistance in the ducts, as well as static pressure, must also be taken into account to optimize the system's performance.

- **Control Systems**:

  Ideally, the forced air system should be controlled by sensors that regulate temperature and humidity based on both internal and external conditions.

  These sensors can adjust the air circulation as needed to maintain an optimal environment for storage.

  If the system is designed to be closed, it will circulate internal air only, while an open system replaces the internal atmosphere with external ventilation.

  Partial openings allow for a mix of internal and external air, which can help achieve the desired temperature and humidity balance.

3.4. Refrigeration

Refrigeration plays a crucial role in extending the shelf life of perishable products by controlling temperature.

Lower temperatures slow down the metabolic processes of the product, as well as the activity of microorganisms that contribute to spoilage.

As a result, refrigeration helps to maintain the product's reserves, reduces respiration rates, delays ripening, and minimizes water loss by reducing the vapor pressure deficit between the product and the surrounding air.

- **Maintaining Freshness**:

The combined effects of temperature control, reduced microbial activity, and slowed metabolic processes help preserve the freshness of products, ensuring that their nutritional value is retained.

The ultimate goal of refrigeration is to delay or prevent deterioration while preserving the quality and nutritional content of the stored goods.

- **Refrigerated Chambers**:

A refrigerated chamber is designed to be relatively airtight to prevent heat from entering. The thermally insulated walls, ceiling, and floors of the chamber must be able to effectively release the heat generated by the stored products to the outside.

The cooling capacity of the refrigeration equipment must be sufficient to remove heat from products with high respiration rates, while also accommodating any other sources of heat gain.

- **Temperature and Humidity Control**:

Precise control of both temperature and humidity is essential for maintaining an optimal storage environment.

The design of the refrigeration system, including the cooling capacity, is influenced by factors such as the type of products stored, their respiration rates, and external heat sources like door openings or mechanical equipment.

- **Storage Space Requirements**:

The refrigeration space must be large enough to accommodate both the products and the necessary aisles for the movement of equipment like forklifts.

It’s important to note that the total space occupied by the products may only be around 75-80% of the total area, with the remaining space required for cold air distribution and product handling.

- **Height Considerations**:

The height of the refrigeration chamber depends on the type of products and the stacking arrangement.

For manual stacking, a height of about three meters is usually sufficient, but when using forklifts or other mechanical equipment, a height of up to six meters may be necessary to allow for proper stacking and maneuverability.

- **Building Materials and Insulation**:

Refrigerated chambers can be constructed using a variety of materials, such as cement, metal, or wood. However, all external surfaces, including floors and ceilings, must provide effective thermal insulation to prevent heat exchange with the external environment.

The choice of insulation material, such as polyurethane, expanded polystyrene, or cork, should be based on the specific needs of the products being stored and the desired temperature conditions.

A vapor barrier must be placed on the warm side of the insulation to prevent condensation and moisture build-up.

- **Refrigeration System Components**:

The mechanical refrigeration system is composed of two main components: the evaporator, which is placed inside the storage area, and the condenser, which is located outside.

The two components are connected by refrigerant-filled coils, typically made of highly conductive materials like aluminum or copper.

The evaporator is designed with finned coils that are integrated with fans, which help distribute cold air throughout the chamber.

As warm air from the storage area passes through the evaporator, heat is absorbed by the refrigerant and carried away to the condenser, where it is released outside. This cycle continues, effectively pumping heat out of the storage area.

- **Refrigerant Types**:

Ammonia and Freon are commonly used refrigerants, though they are being phased out in favor of more environmentally friendly alternatives that have less toxic impact on the ozone layer and the environment.

The refrigeration system’s expansion valve regulates the flow of refrigerant, ensuring that the cooling process operates efficiently.

- **Maximizing Efficiency**:

The maximum benefit from refrigeration is achieved when the cooling capacity is carefully matched to the specific needs of the stored products.

In addition to removing the heat generated by product respiration, the system must account for heat gained through conductive and convective sources, such as the floors, walls, and ceiling, as well as heat from mechanical equipment used in the storage process.

- **Optimal Conditions for Different Products** :

Different products have different optimal temperature and humidity requirements for storage. In many cases, these needs can vary even between different varieties of the same product. Therefore, it is recommended to store only one type of product per room, except for short periods or during transportation.

Sharing storage space between incompatible products can result in temperature and humidity discrepancies, exposure to ethylene, odor contamination, and other factors that can negatively impact the quality and shelf life of the products.

Highly incompatible products should never be stored in the same room for more than a few days.

3.5. Pre-cooling

Pre-cooling is a vital process in the post-harvest handling of perishable products, ensuring that they reach and maintain an optimal storage temperature quickly.

While refrigeration systems are designed to maintain the product's cool temperature, they are not efficient at rapidly lowering the temperature of products that have just been harvested. The field temperature of the product is typically close to the surrounding environment and can be even higher if the product is exposed to direct sunlight, which accelerates the heat absorption.

- **Initial Temperature Challenge**:

When products are exposed to colder conditions after being harvested, they gradually lose their field temperature.

However, it may take anywhere from 24 to 48 hours for them to fully acclimate to the ambient temperature of the storage environment.

The rate at which the temperature decreases is influenced by factors such as the difference in temperature between the product and the surrounding air, the volume of the product, its total mass, and the cooling capacity of the refrigeration equipment.

- **Metabolic Impact**:

The metabolic activity of the product (including respiration, ethylene production, and enzymatic processes) significantly decreases with a reduction in temperature.

The quicker this cooling process is initiated, the less energy, reserves, and quality will be lost during storage or transport.

Early pre-cooling also minimizes the deterioration of product quality, preserving both its nutritional value and shelf life.

- **Importance of Pre-cooling**:

Pre-cooling plays a crucial role in the post-harvest handling of agricultural products by swiftly reducing the field temperature before the product undergoes any further treatment, storage, or transport under refrigeration.

While refrigeration systems are effective at maintaining low temperatures once they are established, pre-cooling is a distinct operation that focuses on rapidly reducing the temperature of the product immediately after harvest.

The goal is to prevent the product from experiencing thermal stress and degradation, which can significantly affect its quality and shelf life.

This process is especially vital for products that will be exposed to ambient temperatures at various points during the distribution chain.

In these cases, pre-cooling ensures that the product reaches storage or transport conditions as quickly as possible, minimizing the time spent at higher temperatures that could promote spoilage, dehydration, or the growth of harmful microorganisms.

By cooling the product efficiently right after harvest, pre-cooling helps maintain the product's freshness, flavor, texture, and nutritional value, all of which are essential for marketability.

The speed and effectiveness of pre-cooling are directly linked to the overall quality retention of fruits and vegetables.

When done correctly, pre-cooling can slow down the natural ripening process and reduce respiration rates, which in turn preserves the product for longer periods.

This process is especially critical for perishable items, as it helps extend their shelf life, reduce waste, and ensure that they remain competitive in the market.

By optimizing the cooling speed, pre-cooling contributes significantly to the overall effectiveness of the entire cold chain management, ensuring that products reach consumers in their best possible condition.

- **Temperature Loss**:

Temperature loss during the pre-cooling phase is not linear. Initially, the cooling rate is rapid, but it gradually slows down as the product temerature approaches the ambient refrigeration temperature.

The operation costs increase with each degree of temperature lost, making it crucial to achieve pre-cooling efficiency.

Typically, in commercial operations, the goal is to reduce the field temperature by about 7/8 of the total temperature difference between the field and the desired final temperature during pre-cooling.

The remaining 1/8 of the temperature difference is typically lost during subsequent refrigerated storage or transport.

For instance, if a product is harvested at a field temperature of 30°C and will be stored at 10°C, the pre-cooling process aims to reduce the temperature to approximately 12.5°C.

- **Cooling Rate Factors**:

The rate of cooling is influenced by several factors, such as the temperature difference between the product and the cooling medium, the individual volume of the product, and the exposure surface area.

Additionally, the type of cooling medium and the air circulation around the product also affect the cooling process.

Water, for example, has a higher capacity to absorb heat compared to air, which makes it a more effective cooling medium.

The circulation of the cooling medium also plays a significant role in how quickly the product's temperature can be reduced.

- **Cooling Systems**:

Cooling systems are essential in post-harvest handling to preserve the quality of agricultural products and extend their shelf life. These systems are tailored to the specific characteristics of the product and the speed at which cooling is required. The effectiveness of cooling methods varies based on factors such as the product's size, moisture content, and how long it will be stored or transported. Several types of cooling systems are commonly used, each with its advantages and applications.

  - **Cold Air Cooling:**

Cold air cooling is one of the most widely used methods, particularly for products that require gentle cooling without risking physical damage.

This system involves using a refrigeration unit to cool the air in a room or storage area where the product is placed.

There are two main approaches within this category: room cooling and forced air cooling. Room cooling, also known as static cooling, is typically slower and relies on the natural circulation of cool air.

It is suitable for large quantities of products that do not need rapid cooling.

In contrast, forced air cooling utilizes fans to accelerate the cooling process by forcing cold air over the products, which is ideal for items that need to be cooled quickly, such as leafy greens or berries. This method helps to lower the temperature uniformly and efficiently, preserving the freshness of the produce.

- **Cold Water Cooling:**

Hydro-cooling, or cold water cooling, involves immersing or spraying the harvested produce with chilled water to quickly absorb heat from the product.

This method is particularly effective for fruits and vegetables with high water content, such as cucumbers, grapes, and leafy vegetables.

The cold water removes heat rapidly, ensuring that the product's temperature is reduced swiftly.

It also helps maintain the product's texture and moisture levels, preventing dehydration. Hydro-cooling is often used when large volumes of produce need to be cooled quickly, but care must be taken to ensure that the water used is clean to avoid contamination.

- **Contact with Ice:**

Using ice for cooling is a more direct method, where produce comes into contact with ice in different forms.

Crushed ice, liquid ice, or dry ice can be applied depending on the product and its storage needs. Crushed ice is often used in bulk for products such as fish, seafood, or leafy vegetables, where it helps absorb heat and maintain a low temperature.

Liquid ice, which is a slurry of water and ice, is used for cooling larger quantities of produce or for products that are sensitive to direct ice contact.

Dry ice, or solid carbon dioxide, is sometimes used for rapid cooling, especially for transportation.

It is a highly effective option because it sublimates directly into gas without leaving any moisture, which is beneficial for preserving dry products or preventing mold growth.

- **Evaporation of Water on the Surface:**

Evaporative cooling methods rely on the principle of heat absorption when water evaporates from the surface of the produce.

This cooling technique can be achieved through two main processes: evaporation cooling and aspiration cooling.

In evaporation cooling, the surface of the product is wetted with water, and as the water evaporates, it draws heat from the produce, cooling it down.

This method is efficient for items like fruits or vegetables that can tolerate some moisture. Aspiration cooling, on the other hand, uses a system that introduces cool air to the product while simultaneously allowing moisture to evaporate into the air.

This method helps to maintain temperature control while also ensuring that excess moisture is removed from the products to avoid degradation or mold growth.

Each of these cooling systems is designed to meet specific cooling needs, ensuring that products maintain their freshness, taste, and texture until they reach consumers.

Choosing the appropriate cooling method is essential to maintaining high-quality produce, preventing spoilage, and optimizing storage and transport conditions.

4. Room Cooling

Room cooling is one of the most commonly used pre-cooling methods and relies on exposing products to cold air within a controlled cold room environment.

This method is relatively simple and effective, particularly when the product is both stored and refrigerated in the same room.

- **Slow Cooling Process**:

  While this system is widely used for its simplicity, it has its limitations.

  The cooling process can be quite slow, with products requiring at least 24 hours to reach the desired storage temperature. This makes it less suitable for products that spoil quickly or require rapid cooling to maintain quality.

- **Product Compatibility**:

  While room cooling can be used for nearly all types of products, it is especially effective for citrus fruits.

  These fruits are more tolerant of slower cooling processes, as their respiration rates are relatively low compared to other highly perishable produce.

  However, the slower rate of cooling makes room cooling less ideal for other products that are more sensitive to temperature changes, as it could lead to premature spoilage if the products are not cooled quickly enough.

- **Limitations for Perishable Goods**:

  For perishable goods that require faster temperature reduction to prevent quality loss, this method may not be sufficient.

  It is generally recommended to use faster and more direct cooling techniques, such as forced air or hydro-cooling, which can reduce the cooling time significantly.

Apple	Lemon	Mandarin
Pear	Melon	Tomato
Banana	Orange	Watermelon
Grapefruit	Prickly Pear	Pumpkin

Table 4. Agricultural Products Typically Cooled at Room Temperature

4.1. Forced Air Cooling

Forced air cooling is a highly effective method for rapidly reducing the temperature of harvested products.

This system works by creating a pressure gradient that forces air through the products, typically by circulating cold air through the packaging.

The air passes directly over and between the products, speeding up the cooling process.

- **Cooling Speed**:

Compared to room cooling, forced air cooling is four to five times faster.

The cooling rate is influenced by both the air flow and the individual volume of the product.

Since the air flows directly over the produce, it accelerates the heat exchange, reducing the temperature more efficiently.

This method is particularly effective for products that require rapid cooling but are not suitable for immersion in water.

- **Versatility**:

Forced air cooling is one of the most versatile cooling systems and can be used for a wide variety of products.

It is commonly applied to fruits and vegetables such as berries, ripe tomatoes, bell peppers, and other delicate fruits that require temperature control during storage.

This system is also used for many other crops because it can be adapted to different product shapes and sizes.

- **Advantages Over Hydrocooling**:

While forced air cooling is slower than hydrocooling, it has the advantage of not exposing the produce to water.

This makes it an excellent alternative for products that are sensitive to moisture, chlorine, or water infiltration.

Some fruits and vegetables are highly susceptible to water damage, which can lead to spoilage or quality deterioration, and forced air cooling helps avoid these risks.

- **Potential Drawbacks**:

One challenge of forced air cooling is that inadequate air circulation can lead to dehydration of the products.

Proper ventilation is crucial to ensure that the air moves efficiently through the produce and prevents moisture loss.

For optimal air circulation, the openings in the packages must be wide enough to allow sufficient airflow, especially when the products are stacked or placed on pallets.

- **Product Placement**:

The arrangement of the products is also critical. Fruits located in the center of stacked packages may not release heat as quickly as those on the outer layers.

This slower rate of heat expulsion can result in uneven cooling, with the inner layers of produce staying warmer for longer periods.

To ensure uniform cooling, careful stacking and placement are necessary, with adequate space between the packages to allow airflow to reach all areas.

4.2. Hydrocooling

Hydrocooling utilizes cold water as a refrigerant, taking advantage of its high capacity to absorb heat more efficiently than air.

This cooling method is faster than forced air cooling, making it highly effective for rapidly reducing the temperature of freshly harvested produce.

- **Cooling Efficiency**:

Cold water is an excellent heat conductor and can absorb warm air more quickly, allowing the cooling process to take place in a fraction of the time compared to air-based methods. Hydrocooling can be performed in two main ways: by immersion or by using a chilled water shower.

In immersion cooling, the produce is submerged in cold water, while in shower cooling, a fine mist of cold water is sprayed onto the produce, helping to lower the temperature rapidly.

- **Uniform Cooling**:

For hydrocooling to be effective, products must be arranged in thin layers or on a conveyor belt so that the water can come into contact with all surfaces of the produce.

This ensures that cooling is uniform, and no part of the product is left warmer than the others. Proper arrangement is critical, especially when dealing with bulk quantities of produce.

- **Limitations**:

Not all fruits and vegetables are suitable for hydrocooling, as this method requires the produce to be tolerant of moisture and water infiltration.

Some products, such as certain types of berries, mushrooms, and delicate fruits, may not be able to withstand immersion or exposure to water without suffering damage.

Furthermore, the water used in hydrocooling must be carefully monitored and treated. It is essential to chlorinate the water to prevent the growth and spread of pathogens, which can contaminate the produce and compromise its quality.

- **Chlorination**:

Chlorinating the water serves as an important step to reduce the risk of microbial contamination.

If pathogens are allowed to proliferate in the cooling water, they can spread to the fruits, leading to potential health risks and spoilage.

By adding chlorine to the water, the risk of pathogen buildup is minimized, ensuring that the produce remains safe and fresh.

However, the water must be kept at an appropriate concentration of chlorine to ensure both effective pathogen control and safety for the products being cooled.

- **Advantages and Disadvantages**:

Hydrocooling is particularly beneficial for products that require rapid cooling to prevent spoilage and extend shelf life.

It is ideal for high-volume crops such as leafy greens, lettuce, and other vegetables that can tolerate immersion.

However, it is not suitable for products that are sensitive to moisture or water exposure. Additionally, the need for water treatment adds complexity and cost to the process.

Table 5. Products typically pre-cooled by forced air circulation

Avocado	Banana	Cherry	Fig
Grape	Grapefruit	Melon	Orange
Persimmon	Pomegranate	Prickly Pear	Pumpkin
Strawberry	Mandarin	Tomato	

Table 6. Products typically hydro-cooled

Orange	Cantaloupe Melon
Pomegranate	Carot

4.3. Ice Cooling

Ice cooling is one of the oldest and most traditional methods of temperature reduction for preserving perishable goods, and it continues to be widely used today due to its simplicity and effectiveness.

The most common technique involves adding crushed ice on top of individual packages of produce before sealing them.

This direct contact between the ice and the products helps to quickly cool them, and the melting ice gradually cools the lower layers of the produce as well.

In some cases, layers of ice are interspersed between the products to ensure that the cooling effect is uniform throughout the load.

- **Liquid Ice System**:

Another variation of ice cooling involves the use of liquid ice, which is a mixture of crushed ice and water, typically made up of 40% water, 60% ice, and a small amount of salt (around 0.1%).

This mixture is injected into open containers, where it forms a large block of ice that can gradually cool the surrounding products.

Liquid ice is particularly effective in environments where space is limited, and it can maintain a steady, low temperature over an extended period.

- **Limitations**:

One of the main drawbacks of ice cooling is that it is only suitable for products that can tolerate being exposed to moisture.

For example, some fruits and vegetables may become damaged by excessive wetness, leading to degradation of quality.

Moreover, the addition of ice adds weight to the product, which increases shipping costs and requires the use of larger packaging.

Additionally, as the ice melts, it creates excess water, which can wet the storage areas, containers, and shelves, causing potential hygiene concerns and logistical challenges.

- **Cost Considerations**:

The cost of ice cooling increases with the additional weight of the ice, as well as the need for larger packages to accommodate the ice and the product.

However, despite these challenges, ice cooling remains a widely used and effective method, especially for short-term cooling and transport of perishables.

4.4. Evaporation

Evaporation cooling is one of the simplest and most cost-effective methods of temperature reduction.

It works by forcing dry air through a wet product, causing heat to be absorbed by the air as the moisture evaporates.

This method is especially useful in low-humidity environments, where the air can absorb moisture efficiently.

- **Simple and Low-Cost**:

The primary advantage of evaporation is that it is inexpensive to implement, as it requires minimal equipment and is straightforward to operate.

However, its cooling efficiency is limited by the low capacity of air to absorb moisture. Because of this, evaporation cooling is most effective in areas with very low relative humidity, where the air can hold a larger amount of moisture.

- **Limitations**:

While this cooling method is cheap and simple, it is not universally applicable, as it requires specific environmental conditions.

The system's performance is greatly reduced in high-humidity areas because the air's capacity to absorb moisture diminishes, making this method less effective in such conditions.

For products with a high moisture content, evaporation may not achieve sufficient cooling to prevent spoilage or deterioration.

4.5. Air Vacuum Cooling

Air vacuum cooling is one of the fastest and most efficient cooling methods available, especially for products that require rapid cooling, such as leafy vegetables. This system operates on the same basic principle as evaporation but under very low pressure.

- **Principle**:

Under normal atmospheric pressure (760 mmHg), water evaporates at around 100°C, but at much lower pressures, the boiling point of water drops significantly.

In the case of air vacuum cooling, the pressure is reduced to 5 mmHg, causing the water in the product to evaporate at a much lower temperature, typically around 1°C. This rapid evaporation draws heat from the product, cooling it quickly.

- **Efficiency**:

The cooling process is highly efficient, with air vacuum cooling resulting in a weight loss of approximately 1% per 5°C temperature reduction.

The faster cooling also reduces the risk of microbial growth and slows down enzymatic activity that causes spoilage.

Modern air vacuum coolers often introduce fine water vapor as the pressure drops, further enhancing the cooling process.

- **Applications**:

  This method is particularly suitable for leafy vegetables and other products with a high surface-to-mass ratio.

  The rapid cooling helps maintain freshness and quality by reducing the time products spend in warmer temperatures, which can lead to quality loss.

  However, the equipment required for air vacuum cooling is typically more expensive, making it less accessible for small-scale operations.

4.6. Short-Term Preservation (Refrigerated Transport)

Refrigeration is not always used to extend the post-harvest life of products in storage rooms. More often, it is used for short periods throughout the cold chain, particularly during transportation.

This is especially true in the case of refrigerated transport, which is one of the most common examples of short-term preservation in the supply chain.

- **Cold Chain**:

  The cold chain refers to the series of steps and processes that products undergo from the point of harvest or production to their final consumption.

  Refrigerated transport ensures that the products remain at the optimal temperature during their journey, preserving quality and preventing spoilage.

  Other short-term storage options, such as keeping products refrigerated at retail or wholesale locations, also fall under this category.

- **Duration of Storage**:

  "Short-term" preservation is somewhat relative, as what constitutes a short period can vary depending on the type of product.

  For instance, 7 days might be considered a short period for highly perishable items like raspberries, but it would be far too short for more durable products like potatoes, onions, or garlic. Generally, short-term storage is considered to range from a few hours to approximately 7 days, depending on the product.

- **Multi-Product Storage**:

  While it is not ideal, it is common to store multiple types of products together in refrigerated transport, especially when there are space constraints.

  If the storage conditions are not optimal, such as in the case of temperature or humidity imbalances, there can be issues with compatibility between different products.

Ethylene accumulation, for instance, can cause ripening or spoilage in sensitive fruits and vegetables. However, if the storage time is limited and conditions are not suboptimal, the risk of incompatibility is minimized.

- **Storage Conditions**:

  A typical strategy for short-term refrigerated storage is to set cold rooms at around 5°C with a humidity level of 90-95%.

  Different types of products require different temperature and humidity combinations to ensure optimal preservation.

  For example, temperate fruits may require a temperature of 0-2°C with 90-98% relative humidity (RH), while tropical fruits and melons are better suited to 13-18°C with 85-95% RH. It is also important to adjust the storage conditions for specific product types, including apples, bananas, avocados, and others, to maximize their shelf life.

- **Storage Regimes**: Several different storage regimes are recommended depending on the type of product, such as:
  - 0°C and 90-100% RH for certain fruits like apples and pears.
  - 7-10°C and 90-100% RH for citrus fruits.
  - 13°C and 85-90% RH for bananas and papayas.
  - 20°C for pineapples and other tropical fruits.
  - Ambient conditions for products like onions and garlic.

- **Transportation Challenges** :

  In refrigerated transport, managing the compatibility of different products is a key challenge. Differences in package sizes, ventilation openings, and the products' cooling requirements can lead to inefficiencies in cooling and storage.

  When different types of products are stored together, the ventilation openings of various packages may not align, preventing efficient airflow and creating micro-environments that are not ideal for preservation.

  Proper packaging and stacking are crucial to ensuring uniform cooling and preventing damage during transport.

4.7. Controlled Atmospheres

Controlled atmospheres (CA) represent an advanced technique for modifying the storage environment to slow down the metabolism of perishable products, thus extending their shelf life without compromising their quality.

This system relies on carefully adjusting the atmospheric composition around the product, as well as strict monitoring of the storage conditions to maintain the desired effects over time.

- **Atmospheric Composition**:

Under normal conditions at sea level, the atmosphere consists of 78.1% nitrogen (N_2), 21% oxygen (O_2), and 0.03% carbon dioxide (CO_2).

In controlled atmosphere storage, the composition of these gases is altered to create an environment that slows down the biological processes of the stored products.

The gases are typically adjusted by reducing oxygen levels and increasing carbon dioxide concentrations, although the specific proportions depend on the type of product being stored.

- **Types of Atmospheric Control**:
  - **Controlled Atmosphere (CA)**:

This system involves maintaining a stable and specific atmospheric composition throughout the storage period.

It is typically used for long-term storage of certain fruits and vegetables, requiring dedicated, purpose-built facilities designed to keep the atmosphere sealed.

  - **Modified Atmosphere (MA)**:

In this case, the atmosphere within the packaging is temporarily altered by using semi-permeable films, which allow gases to pass through and gradually reach equilibrium with the ambient conditions.

This method is used for short-term storage and transportation of products.

The atmospheric composition inside the packaging changes depending on the product, the permeability of the packaging material, and the storage temperature.

- **Benefits of Atmosphere Modification**:
  - **Slowing Down Biochemical and Physiological Changes**:

By controlling the atmospheric conditions, it is possible to delay several aging processes in produce, such as respiration rate, ethylene production, softening, and changes in chemical composition.

  - **Reduced Sensitivity**:

Modifying the atmosphere can reduce the product's sensitivity to ethylene, a plant hormone that accelerates ripening, and in some cases, can also reduce the severity of pathogen attacks.

  - **Insect Control**:

The atmospheric composition can be adjusted to control insect pests by reducing the oxygen levels to levels that are inhospitable to insects.

- **Risks and Challenges**:

- **Fermentation and Asphyxiation**:

  One of the risks of using controlled atmospheres is the potential for fermentation, which occurs if anaerobic conditions develop (lack of oxygen).

  Fermentation can result in the production of undesirable by-products, including altered odors and flavors.

- **Quality Issues**:

  If the atmosphere is not properly controlled, it can also lead to the asphyxiation of the product, causing spoilage.

  Close monitoring and quality control are essential to mitigate these risks.

- **Facility Design**:

- Controlled atmosphere chambers are similar to refrigerated storage facilities but require additional features to maintain an airtight environment.

  The key aspect of these chambers is that they must be sealed to prevent any outside air from entering, thus maintaining the desired atmosphere.

- **Oxygen and Carbon Dioxide Balance**:

  The consumption of oxygen by the product, coupled with the release of carbon dioxide from respiration, helps create the modified atmosphere.

  Once the desired balance is achieved, minimal oxygen is required to sustain the lower respiration rate.

  Carbon dioxide accumulation is managed by various methods, such as ventilation or scrubbing systems.

- **Pressure Compensation**:

  Because the internal atmosphere reacts differently from the external environment, pressure compensation is necessary to maintain equilibrium.

  This means that the pressure inside the chamber must be adjusted to match the outside pressure, preventing damage to the products and storage equipment.

- **Monitoring**:

  Since controlled atmosphere chambers are typically sealed until the end of the storage period, inspection windows or monitoring systems must be installed to observe the refrigeration equipment and ensure that the conditions inside the chamber remain stable throughout the storage period.

- **Common Atmospheric Compositions**:

  The most typical atmospheric compositions for controlled atmosphere storage are:

2-5% oxygen and 3-10% carbon dioxide, though the exact mix can vary depending on the specific product being stored.

- **Product Suitability**:

While controlled atmosphere storage can benefit all agricultural products, its use is not widespread due to the significant investment required for the infrastructure and operational costs. The ideal product for CA storage is one that:

  - Has a steady demand throughout an extended marketing period.
  - Is unique enough to justify the cost of controlled atmosphere technology, meaning it is not easily replaced by other products.
  - This is why controlled atmosphere technology is mainly used for products like apples and pears, which meet these criteria.

- **Modified Atmosphere Packaging (MAP)**:

While controlled atmosphere storage is more specialized, modified atmosphere packaging (MAP) is widely used for consumer products.

This involves packaging produce in films that allow for controlled gas exchange, creating an environment that prolongs freshness.

MAP is particularly useful for pre-packaged items like fresh-cut fruits and vegetables or those sold in consumer bags.

4.8. Combination of Storage Systems

Long-term storage facilities for products like potatoes, onions, and sweet potatoes often use a combination of forced air systems and heating and/or refrigeration equipment. These facilities are designed to maintain optimal conditions throughout the storage period, adjusting to the needs of the products being stored.

- **Initial Treatment**:

Many long-term stored products, such as potatoes, require a pre-treatment phase where warm, humid air is introduced to the storage area.

This phase is essential for stabilizing the products and preparing them for the cooling phase.

- **Cooling Process**:

Once the pre-treatment phase is complete, the temperature is gradually reduced through forced air cooling or natural ventilation.

Forced air cooling involves blowing cool air over the products to rapidly lower their temperature, while natural ventilation relies on the outside air to gradually reduce the temperature.

- **Blended Air Systems**:

To achieve the proper temperature and humidity conditions, the indoor air can be blended with outside air, adjusting it as necessary by heating or refrigeration.

This allows the same facility to be used for both treatment and long-term storage, which is especially important in mechanized harvesting systems where large quantities of products need to be processed and stored efficiently.

5. Problems Encountered During Storage

The post-harvest storage of fruits and vegetables involves a number of challenges that directly impact both their quality and shelf life.

These challenges stem from a combination of environmental factors, physiological changes within the produce, and external contaminants.

The key to mitigating these issues lies in managing storage conditions properly, ensuring optimal temperatures, humidity, and ventilation, while also addressing any risks that could accelerate deterioration.

5.1. Deterioration Due to Cooling

Refrigeration is widely used to slow the metabolic rate of fruits and vegetables after harvest, thereby extending their shelf life.

However, when cooling systems are not well-maintained or when products are exposed to temperatures that are too low for their tolerance, significant damage can occur to plant tissues, leading to deterioration.

- **Freezing and Ice Crystallization**:

  Freezing occurs when temperatures drop below 0 °C, causing ice crystals to form inside the plant tissues.

  These crystals disrupt cell structures, which is particularly damaging during thawing. The typical symptoms include a loss of turgidity (firmness), sweating, and the disorganization of cellular structures.

  This damage is primarily a result of faulty refrigeration equipment or improper handling, though it is generally rare under typical commercial conditions.

- **Chilling Injury**:

  Many fruits and vegetables, especially those from tropical and subtropical regions, are highly sensitive to cold temperatures.

  Exposure to chilling temperatures (typically between 0 and 15 °C) can result in various symptoms such as tissue browning, off-flavors, or an overall loss of quality.

  Products like tomatoes, peppers, eggplants, zucchinis, sweet potatoes, and bananas are highly vulnerable to chilling injury.

Some temperate products, including potatoes, asparagus, and certain apple varieties, can also suffer from this type of damage when exposed to low temperatures.

In tropical fruits, the critical temperature range is often narrower, typically between 7 and 15 °C.

- **Symptoms of Cooling Damage**:

Damage caused by refrigeration can vary depending on the type of product, but typical symptoms include discoloration, sunken areas, softening, and accelerated ripening.

For example, bananas may develop skin darkening and a softened texture, while tomatoes, peppers, and eggplants may show sunken spots that are often linked to the growth of spoilage organisms.

Other common signs include internal browning, which can be especially pronounced in some fruits and vegetables after they return to normal temperatures.

- **Factors Affecting the Severity of Damage**:

The extent of the damage due to cooling depends on several factors, including the specific type of produce, the temperature to which it was exposed, and the duration of exposure.

For instance, unripe fruits are generally more susceptible to damage than ripe ones, and the physiological changes in cooling-induced damage are reversible in the early stages.

If the product has not sustained permanent damage, a slight increase in temperature can restore it to its original condition.

- **Management of Cooling Deterioration**:

To combat cold-related deterioration, studies have shown that intermittent periods of warming, such as interruptions ranging from 6-7 to 15 days or shorter breaks of 5 to 48 hours with temperatures rising from 12 to 25 °C, can help to extend the post-harvest life of stored produce.

These temperature variations help mitigate cumulative cooling damage that builds up over time.

Therefore, careful monitoring of storage conditions is essential to avoid excessive exposure to low temperatures and to ensure the produce is kept within optimal temperature ranges during handling and storage.

5.2. Ethylene and Other Gas Contaminations

Ethylene is a naturally occurring plant hormone that regulates various stages of plant growth, including ripening and senescence.

While it plays a crucial role in the natural development of fruits and vegetables, when accumulated in storage environments, it can have adverse effects on the quality of produce.

Additionally, other gases and volatile compounds can also cause contamination, exacerbating storage issues.

- **Ethylene Production and Effects**:

  Ethylene is produced in large quantities by climacteric fruits such as apples, bananas, and tomatoes as they ripen.

  It can also be released when fruits or vegetables undergo physical stress or damage.

  When ethylene builds up in a storage environment and is not adequately vented or removed, it can accelerate ripening, increase respiration rates, promote aging, cause the loss of green color, induce yellowing, and create necrotic spots on the tissue.

  Ethylene exposure can also lead to sprouting in potatoes, altered flavor in root vegetables, and the hardening of asparagus, among other issues.

  These effects can significantly compromise the shelf life and marketability of the produce.

- **Ethylene Sensitivity**:

  Many fruits and vegetables are sensitive to ethylene. When stored together with ethylene-producing fruits, they may undergo rapid deterioration.

  For example, ethylene can cause apples to ripen prematurely, leading to softening and loss of quality.

  To prevent these issues, it is essential to maintain ethylene concentrations in storage areas below 1 ppm (parts per million) to avoid triggering these negative effects.

- **Aromas, Odors, and Other Volatile Compounds**:

  Besides ethylene, other volatile compounds such as aromas, odors, and gases produced by plants can accumulate in storage environments and contribute to contamination.

  When high-emission products are stored alongside sensitive items, they can transfer off-flavors, undesirable odors, or other volatile compounds, negatively affecting the flavor and overall quality of the products.

  This contamination can be especially problematic when different varieties of produce are stored in close proximity, leading to flavor and odor cross-contamination.

- **Managing Gas Contaminants**:

  To manage the accumulation of ethylene and other volatile compounds, proper ventilation is crucial in storage environments.

  Ventilation allows for the removal of excess gases and maintains air quality within the storage area.

  In addition, some facilities use chemical methods such as ethylene scrubbers, absorbent materials, or even filtration systems to actively remove ethylene from the air.

This helps reduce the concentration of ethylene and other gases, ultimately extending the shelf life of sensitive produce and maintaining its quality.

5.3. Humidity Levels

Water constitutes the majority of the composition of fruits and vegetables, making the maintenance of adequate humidity levels within storage environments a critical factor in preserving post-harvest quality.

Proper humidity control is essential not only to prevent weight loss but also to safeguard the appearance, texture, taste, and overall freshness of stored produce.

- **Impact of Water Loss on Quality**:

Water loss from fruits and vegetables leads to dehydration, which is directly associated with a reduction in weight and a decline in quality.

Dehydration affects several sensory attributes of produce, such as its texture, crispness, and visual appeal.

For example, leafy vegetables may wilt, fruits may shrivel, and the overall product may lose the fresh appearance that is highly desirable to consumers.

The feeling of freshness is often linked to the turgidity or swelling of produce, which can only be maintained when adequate water levels are retained.

- **Humidity and Its Role in Water Balance**:

Humidity is typically expressed as the percentage of water vapor present in the air relative to the maximum amount it can hold at a specific temperature (saturation point).

This relationship is crucial because water vapor naturally moves from areas of higher concentration or pressure to areas of lower concentration, in accordance with physical laws. Within plant tissues, water exists primarily as cellular fluids that are in equilibrium with the surrounding intercellular spaces, which are saturated with water vapor (100% humidity). However, when the surrounding air has lower humidity levels, water vapor from the intercellular spaces will diffuse outward, leading to tissue water loss.

This imbalance results in dehydration and reduced freshness, which can compromise both quality and marketability.

- **Temperature-Humidity Interaction**:

Temperature significantly influences the air's capacity to hold water. Warmer air can retain more water vapor, while cooler air has a reduced capacity.

This interaction is particularly relevant in refrigerated storage environments, where the air's humidity often increases due to condensation effects.

However, in some cases, refrigeration alone may not suffice to maintain the desired humidity levels for optimal preservation.

To address this, humidifiers are often employed to raise the humidity and achieve ideal conditions.

- **Optimal Humidity Levels for Different Produce**:

The ideal humidity levels for storage vary depending on the type of produce.

Most fruits and vegetables require high humidity levels of 90–95% to minimize water loss and maintain quality.

Some produce, such as certain root vegetables or fruits that are prone to mold or decay at excessive moisture levels, are better preserved at slightly lower humidity levels of 60–70%. However, certain delicate items or those highly susceptible to dehydration may require storage environments with near-saturation humidity levels to maintain their freshness.

- **Challenges in Maintaining Humidity**:

Achieving and maintaining the right balance of humidity in storage facilities can be challenging, particularly when dealing with mixed loads of produce with varying humidity requirements.

Overly high humidity can lead to problems such as mold growth, condensation on surfaces, and increased susceptibility to decay.

Conversely, insufficient humidity accelerates water loss and dehydration, impacting the produce's quality.

Therefore, precise monitoring and control of humidity levels, often through the use of specialized equipment such as hygrometers and humidifiers, are essential in ensuring optimal conditions for post-harvest storage.

- **Consumer Perception of Freshness**:

From a consumer perspective, freshness is often judged by the appearance and texture of fruits and vegetables.

Produce that retains its original turgidity and crispness is perceived as freshly harvested, which enhances its appeal and market value.

Thus, maintaining proper humidity levels not only preserves the intrinsic qualities of the product but also aligns with consumer expectations for high-quality, fresh produce.

6. Microbiological Risk in Fruit Production and Distribution

Fruits and vegetables can be exposed to numerous opportunities for contamination during post-harvest handling, processing, packaging, and distribution.

These risks are compounded by the inherent vulnerabilities present during cultivation in the field.

- **Contamination During Handling and Packaging**:

  Consumers expect products to be free from any foreign materials such as dirt, animal feces, lubricating oils, human hair, insects, plant debris, and packaging residues.

  While these contaminants are undesirable, they are usually visible and can be detected and removed through proper inspection and handling practices.

- **Invisible Threats: Pathogenic Contamination**:

  Far more concerning is the presence of invisible pathogens that can remain on the surface of fruits and vegetables without altering their external appearance, taste, or color.

  Pathogens such as viruses, bacteria, and parasites can survive on produce long enough to pose significant health risks.

  Numerous outbreaks of foodborne illnesses have been traced back to contaminated fruits and vegetables.

- **Key Pathogens of Concern**:

  Three main groups of pathogens can be transmitted through fruits and vegetables:

1. **Viruses**: Hepatitis A and noroviruses are common examples.
2. **Bacteria**: *Salmonella spp.*, *Escherichia coli* (E. coli), *Shigella spp.*, and *Listeria monocytogenes*.
3. **Parasites**: Organisms such as *Giardia spp.*, *Cyclospora*, and *Toxoplasma gondii*.

   Additionally, mycotoxins produced by fungi are a concern, although fungal growth is generally visible and addressed before mycotoxins develop.

- **Primary Causes of Illness**:

  Bacteria are the most common cause of foodborne illnesses associated with fruits and vegetables.

  These illnesses often result from contamination during production, processing, or storage.

- **Strategies for Risk Mitigation**:

  The most effective way to ensure the safety of produce is to adopt preventive measures throughout the supply chain.

  This includes maintaining sanitary conditions, implementing disinfection protocols, and storing products under temperature conditions that inhibit microbial growth.

6.1. Contamination Risks Before Harvest

Many of the pathogens that contaminate fruits and vegetables originate from the environment. Among these, fecal matter whether human or animal is the primary source of contamination, often entering the system through irrigation or washing water.

6.1.1.Water as a Contamination Vector

- **Surface Water**:

Rivers, lakes, and other surface water sources are particularly vulnerable to contamination, especially when located downstream from areas where untreated municipal wastewater is discharged.

- **Groundwater**:
  Groundwater can also be contaminated if septic tanks leak into the soil, allowing microorganisms to reach aquifers.
- **Irrigation Practices**:

When only contaminated water is available, it is recommended to use underground irrigation methods, such as drip irrigation, to avoid direct contact between water and the edible parts of plants.

6.1.2.Fertilizers and Animal Presence

- **Use of Manure**:

Fertilizers derived from animal waste, such as manure, can be a major source of contamination.

To mitigate risks, manure should be composted at high temperatures (60–80 °C) for at least 15 days. Static piles and vermicomposting are less effective at inactivating harmful microorganisms.

- **Animal Activity in Fields**:

The presence of domestic or wild animals in production areas poses significant contamination risks. Efforts should be made to limit animal access to fields during cultivation.

6.2.Wastewater Management

- **Recycled Water**:

The use of wastewater from municipal sources or on-site processing facilities should only be considered if an effective disinfection system is in place to eliminate pathogens.

- **Comprehensive Monitoring**:

Regular testing of water quality for irrigation and cleaning is essential to ensure its safety and suitability for use in agriculture.

6.3.Factors Influencing Contamination Risks

- **Type of Product**:

Different crops vary in their susceptibility to microbial contamination. For example:

- **Vegetables** (low-acidity products) are more prone to bacterial colonization.
- **Fruits**, with their higher acidity levels, tend to be predominantly colonized by fungi.

- **Proximity to the Ground**:

Crops grown close to the soil, such as strawberries and leafy vegetables, face greater contamination risks from water, soil, and animals.

Tree crops, on the other hand, are less likely to come into contact with these contaminants.

- **Natural Defenses**:

Certain chemical compounds in plant tissues provide some level of protection against microbial colonization. These include:

- Organic acids
- Essential oils
- Pigments
- Phytoalexins

These natural defenses act as antagonistic agents, inhibiting the growth and establishment of microorganisms.

6.4.Harvesting Practices and Contamination

- **Bruising and Damage**:

Harvesting activities often involve handling that can bruise or damage the produce.

This damage releases plant fluids, such as latex or sap, which create a nutrient-rich substrate for microorganisms.

Contaminants can be introduced through:

- Workers' hands
- Tools and equipment
- Clothing
- Water used during harvesting or cleaning
- Storage and transportation containers

- **Temperature as a Critical Factor**:

Contamination risks increase significantly with improper temperature management throughout the supply chain.

Elevated temperatures accelerate the growth of microorganisms, while maintaining produce at appropriate temperatures can slow or prevent contamination.

Table 7. Pathogenic Elements Isolated in Fruits and Reported Diseases

Escherichia coli O157:H7	pineapple, cider apple
Listeria monocytogenes	tomato
Salmonella spp.	tomato , cider apple, cantaloupe melon, watermelon
Cryptosporidium spp.	Cider apple (*)

Table 8. Potential Risks of Microbial Contamination and Recommended Preventive Measures

Production Step	Risks	Prevention
Production Area	Contamination by animal feces	Prevent animal access, whether it's wild animals, livestock, or even pets.
Fertilization	Pathogens from organic fertilizers	Use non-organic fertilizers. Properly carry out composting operations.
Irrigation	Eléments pathogènes présents dans l'eau	Pathogens present in water Subsurface drip irrigation. Check for the presence of microorganisms in the water.
Harvesting	Contamination by fecal matter. Eléments Pathogens on containers or tools Personal hygiene.	Portable toilets. Awareness of risks. Use plastic bins. Clean and disinfect tools and containers.
Packaging Facility	Contamination by fecal matter. Contaminated water	Staff hygiene. Presence of sanitation facilities. Prevent animal entry. Eliminate places that may shelter rodents. Alternative methods for pre-cooling. Use potable water. Filtration and chlorine addition to the recycled water. Multiple washes.
Storage and Transportation	Growth of microorganisms on	Adequate temperature and relative humidity. Monitor conditions inside packaging.

	products	Cleaning and disinfection of premises. Avoid re-packaging. Staff hygiene. Do not store or transport with other fresh products. Use new packaging materials.
Sales	Contamination des produits	Product contamination Staff hygiene. Prevent animal access. Sell whole units. Clean and disinfect premises. Empty trash bins daily.

6.5. Market Preparation

When preparing fruits and vegetables for market, the principles of proper product handling and worker hygiene outlined earlier are equally important, with additional considerations specific to this phase of the supply chain.

- **Worker Hygiene and Attire**:
  - Workers involved in packing and processing must follow strict hygiene protocols. Individuals who are ill or have open wounds should not handle products to prevent contamination.
  - Hairnets and clean uniforms must be worn, and street clothes or personal belongings should be left outside the work area.
  - Eating, drinking, or smoking in areas where products are handled should be strictly prohibited.
- **Handwashing**:
  - Workers should wash their hands thoroughly before starting their tasks and each time they resume work, especially after restroom breaks.
- **Water as a Contamination Source**:
  - Water is a critical component in market preparation, used for washing produce, cleaning containers and premises, hydraulic cooling, and as a medium for applying waxes, chemicals, or disinfectants.
  - Contaminated water can easily spread microorganisms, making its proper treatment and maintenance essential for food safety.

6.6. Water Disinfection

Ensuring the safety of water used in post-harvest operations is paramount to prevent cross-contamination.

Common Impurities in Water

Water used in these processes often contains impurities such as:

- Suspended particles (dirt and plant debris)
- Microorganisms (bacteria, fungi, viruses)
- Organic matter
- Abnormal odors, colors, or dissolved gases

Water Sources and Treatment

- **Municipal Water**:

  Generally filtered and chlorinated to meet safety standards.

  However, further treatment is required in post-harvest operations to address contaminants introduced during usage.

- **Non-Municipal Water**:

  Must be filtered and treated before use.

Chlorine as a Disinfectant

Chlorine is the most common and cost-effective disinfectant for post-harvest water treatment due to its ability to kill bacteria and fungi.

It is available in three primary forms:

Chlorine Gas:

Effective but hazardous and used only in large-scale operations.

Calcium Hypochlorite:

A solid form used at concentrations of 65%, though difficult to dissolve in cold water.

Sodium Hypochlorite:

Commonly known as bleach, it is easy to use for small-scale operations despite its higher cost per concentration.

Optimal Conditions for Chlorine

Chlorine’s germicidal efficiency depends on the pH of the water:

- **pH 6.5–7.5**: Ideal range for maximizing hypochlorous acid (the active germicidal form).
- Below pH 6.5: Chlorine escapes as gas, posing health risks and corroding equipment.
- Above pH 7.5: Effectiveness decreases significantly.

- Adjustments to pH can be made using vinegar (to lower pH) or sodium hydroxide (to raise pH).

Chlorine Concentrations

- Concentrations of 0.2–5 ppm are sufficient for killing most microorganisms in water.
- Commercial operations often use 100–200 ppm for washing and hydraulic cooling.
- For example, one liter of household bleach diluted in 400 liters of water provides approximately 200 ppm.

Limitations and Alternatives

- Some countries prohibit chlorine due to its potential to form carcinogenic chlorinated compounds. Alternative disinfectants include:
  - **Ozone**: Highly effective but challenging to control and hazardous at high concentrations.
  - **Ultraviolet (UV) Light**: Efficient at 250–275 nm wavelengths, unaffected by pH or temperature, but less effective in turbid water.

Best Practices for Washing and Cooling

- Sequential washing is more effective than a single wash:
  - Initial wash to remove debris.
  - Chlorinated water for disinfection.
  - Final rinse with clean water.
- Recirculated water should flow opposite to the product's movement to minimize contamination risks.
- Hydraulic cooling, while efficient, poses high microbial contamination risks. Alternative methods like forced-air cooling are safer for certain applications.

By following stringent hygiene practices and optimizing water disinfection processes, producers can significantly reduce the risk of contamination, ensuring the safety and quality of fruits and vegetables prepared for market.

6.7. Hygiene at the Infrastructure Level

Hygiene at the infrastructure level plays a pivotal role in ensuring the safety and quality of fresh produce, a concern often overlooked in comparison to industrial facilities.

Unlike industrial setups where stringent hygiene protocols are mandatory, the preparation of fresh produce for the market often suffers from lax practices.

This is particularly true when packing sheds are constructed using low-cost materials, leading to inadequate cleaning and disinfection capabilities.

Such oversights heighten the risk of contamination and pose significant public health challenges, necessitating comprehensive measures to mitigate these risks.

Infrastructure Design and Layout

A well-thought-out design and layout are critical to maintaining hygiene at the infrastructure level.

1. **Cleanability**:

- Packing sheds must be designed to facilitate effective cleaning and disinfection operations. Materials used for construction should be durable, non-porous, and resistant to moisture and chemicals.

  Smooth surfaces are preferable for walls and floors to minimize dirt accumulation.

2. **Zoning**:

- Proper zoning is essential to prevent cross-contamination. Facilities should clearly separate:

  - **Receiving Areas**:

    Dedicated spaces where goods arriving from the field are unloaded.
  - **Clean Zones**:

    Areas designated for preparing, sorting, and packing products for market.
  - **Unclean Zones**:
  - Spaces where initial handling occurs, including the removal of soil, debris, and non-marketable parts.
  - Clearly marked pathways should be established to control the flow of personnel and materials, ensuring that clean and unclean zones remain isolated.

3. **Worker Facilities**:

- Workers must have access to well-maintained facilities to ensure personal hygiene. These should include:
  - Clean and spacious rest areas.
  - Changing rooms with lockers to store personal items.
  - Toilets equipped with running water, soap, and hand dryers.
  - Showers with access to hot water.
- These facilities should be positioned away from the processing areas to avoid contamination risks.

Cleaning and Disinfection

Maintaining cleanliness and hygiene requires a systematic approach to cleaning and disinfection.

1. **Debris Removal**:

- Routine removal of dust, soil, and organic matter is critical to minimize microbial growth. Sweeping and vacuuming should be supplemented with washing surfaces and equipment regularly.

2. **Disinfectants**:

- The selection of disinfectants depends on the type of equipment, surface material, and operational needs.

  Commonly used disinfectants include:

- **Chlorine-based products**:

  Effective and affordable but require careful monitoring of water quality and pH to ensure efficacy.

- **Iodine-based disinfectants (iodophores)**:

  Suitable for organic matter-rich environments but limited by a narrow effective pH range.

- **Quaternary ammonium compounds**:

  Offer broad-spectrum antimicrobial activity, are non-corrosive, and work across a wide pH range, though they may leave residues.

- **Other Disinfectants**:

  Alcohol-based solutions and hydrogen peroxide-based products can also be used, depending on specific requirements.

3. **Cleaning Protocols**:

- Establishing clear cleaning schedules and protocols ensures consistency. Cleaning logs should be maintained to track activities and verify compliance with hygiene standards.

Animal and Pest Control

Animals and pests are major vectors of contamination. Preventive measures include:

1. **Physical Barriers**:

- Seal cracks, install screens on doors and windows, and use self-closing mechanisms to prevent entry.

2. **Pest Management Programs**:

- Implement integrated pest management (IPM) strategies, including:
- Traps and baits for rodents and insects.
- Regular application of approved pesticides in high-risk areas.
- Monitor pest activity and respond promptly to infestations.

3. **Environmental Cleanliness**:

- Keep surroundings free of debris and food scraps that attract pests.

- Garbage should be stored in covered containers and removed daily to prevent the breeding of pests.

By integrating these design and operational practices, infrastructure-level hygiene can be significantly improved, reducing the risks of contamination and ensuring the safety of fresh produce throughout the supply chain.

6.8. Final Considerations

From a microbiological perspective, fruits and vegetables are generally considered safer than foods such as meat, milk, and poultry.

However, this perception does not eliminate the potential risks they pose.

Unlike many other food types, fruits and vegetables are rarely subjected to processes like cooking, which are effective at eliminating microorganisms. Consequently, if contamination occurs, these products can become hazardous.

Potential Risks and Perception

The risk associated with microbial contamination in fruits and vegetables is challenging to quantify.

Often, cases of contamination are underreported unless they result in severe outbreaks.

The perception of fruits and vegetables as "healthy foods" further complicates this issue, as they are less likely to be blamed for foodborne illnesses.

Instead, other foods consumed on the same day are often assumed to be the culprit.

Despite this, increasing data suggests that contamination of fruits and vegetables is becoming a significant concern in food safety.

Factors Contributing to Increased Risks

1. **Environmentally Friendly Agriculture**:
   - The adoption of sustainable farming practices, such as the use of organic fertilizers and soil amendments, can increase the risk of contamination by introducing harmful microorganisms into the food chain.
2. **Centralized Distribution Systems**:
   - The concentration of supply chains, particularly within large-scale retail systems, has amplified the impact of contamination.
   - A single incident can quickly affect a vast network of stores, potentially exposing a large number of consumers to health risks.

Complexity of Microbial Contamination

Recognizing the intricate nature of microbial contamination is critical for achieving a high-quality product with minimal risk.

While not all fruits and vegetables may benefit from the same preventive measures, tailored approaches can enhance food safety.

Mitigating Risks

While it is impossible to eliminate the risk entirely with current technology, it is vital to focus on minimizing it.

Preventing contamination is not only more cost-effective but also significantly more efficient than addressing the issue after it occurs.

1. **Commitment Across the Food Chain**:
   - A successful food safety program relies on the dedication of all stakeholders, from producers to consumers.
   - This involves employing qualified personnel and implementing systems to identify and mitigate critical points of vulnerability within the supply chain.
2. **Microbial Testing and Limitations**:
   - Common microbial testing methods, such as total plate count or aerobic plate count, provide an overview of contamination levels but are limited in assessing food safety.
   - These tests are more useful for evaluating the effectiveness of hygiene systems and measuring the impact of specific sanitation measures.
   - Detecting pathogens like *Salmonella spp.*, fecal coliforms, and *E. coli* requires targeted tests. However, the absence of these pathogens does not guarantee that the product is free of harmful microorganisms.

Traceability as a Key Element

Traceability is a cornerstone of good agricultural and manufacturing practices.

A robust traceability system enables quick identification and resolution of contamination issues, minimizing the impact on public health.

1. **Rapid Response to Contamination**:
   - Given the short timeframe between harvest and consumption, rapid identification and corrective action are critical to addressing contamination before it spreads.
2. **Record-Keeping**:
   - Maintaining detailed records supports traceability efforts and reduces the potential at-risk population in the event of a food safety issue.

Hygiene Systems and Preventive Measures

Effective hygiene systems are the foundation of a successful contamination prevention strategy. Monitoring sanitation measures, combined with comprehensive testing and traceability programs, ensures a safer food supply.

Course 3. Harvest and conservation of forage

1.Different Modes of Forage Conservation

Forage conservation is a cornerstone of modern livestock farming, ensuring that animals have a steady supply of nutritious feed throughout the year.

This is especially critical during periods of feed scarcity, such as winter or drought. The primary methods of forage conservation are **Hay**, **Silage**, and **Bale Wrapping**, each with unique benefits, challenges, and techniques.

1.1. Hay

Hay production is a widely practiced method focused on reducing the water content of forage to around **25%** (85% dry matter).

This moisture reduction inhibits the growth and proliferation of microorganisms, particularly molds, and preserves the nutritional quality of the forage.

The Drying Process

The time required for haymaking depends on several factors and can range from **2 days to over a week**:

- **Climatic Conditions:**

  Sunshine, wind, and low humidity accelerate drying, while rainy or humid weather slows the process.
- **Forage Characteristics:**

  The type of forage, initial moisture content, and the amount of biomass influence the drying rate.
- **Equipment and Techniques:**

  Proper use of machinery, including mowers, tedders, and rakes, ensures efficient drying.

Key Steps

1. **Raking Operations:**

Multiple raking passes are essential, especially for large volumes of forage.

These operations:

  - Promote even drying by exposing all parts of the forage to air and sunlight.
  - Reduce nutrient loss by preventing over-drying in certain areas.

2. **Monitoring:**

Close monitoring of weather conditions and moisture levels ensures optimal timing for baling, minimizing losses and preserving forage quality.

3.Advantages and Considerations

- **Advantages:**

Hay is easy to store, transport, and distribute.

It is also versatile, suitable for various livestock species.

- **Challenges:**

  Hay production is weather-dependent, requiring dry conditions to prevent spoilage during the drying process.

1.2. Silage

Silage involves preserving forage with high moisture content (**15%–35% dry matter**) through anaerobic fermentation.

This method is especially useful in regions with unpredictable weather, as it allows for harvesting and storage under less-than-ideal conditions.

The Silage Process

The key to successful silage is rapid **acidification**, achieved through the activity of **lactic acid bacteria**.

These bacteria convert soluble sugars into lactic acid, creating an acidic, oxygen-free environment that inhibits spoilage.

Quality Indicators

High-quality silage is defined by the following parameters:

- **pH:** ≤ 4 for forage with ≤ 35% dry matter.
- **Ammonia Nitrogen (N-NH3):** 5%–7% of total nitrogen.
- **Acetic Acid Content:** < 25 g/kg of dry matter.
- **Propionic and Butyric Acids:** Minimal or absent, indicating successful fermentation.

Critical Success Factors

1. **Fermentable Sugars:**
   - Forage species, growth stage, and sugar content are crucial. Ryegrass, for example, has sufficient sugar levels, while species like alfalfa and dactyl often require additional management.
   - Fine chopping enhances sugar availability for bacteria, improving fermentation.
2. **Anaerobic Conditions:**
   - Oxygen removal is critical.

   This is achieved by:

     - Rapidly filling the silo.

        - Thoroughly compacting the forage to eliminate air pockets.
        - Hermetically sealing the silo to maintain anaerobic conditions.
    - Proper compaction is especially important for drier forage (e.g., pre-wilted corn or legumes).

Advantages and Considerations

- **Advantages:**
  Silage retains high nutritional value, minimizes field losses, and can be stored for long periods.
- **Challenges:**
  Requires specialized equipment, careful management, and adherence to strict procedures to prevent spoilage.

1.3. Bale Wrapping

Bale wrapping is a hybrid conservation method that combines aspects of both hay and silage preservation.

It involves wrapping bales of forage in stretchable plastic film, creating an anaerobic environment that slows spoilage and maintains feed quality.

Key Principles

- Forage is harvested at a **higher dry matter content (50%–60%)** than traditional silage, reducing the risk of poor fermentation.
- The drying process is relatively quick, often completed in **less than 2 days** under favorable weather conditions.

Process Advantages

1. **Efficiency:**
    - Bale wrapping uses the same equipment chain as haymaking, with the addition of a bale wrapper.
2. **Flexibility:**
    - Bales can be wrapped shortly after pressing, with a delay of up to **24 hours** if protected from adverse weather conditions.
3. **Reduced Steps:**
    - This method eliminates some labor-intensive steps of traditional silage or haymaking, offering a practical solution for medium-sized operations.

Considerations

- **Costs:** Bale wrapping involves additional expenses for plastic film and requires skilled labor for efficient implementation.

- **Capacity:** Harvesting is typically limited to **3–4 hectares per day**, making it suitable for small to medium-sized farms.

2. Problems Arising from Forage Harvesting and Conservation

Forage harvesting and conservation are integral practices in livestock farming, as they help ensure the availability of quality feed throughout the year. However, these processes come with various challenges that can significantly affect both the quantity and quality of forage. These challenges primarily revolve around the loss of dry matter (DM) during harvesting, storage, and the activity of microorganisms that affect the preservation of forage.

2.1. Losses at Different Stages of Harvesting and Storage

Dry matter losses during the harvesting and conservation of forage occur due to a combination of physical, chemical, and biological factors. These losses are observed at every stage of the forage management process, starting from mowing, continuing during drying, and throughout storage.

2.2. Losses Due to Respiratory Processes

After the forage is mowed, it continues to undergo respiratory processes, which lead to the breakdown of stored carbohydrates and the loss of DM. This is a natural process as the plant material remains alive and respiring even after being cut.

- **Factors Affecting Respiratory Losses:**
  - **Plant species and moisture content:**

Different species of plants have varying moisture levels that influence the rate of respiration.

  - **Drying speed and environmental conditions:**

Fast drying in dry, sunny weather leads to quicker cessation of respiration, while slower drying in humid or cooler conditions prolongs the process.

  - **Harvesting method (dry or wet):**

Dry methods typically result in slower respiration once drying occurs, while wet methods (such as silage) can continue respiration for a longer period, even after harvesting.

- **Extent of Losses:**
  - **Hay production:**

The drying process for hay continues until the DM reaches approximately 75%.

During this phase, losses occur at rates of 1%–1.5% of the mowed DM per day.

These losses are significantly reduced in hot, dry weather conditions.

  - **Silage or bale wrapping:**

For wet forages, the respiratory losses continue for some time, but they are followed by anaerobic fermentation processes that help preserve the forage.

This leads to additional DM losses, but these are generally less severe compared to those in hay production.

2.3. Mechanical Losses

Mechanical losses are caused by the handling of forage during the harvesting process, and these losses accumulate throughout the different stages of the operation.

Improper use of equipment or inefficient practices can exacerbate these losses.

- **Mowing Losses:**
    - **Cutting height:**

The height at which forage is cut plays a crucial role in the yield. For grasses, even a small variation of 1 cm from the recommended cutting height of 6–7 cm can result in a variation of 100 to 200 kg DM per hectare.

- - **Lodged vegetation:**

When plants are flattened due to weather or other factors, the mower may not be able to cut them effectively, leading to additional losses.

- **Handling Losses:**
    - **Raking and Tedding:**

Forage requires manipulation to aid the drying process. Each handling operation (such as raking and turning) increases the exposure of the forage to air and sunlight, but it also results in DM losses.

The effectiveness of the equipment and the moisture content of the forage directly impact the extent of these losses.

- - **Losses due to equipment efficiency:**

Poorly calibrated equipment can leave a significant portion of forage in the field, particularly during raking, where small, broken pieces of forage may not be collected efficiently.

2.4. Losses Due to Leaching

Leaching occurs when rainfall affects forage during the drying process, particularly in the case of hay.

The direct and indirect effects of rain can cause nutrient losses and deteriorate the nutritional value of the forage.

- **Direct and Indirect Effects:**
    - **Direct rain impact:**

Rainwater can wash away soluble nutrients, such as sugars, nitrogen, and water-soluble vitamins, from the forage.

This results in significant nutritional losses.

- **Extended drying time:**

If rain delays the drying process, the forage remains exposed to the elements for longer periods, increasing the chances of nutrient leaching.

- **Impact on Nutritional Quality:**
  - **Energy and nitrogen losses:**

Rain can reduce the energy and nitrogen content of meadow hay, potentially lowering both by up to **12%**. For example, meadow hay harvested at the heading stage could experience a loss of **0.08 FC** and **7 g DDM/kg DM**.

- **Conservation Losses:**
  - Properly dried hay (>85% DM) results in minimal losses of **1%–4%** during storage if appropriate conditions are maintained.
  - Forages with lower DM content (like those used for ensilage or bale wrapping) tend to incur higher losses, especially if improper fermentation conditions or high moisture content lead to heating or juice production during ensilage.

2.5. A Complex Microflora

Forage is home to a complex and diverse microflora, consisting of a variety of microorganisms such as bacteria, yeasts, and molds.

These microorganisms are integral to the process of forage conservation, as they directly influence the preservation of the forage after it has been harvested.

The microflora can be classified into beneficial and harmful microorganisms, each playing distinct roles during the conservation process.

Beneficial microorganisms, such as lactic acid bacteria, contribute to the fermentation process, creating conditions that favor the preservation of the forage, while harmful microorganisms can lead to spoilage, mold growth, and the degradation of the forage's quality.

The success of the conservation process relies heavily on managing the balance of these microorganisms.

Ensuring that beneficial organisms dominate is key to maintaining the quality and nutritional value of the forage.

For example, in silage, lactic acid bacteria are encouraged to proliferate, as they produce lactic acid, which lowers the pH and prevents the growth of harmful bacteria.

On the other hand, molds and certain bacteria can cause undesirable effects such as rancidity, mycotoxin production, and the deterioration of the forage's palatability.

These harmful microorganisms can thrive in conditions of high moisture, improper pH levels, or inadequate storage practices, making it crucial to carefully monitor and control the conditions during the conservation process.

To maintain the dominance of beneficial microorganisms, proper management techniques are necessary, including optimizing the fermentation environment, controlling moisture levels, and ensuring an anaerobic atmosphere in the case of silage.

Regular monitoring of temperature, pH, and microbial activity is also essential to ensure that harmful microorganisms do not overtake the conservation process.

In some cases, inoculants containing specific strains of beneficial bacteria may be added to help boost the growth of the desired microorganisms and improve the preservation process. By managing the complex microflora effectively, it is possible to enhance the quality and shelf life of the forage, ensuring it remains nutritious and safe for livestock consumption.

2.6. An Abundant and Diverse Microflora

The microflora associated with forage is diverse and evolves over the course of harvesting and storage.

Microbial activity can significantly influence the quality of stored forage and can lead to further losses or health risks if not managed properly.

- **Microorganisms are classified into the following categories:**

2.6.1. Lactic Acid Bacteria

- **Characteristics:**

  Lactic acid bacteria (LAB) are anaerobic microorganisms that have the ability to produce lactic acid.

  This acidification reduces the pH of the forage, creating an environment that inhibits spoilage and supports fermentation.

- **Requirements:**

  LAB require fermentable sugars, which are available immediately after the forage is cut. Their activity is essential in the preservation of wet forages, especially in silage.

2.6.2. Other Bacteria

- **Types:**

  This category includes aerobic, facultative anaerobic, and strict anaerobic bacteria, such as **butyric bacteria**.

- **Sources:**

  These bacteria often exist in the soil as spores and germinate when the conditions in the silo or storage environment are favorable for their growth.

2.6.3. Yeasts and Molds

- **Characteristics:**
  - Molds are aerobic, requiring oxygen for growth.
  - Yeasts can grow in both aerobic and anaerobic conditions.
- **Effects on Forage:**
  - Yeasts and molds use sugars and amino acids in the forage, resulting in a decrease in DM and nutritional value.
  - They also produce secondary metabolites that can make the forage unappetizing or even toxic. Some molds, such as **Aspergillus**, produce mycotoxins that can cause serious health issues.

2.7. Health Risks from Contaminated Forage

The growth of harmful microorganisms in forage can pose serious health risks to both animals and humans.

- **Examples of Harmful Microorganisms:**
  - ***Listeria monocytogenes:***

Can cause encephalitis and abortions in small ruminants, particularly when the forage is heavily contaminated.

  - ***Aspergillus fumigatus:***

Often found on overheated or improperly stored forage, it can cause respiratory issues and may lead to abortions in livestock.

  - ***Fusarium spp.:***

Known for producing toxins that lead to mycoses (fungal infections) and allergic reactions in animals and humans alike.

- **Human Health Risks:**
  - **Respiratory conditions:**

Exposure to molds and bacteria can cause a range of respiratory issues in humans, including **farmer's lung**, **asthma**, and **chronic bronchitis**. Mold exposure can also lead to severe allergies, especially in individuals who work closely with contaminated forage.

3.Different Development Conditions by Categories

The various categories of microorganisms present in forage during harvesting and storage exhibit different requirements for their development, as well as varying sensitivities to factors such as pH and osmotic pressure.

These factors play a crucial role in determining the microbial growth and the overall preservation of forage.

Osmotic Pressure and pH Sensitivity:

- **Osmotic Pressure:**

  Osmotic pressure is influenced by the concentration of cellular fluids in the plant, which is directly linked to the dry matter (DM) content.

  For instance, forages with higher DM content have higher osmotic pressure due to the increased concentration of solutes (like sugars and salts) in the plant cells.

- **pH Sensitivity:**

  Different microorganisms exhibit varying sensitivities to pH levels.

  Butyric bacteria are particularly sensitive to relatively low acidity levels (pH below 4), and they struggle to thrive in such conditions.

  In contrast, **lactic acid bacteria** (LAB), which are essential for proper fermentation in silage, can tolerate and even benefit from low pH conditions as they aid in lowering the pH to inhibit spoilage.

  Butyric bacteria, known for producing off-smelling butyric acid, are more sensitive to high osmotic pressures than lactic acid bacteria.

  Therefore, any increase in DM content, which raises the osmotic pressure of the plant, helps suppress the development of undesirable microorganisms, particularly butyric bacteria, which are often associated with poor-quality silage.

Impact of High DM Content:

- Increasing the DM content of the forage at the time of harvest is a common practice to improve its conservation.

  For example, **bale wrapping** is an effective method for preserving long-stemmed forage with higher DM content. This approach helps minimize the growth of detrimental microorganisms and promotes better quality preservation. Higher DM content typically ensures a more stable fermentation process, reducing the chances of unwanted microbial development, such as the growth of butyric bacteria.

Listeria Monocytogenes and Contamination Levels:

- ***Listeria monocytogenes*** is a pathogenic bacterium that can pose serious risks to both livestock and humans if present in forages. However, research conducted by INRA (Institut National de la Recherche Agronomique) between 1990 and 1992 revealed that, out of more than 350 forage samples tested, less than 8% tested positive for Listeria monocytogenes. Furthermore, **silages** and **big round bales (BRB)** were found to be no more contaminated than hay.

This finding suggests that the risk of Listeria contamination in stored forage is relatively low, particularly when proper harvesting and conservation techniques are used, such as those that limit the exposure of the forage to excess moisture and poor fermentation conditions.

Adapting to Climatic Conditions

Harvesting and conservation methods for forage are highly dependent on favorable climatic conditions, which can be unpredictable.

The most critical factor for successful forage harvesting and preservation is consistent, dry weather that lasts for several days.

3.Weather Requirements for Different Methods:

- **Pre-wilted Silage, Bale Wrapping, and Haymaking:** These methods, which are commonly used for grasses and legumes, require several consecutive days of favorable weather. Specifically, the forage must remain dry during harvesting, which necessitates:
  - No rain during the harvest period.
  - Preferably sunny conditions to aid in the drying process, especially for haymaking and bale wrapping.

Challenges with Weather Variability:

- One of the main challenges of forage harvesting is the difficulty of predicting and ensuring optimal weather conditions throughout the entire process.
- This becomes particularly challenging when the harvesting period is long, or when it occurs early in the year, such as in **spring**, when weather conditions can be less predictable and more variable.
- **Spring Harvesting Risk:**

  The risk of unsuitable weather is higher during spring, when conditions can be fluctuating, with periods of rain or cold weather that can disrupt the harvest and increase the risk of losses in quality or quantity.

Bale Wrapping as an Alternative:

- **Bale wrapping** has emerged as a highly effective alternative for forage conservation. This method allows for mowing and harvesting forage earlier in the **spring** or even in the **autumn** without the same dependency on perfect weather conditions.
- By wrapping the forage in plastic soon after mowing, moisture is retained and fermentation is controlled, creating a stable, anaerobic environment that helps preserve the forage even in less-than-ideal conditions. This method also reduces the exposure of the forage to spoilage, making it a particularly viable option for those looking to secure a harvest despite the uncertainty of weather patterns.

4. Precautions to Take from Harvest to Conservation

Proper handling of forage from harvest through to conservation is crucial for ensuring high-quality preserved forage.

The following precautions focus on optimizing drying, reducing losses, and preserving nutritional value.

4.1. Ensure Rapid Drying

- **Minimize Ground Contact:**

It is critical to minimize the time forage stays on the ground after mowing.

The longer forage remains exposed to the elements, the higher the risk of losing nutrients and the more vulnerable it becomes to weather-related damage.

Rapid drying also helps preserve the nutritional quality of the forage by preventing microbial activity that can degrade its value.

- **Optimal Drying Conditions:**

Ensuring a rapid drying process helps reduce the potential for spoilage, mold, and other microbial issues, maintaining the forage's quality for future use, especially in high-moisture environments or wet conditions.

This precaution is essential not only to combat the impact of fluctuating weather conditions but also to preserve the forage's inherent nutritional benefits.

4.2. Avoid Mowing Too Low

- **Mowing Height and Drying Speed:**

The mowing height is a critical factor influencing the drying process. Mowing too low increases the amount of forage to be dried, and the denser, wetter material will take longer to dry.

A mowing height of **6 to 7 cm** is considered ideal, providing a balance between maximizing yield (tons of dry matter per hectare) and ensuring high-quality forage.

- **Improved Air Circulation:**

Maintaining a higher mowing height allows for better airflow within the swath, which helps accelerate the drying process.

Additionally, mowing should only be done when the forage is dry enough to avoid additional moisture uptake, which could extend drying time.

Mowing after the dew has evaporated ensures the forage does not remain overly wet, which can further complicate the drying process.

4.3. Ted After Mowing

- **Maximizing Drying Efficiency:**

While it is common practice to wait a few hours before tedding, **tedding immediately after mowing** can significantly improve the drying process.

This technique allows the swath to be aerated right away, promoting better ventilation throughout the forage.

The faster the drying process begins, the fewer the losses, particularly for legumes like alfalfa and crimson clover, where the leaves dry much faster than the stems.

- **Reducing Losses:**

Tedging also helps minimize respiration losses by ensuring the forage is spread out and dries more evenly.

By handling the forage early, the risk of over-drying, which can cause significant losses, is reduced.

4.4. Preferentially Use Conditioners

- **Accelerating Drying:**

Conditioners, such as **flail** or **roller conditioners**, are essential tools that help speed up the drying process, especially for legumes like alfalfa.

These devices crush or break the stems, which are often more resistant to drying, thereby facilitating quicker moisture loss.

- **Reducing Handling Requirements:**

Conditioners reduce the need for multiple tedding operations, which can reduce the risk of mechanical losses and the time required for drying.

By improving the efficiency of the drying process, conditioners can also help maintain the quality of the forage by reducing the time it spends on the ground exposed to the weather.

- **Minimizing Mechanical Losses:**
- In addition to accelerating drying, conditioners help reduce losses caused by mechanical factors.

For instance, fewer tedding operations lead to less disturbance to the forage, reducing the risk of losing small particles, which may result in a loss of nutritional value.

4.5. Act at the Beginning or End of the Day

- **Timing and Drying Uniformity:**

Forage, particularly grass, dries unevenly depending on the moisture content of its components.

Leaves lose moisture faster than stems or inflorescences, which can lead to a situation where the upper parts of the forage are dry while the lower portions remain wet.

This differential drying can result in losses, particularly affecting the leaves and diminishing the overall value of the forage.

- **Optimal Harvesting Time:**

To prevent such losses, it is important to work with the forage at the right time of day.

The best approach is to start early, once the dew has evaporated, but before the sun becomes too strong.

This timing ensures that the forage is dry enough to handle but not overly dry, preserving the leaves and improving the quality of the harvested material.

4.6. Barn Drying

- **Controlled Drying Environment:**

Barn drying is an alternative technique that provides a controlled environment for forage drying, making it less dependent on fluctuating weather conditions.

By drying forage indoors, you can avoid the uncertainties associated with rain or excessive humidity, ensuring that the forage is dried under optimal conditions.

This method also protects the forage from potential damage due to extreme weather.

- **Cost and Scale Considerations:**

While barn drying is highly effective, it is also more expensive and may not be feasible for smaller operations.

This method is best suited for larger-scale operations where significant amounts of forage need to be harvested and dried quickly.

In addition to the financial investment, barn drying requires careful management of space, air circulation, and temperature to maintain forage quality throughout the drying process.

5. Limiting Contaminations and Forage Losses at Harvest

Forage contamination is a significant concern during the harvest process, as it can affect the overall quality and safety of the final product.

Contamination often occurs when soil is inadvertently picked up during mowing, tedding, or raking operations. This issue can be exacerbated in permanent pastures, where the mixture of soil and plant material is more likely to occur.

The presence of soil not only reduces the quality of the forage but can also introduce pathogens, weed seeds, and undesirable microorganisms that could negatively impact the nutritional value and palatability of the feed.

Additionally, contamination can complicate the preservation process, especially in the case of ensilage or bale wrapping, where soil particles can interfere with fermentation or introduce harmful bacteria.

To ensure the harvested forage meets high-quality standards, it is essential to implement measures that minimize contamination from the outset.

One of the most effective ways to reduce contamination is by ensuring that mowing is done at an appropriate height.

Mowing too low to the ground can increase the likelihood of soil being picked up, as well as other undesirable debris.

A mowing height of 6-7 cm is typically recommended to avoid excessive soil contact while still allowing for an adequate harvest.

This height helps reduce the chances of mixing soil with the plant material and facilitates better air circulation during the drying process, further reducing contamination risks.

Additionally, the timing of tedding and raking operations is crucial. Tedding should be performed when the forage is dry and free of excessive moisture, as wet conditions increase the likelihood of soil adhering to the plants.

Moreover, tedding too late in the morning or early in the afternoon, when the air is warmer and more humid, can lead to mechanical losses and further contamination.

Ideally, these tasks should be carried out early in the morning, after the dew has disappeared, or in the evening, when humidity levels are higher and the risk of soil being disturbed is lower.

In some cases, the design and maintenance of harvesting equipment play a significant role in minimizing contamination. For example, regular cleaning of mowers, tedders, and rakes can prevent the accumulation of soil, plant material, and other contaminants.

Ensuring that the equipment is free from dirt and debris before each use helps to reduce the risk of transferring contaminants onto the forage. Furthermore, equipment should be properly calibrated to ensure that it operates at optimal efficiency, reducing the chances of unnecessary soil contact or damage to the plants.

Finally, proper storage and handling of the harvested forage are critical in maintaining its quality and minimizing the risk of contamination.

For example, storing the forage on clean, dry surfaces and ensuring that storage areas are free from pests and rodents can further reduce the chances of contamination.

For silage or bale-wrapped forage, it's important to store it in areas where the temperature, humidity, and air circulation are carefully controlled to prevent the growth of harmful bacteria or mold.

By applying these strategies during the harvest process, farmers and forage producers can effectively minimize contamination and preserve the high quality of the forage, ensuring that it meets the nutritional needs of livestock and the standards required for market sale.

5.1. Avoid Mowing Too Low

- **Maintaining Proper Mowing Height:**

Mowing at too low a height can lead to increased contamination as more soil is collected during the harvesting process.

To reduce this risk, it is essential to **mow at a height of 6-7 cm**, especially for forages that will be used for ensilage or bale wrapping, as these are more sensitive to contamination.

- **Impact on Soil and Forage Collection:**

Mowing lower than this height requires setting the **tedder and rake** lower as well to pick up the forage.

This increases the chances of soil contamination, which can reduce the nutritional quality of the forage and cause issues during storage.

5.2. Time the Tedding Right

- **Tedding Timing and Its Importance:**

Tedding should be done carefully, and the timing plays a significant role in minimizing mechanical losses and preserving forage quality.

It is better to avoid tedding late in the morning or early in the afternoon when the sun is strongest.

Instead, **tedding should be done early in the morning** after the dew has disappeared, or in the evening when the humidity levels are higher.

- **Minimizing Leaf Losses:**

Tedding at the right time reduces the risk of leaf losses, which can impact the overall quality of the forage.

This is particularly true for **large legumes** like alfalfa, but it applies to grasses and mixed pastures containing clover as well.

- **Avoiding Haste:**

Tedding should be carried out carefully, without rushing, to prevent further mechanical damage and losses of valuable forage material, particularly the leaves.

5.3. Maintain a Clean Harvest Process

- **Clean Harvesting to Prevent Soil Contamination:**

One of the most significant sources of contamination during forage harvest is the introduction of soil, especially when making **silage**.

Ensuring a **clean harvest process** is crucial to minimize the risk of soil contamination.

This is particularly important for ensilage and, to a lesser extent, for bale wrapping.

- **Harvesting in Controlled Environments:**

  To minimize contamination, it is advisable to carry out harvesting operations on **concrete floors** or **bunker silos**, which are more efficient in controlling and containing soil and debris. This approach is especially important for silage, where even small amounts of soil can severely impact quality.

5.4. Harvest at the Right Moment

- **Optimal Dry Matter (DM) Content for Harvest:**

  It is essential to target the correct **dry matter (DM) content** for each type of harvest.

  For instance, **hay** requires complete dryness, whereas **ensilage** and **bale wrapping** need specific DM levels to ensure optimal preservation and quality.

  - **DM Content for Ensilage:**

    For grass silage, aim for around **25% DM**, while for corn, a **35% DM** is ideal.

    These ranges allow for proper fermentation without the risk of undesirable microbial activity.

  - **Bale Wrapping Flexibility:**

    With **bale wrapping**, there is more flexibility, with a desired DM content of **50% to 60%**. Harvesting slightly above or below this range will not significantly affect the quality of the forage distributed, but it's crucial to avoid extremes to prevent the development of **butyric acid bacteria**, which can cause spoilage, especially in dairy operations.

6. Ensuring Perfect Preservation

Regardless of the storage method used, especially for forage that does not meet optimal characteristics, ensuring **perfect preservation** is key to maintaining forage quality and preventing spoilage or the growth of pathogenic microorganisms.

6.1. Silage Case

- **Quality of Silage Preservation:**

  The success of **silage** particularly **grass silage** depends largely on how well it is preserved. One of the most critical aspects is preventing **re-fermentation** during storage.

  This requires creating an anaerobic environment to maintain the silage's quality until the silo is opened.

  - **Resumption of Fermentation During Feedout:**

    Once the silo is opened, fermentation will resume, so it's crucial to **advance quickly** on the feedout face to avoid spoilage.

    - **Feedout Rate:**

To ensure optimal preservation, a **feedout rate** of **10 to 20 cm per day** is generally advised. When constructing a silo, it should be sized appropriately based on the **daily feeding requirements** of the herd, ensuring that there is a constant supply of fresh, quality silage.

6.2. Bale Wrapping Case

- **Proper Bale Wrapping Techniques:**

Just like with silage, ensuring perfect preservation of **bale wraps** requires following specific guidelines:

- **Bale Shape and Density:**

It is crucial to ensure that round bales are **uniform in shape** and are **densely packed**.

This helps in sealing the bale properly to prevent air from entering, which could lead to spoilage.

- **High-Quality Plastic and Sufficient Overlap:**

Use **high-quality plastic** for wrapping the bales, preferably wide films. When wrapping, make sure there is a **50% overlap** of the film at each pass.

Additionally, the minimum number of layers should be **four**, or more for **drier forages with stems**, to reduce the risk of punctures.

- **Storage Conditions:**

Bales should be stored **on their flat side**, on a **flat surface**, and **not stacked** to avoid pressure on the wraps.

During storage, regularly monitor for the appearance of **holes** caused by external factors like **birds or rodents**, which can compromise the seal and allow spoilage.

- **Feedout Control:**

Similar to silage, when opening bale wraps, fermentation resumes, so it's crucial to observe a controlled **feedout rate** to limit fermentation damage.

During **winter months**, it is advisable to consume a bale wrap within **5 to 6 days** to ensure the forage remains in optimal condition.

7. Preservatives

The use of **preservatives** can sometimes be beneficial for both **ensilage** and **hay**, particularly when conditions are not optimal for preservation.

A range of preservatives, such as **formic acid**, **propionic acid**, **acid salts**, and **lactic acid bacteria**, can be applied to inhibit the growth of undesirable microorganisms or to lower the pH to a level that prevents spoilage.

7.1. Effectiveness of Preservatives

- **Variety of Preservatives:**

  Preservatives work in different ways—some alter the pH of the forage, while others destroy or inhibit the activity of harmful microorganisms.

  While certain preservatives are quite effective, their application often requires specialized equipment, which can limit their practicality for smaller operations.

- **Limitations of Preservatives:**

  It is important to note that the use of preservatives does not eliminate the need for careful management of the harvest process.

  Even with preservatives, ideal conditions for preservation must still be met, such as controlling moisture levels and temperature.

7.2. Realistic Expectations for Preservation

- **Imperfect Preservation:**

  Even with the best efforts, it is unrealistic to expect **perfect preservation** for all forage.

  In many cases, especially with **wet-stored forages**, some areas of the silo or bale wraps particularly near the periphery may show signs of spoilage.

  These altered zones should be removed before feeding. If spoilage is extensive, it is best not to distribute the affected bale wrap.

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