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Experimental analysis of the conservation conditions and development of a traceability device for fruit products

Diogo Cerqueira Morais

Dissertação para obtenção do Grau de Mestre em
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Orientador: Prof. Doutor Pedro Miguel de Figueiredo Dinis Oliveira Gaspar
Coorientador: Prof. Doutor Pedro Dinho da Silva

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Resumo

Os produtos hortofrutícolas encontram-se muitas das vezes sujeitos a condições durante a conservação e o transporte que em nada promovem a manutenção das suas propriedades biológicas. Como resultado desta perda de qualidade, ocorre um decréscimo da valorização do produto. Mas mais importante que a perda do valor económico, é a segurança e o desperdicio alimentar.

Esta dissertação envolveu um estudo experimental caracterizado pela avaliação das condições de conservação no interior de câmaras de conservação de produtores de frutícolas, nomeadamente de pêssego e de cereja da região da Beira Interior, Portugal. Este estudo consistiu na monitorização durante duas campanhas, a de 2018 e a 2019, da temperature e humidade relativa do ar de conservaçao fazendo uso de vários dataloggers da “LASCAR ELETRONICS”, dispostos em diferentes caixas localizadas a diferentes posições e alturas numa palete. Com os resultados, foi feita a caracterização do ambiente de conservação a que os produtos frutícolas estiveram sujeitos, bem como ao dimensionamento de um sistema de monitorização.

Todavia, o sistema de monitorização utilizado não permite realizar uma rastreabilidade em tempo real dos parâmetros influentes na qualidade dos produtos. Os sistemas de monitorização remota, cujos requisitos fundamentais se prendem com a autonomia e alcance, fazem uso de tecnologias de comunicações para formar mapas dos parâmetros característicos de culturas com o intuito de reduzir a aplicação desnecessária de recursos ou materiais.

Foi assim desenvolvido um protótipo com a função acompanhar as caixas de produtos frutícolas durante o transporte entre o produtor e o centro de distribuição. Este dispositivo é composto por um microcontrolador ARDUINO UNO Rev3 que faz a aquisição a cada 5 minutos da temperatura e humidade relativa do ar por intermédio de um sensor DHT 11, dispõe de um módulo SIM800L que o dota da capacidade de comunicação em tempo real via GSM. Incorpora ainda uma bateria de 3.7 V - 2600mAh que lhe proporciona uma autonomia energética aproximada de 60 horas.

O sistema, ao proceder à aquisição, permite ao produtor um controlo remoto do seu produto durante as etapas mais críticas da cadeia de frio, o transporte e o armazenamento no centro de distribuição. Enquanto que os dados de temperatura e humidade podem ser utilizados pelo produtor para assegurar a qualidade do seu produto no momento de entrega no centro de distribuição, o histórico de localizações permite a otimização das rotas de transporte, visando a extensão do tempo de vida do produto, que por sua vez, se reflete num aumento da receita económica das PMEs e numa redução do alimento desperdiçado.

Palavras-chave

Conservação, transporte, produtos frutícolas, desperdicio alimentar, avaliação, sistema de monitorização

Abstract

Fruit and vegetables are often subject to conditions during storage and transport which in no way promote the maintenance of their biological properties. As a result of this loss of quality, there is a decrease in product appreciation. But more important than the loss of economic value is safety and food waste.

This dissertation involved an experimental study characterized by the evaluation of the conservation conditions inside the conservation chambers of fruit, namely peach and cherry producers in the Beira Interior region, Portugal. This study consisted of monitoring during two campaigns, 2018 and 2019, the temperature and relative humidity of the conservation air using several “LASCAR ELECTRONICS” dataloggers, arranged in different boxes located at different positions and heights on a pallet. With the results, it was made the characterization of the conservation environment to which the fruit products were subjected, as well as the dimensioning of a monitoring system.

However, the monitoring system used does not allow real-time traceability of parameters influencing product quality. Remote monitoring systems, whose fundamental requirements relate to range and autonomy, make use of communications technologies to map characteristic crop parameters to reduce the unnecessary application of resources or materials.

A prototype was developed with the function of monitoring the boxes of fruit products during transport between the producer and the distribution center. This device is composed of an ARDUINO UNO Rev3 microcontroller that acquires every 5 minutes of temperature and relative humidity through a DHT 11 sensor. It has a SIM800L module which gives it the ability to communicate in real-time via GSM. It also incorporates a 3.7 V - 2600mAh battery which gives you an approximately 60-hour power range.

By acquiring temperature and relative humidity values, the system allows the producer to remotely control their product during the most critical stages of the cold chain, transportation, and storage at the distribution center. Although temperature and humidity data can be used by the producer to ensure the quality of their product upon delivery to the distribution center, location history allows for the optimization of transportation routes to extend product life., which, in turn, is reflected in the increased economic revenue of SMEs and the reduction of food waste.

Keywords

Conservation, transport, fruit products, food waste, evaluation, monitoring system

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Acronyms List

UBI	Universidade da Beira Interior
RSSI	Received signal strength indication
PCB	Printed circuit boards
HACCP	Hazard Analysis and Critical Control Point
QACCP	Quality Analysis and Critical Control Point
AoA	Angle of Arrive
AoD	Angle of Depart
BLE	Bluetooth low energy
RFID	Radio frequency identification
NFC	Near field communication
GSM	Global System for Mobile Communications
GPRS	Global Pac
RTLS	Real Time Location System
IPS	Indoor Positioning System
IDE	Integrated development environment
QTT	Quality oriented tracking and tracing system
SME	Small and Medium Enterprises
MAP	Modified atmosphere package
FEFO	First Expires First Out

Symbols List

1 Introduction

1.1 Background

Food security has been a key subject to policy changes as a result of increased consumer interest in the way food is produced, transported and stored and due to various incidents (Kleter *et al.*, 2008). Food products such as fruit and vegetables are susceptible to a variety of risks during transport and storage, which are responsible for the loss of quality (Ruiz-Garcia et al., 2008). As an example, they are vulnerable to deterioration caused by natural, chemical or contamination factors. The possibility of measuring the qualitative properties of the fruits allows to supervise, normalize and characterize, leading to an economic valorization of the products and reducing food waste (Chen, Ruiz-Altisent, & Barreiro, 1996).

The exponential increase in the world population expected up to the year 2050 will lead to tensions in the environment, such as resource overuse, climate change, land degradation, deforestation and water scarcity, social organization, economic systems and development technological development. According to FAO, to meet a population of 9 billion by 2050, it is vital that food production increases by at least 60% (FAO, 2009). In order to achieve this objective, joint efforts and investments are needed to promote this global transition to sustainable agriculture and land management systems. These measures imply an increase in efficiency of the use of natural resources - mainly water, energy and land - but also in the considerable reduction of food waste. In this sense, traceability systems for food products based on the analysis of conservation parameters are seen as a means of controlling environments during storage at the producer and during transportation, allowing real-time monitoring of food conditions. At present, the devices that exist in the market have a high initial investment depending on the required functions.

The technological development that surrounds us today allows the incorporation of communication capabilities in almost all devices, which is called the Internet of Things (IoT), or Revolution 4.0. Researchers in the field estimate that the connected IoT devices will grow to 50 billion by 2020, with an average of 6.5 devices per person (Nukala *et al.*, 2016). This phenomenon is well regarded by the industry, allowing the incorporation of wireless devices that allow the control of production lines, energy costs, state of production and the quality of the produced goods. In this context, smart packaging systems are included.

1.2 Main objective

Food waste is one of the largest current problems of the century. According to the Economist Intelligence Unit, one-third of global food production is wasted, equivalent to four times the food needed to feed the world's undernourished people (BCFN, 2015). The cost associated with food waste in the EU-28 in 2012 was estimated to reach 143 billion euros (FUSIONS, 2016).

But what will be the most adequate response to the population growth that is approaching? Finding new areas for cultivation alone will not solve the problem of food production, but innovation may help. The increase in production between 1961 and 2005 was 77% due to the development of agricultural techniques and equipment, and only 14% due to the expansion of cultivated areas (Fixing Food, 2018).

Along the transport chain, i.e. from production to storage and through transport and marketing, the food should be maintained at temperature and humidity conditions that promote the extension of the life span. These conditions should be monitored with in order to optimize the process.

In Portugal, the business sector is made up mostly of Small and Medium Enterprises (SMEs), with a total of 1 213 107 companies divided by the various sectors of activity in 2016 (PORDATA, 2019). The agribusiness sector is the largest contributor to the Portuguese economy with 14 billion euros, 25% of the existing industry (Gaspar *et al.*, 2014). In this perspective, the implementation of a device that allows real-time monitoring of the conservation conditions yields the SMEs with a superior logistics capacity, allowing the expansion of the trade routes of their products.

1.3 Objectives and contribution of the dissertation

It is intended to develop an equipment capable of real-time monitoring of the conservation conditions within the transport boxes of horticultural products throughout the marketing process, whose operating parameters must be previously established using experimental tests to quantify the temperature and humidity values inside the conservation chambers. The possibility of being able to follow in real-time the state of conservation in which the product is found meets the needs of the agro-food sector and the consumer. For the sector, it allows analyzing and evaluating the atmosphere in which the product is, and knowing the critical points, necessary in the control of food safety determined by HACCP (Hazard Analysis and Critical Control Point) systems. For the consumer, this translates into a better quality of food as well as a reduction in the final price, since as there is less loss for the retailer the price can be reduced.

1.4 Overview and organization of the dissertation

This dissertation is essentially organized in two parts, the first one evaluating the conservation conditions of fruit products, and the second one where a prototype is developed to allow the monitoring of fruit products.

The first part is to evaluate the conservation conditions of fruit products, particularly cherry and peach, in the Producers' chambers by conducting an experimental test. HACCP legislation and standards regulating food transport are also reviewed.

The second part is aimed at developing a real-time monitoring system to monitor fruit products during transport and allowing access to conservation and location values through IoT technologies. Finally, two tests are performed that validate the operability of the device.

Thus, Chapter 1 includes the background and objectives of the dissertation. Chapter 2 provides a brief introduction to the food security and food transportation subject, the different types of packaging used for food and the different types of communication technologies currently used. Chapter 3 refers to the experimental study, where is included the experimental tests did in 2018 and 2019, which allowed the definition of the range values of measurement for the device. The results of the experimental tests performed inside the chambers are presented in Chapter 4, with the results of each year of measurement and, finally, the comparison of the results for each year of test per fruit.

Chapter 5 contains 4 sections, the first dealing with the thermal inertia to which a pallet is subjected, as well as the temperature variation between the top of the pallet and the base, in the second, the range of values to which the device will operate. The third section explains the device development process and the last section, the results obtained in the validation of the system.

Finally, in Chapter 6, a general analysis of the work developed is made, as well as the conclusions resulting from it, and the ideas and directions of research for the development of future works are presented.

2 State of art

2.1 Food security

The quality of fruits and vegetables is the result of the physical and chemical properties to which the vegetables are subject, as well as the consumer's opinion regarding the state of the product. According to Schreiner *et al.* (2013), the definition of quality sometimes discards intrinsic characteristics inherent to the nature of the product, dictated by agri-food factors and post-harvest, and extrinsic characteristics influenced by market and socioeconomic factors, influencing consumer opinion about products. The acceptability of a product by the consumer is reflected in an increase in the number of sales of that product, thus constituting a benchmark for quality (Abdel-Kader & Luther, 2008). Still, consumer needs and perception of quality are not static but evolutionary and dependent on individualized lifestyles, time spent on food confectionery, population flows, marketing, food concerns, and gastronomic trends (Jabs & Devine, 2006). However, although there are a large number of studies about how different factors can influence product quality, i.e., rigidity, color, taste, acidity, among other properties, little is known about the impact of these attributes on quality perception (Sargent & Moretti, 2016). The use of sensors and instruments to determine the safety and quality states of fruit and vegetable products can be seen as a solution for the standardization of the definition of quality, allowing the establishment of a quality interpretative structure and the construction of predictive models of products quality along the transport chain (Kyriacou & Rouphael, 2018).

The consumer's access to new technologies has given him greater concern about his food and the origin of the products, including the use of chemicals and their ecological footprint. Due to their biological nature, fruit and vegetable products after harvest remain with their active metabolism and as such are susceptible to cell degradation, meaning a race against time by all actors in the distribution chain.

Thus, notwithstanding the fact that the quality of food can only be maintained and not improved, the development of a monitoring system could be the key to quality control, from harvest to commercialization.

2.2 Transportation and cold chain

The last mile of food delivery is often the most challenging, especially when it comes to ensuring reliable access to healthy, affordable, and culturally appropriate food. According to Baptista (2003), when it is necessary to move the horticultural products of the producer to a distribution center, special vehicles are used which have been designed and constructed in such a way as to:

- Not contaminate food or packaging, providing effective protection;
- Be effectively cleaned;
- Be able to effectively maintain the temperature, humidity, atmosphere and other conditions necessary to protect food from unwanted microbiological growth and deterioration.

According to Decree-Law no. 425/99, these cargo vehicles are subject to tight regulation, which is applicable to land vehicles or maritime transport, which must meet the following requirements:

- Interior walls, including floor and ceiling, shall be lined with corrosion-resistant, impervious, imputable, easy to clean and disinfect materials and shall not emit or absorb odors;
- Interior walls should be smooth and light in color;
- Where necessary, floors must have a water drainage system;
- All materials that may come into contact with transported foodstuffs must be of material that does not contaminate them or transmits toxic substances, odors, color or taste;
- All the devices relating to the closure, ventilation and aeration of vehicles, where necessary, shall allow the transport of food from all contaminations;
- Thermometers shall be placed in a visible place to measure the temperatures to which the food is subjected during transport;
- Easily washable pallets intended to allow adequate air circulation should be provided, ensuring hygienic conditions for food transported;
- The exterior walls of the isothermal boxes must be light colored and the inscriptions, which may be printed on them, must be of different colors and as small as possible.

Regulations to mitigate food contamination due to incorrect handling are designated as HACCP (Hazard Analysis and Critical Control Point), constituting a systematic approach to biological, chemical and instead of inspections and tests on final products, thus being a system of preventive measures (Batista, 2003).

The HACCP system was developed in the 1960s by several partners in the United States to produce safe food for the country's space program. Since 1980, this methodology has been recommended for food companies by the World Health Organization (WHO), the International Commission on Microbiological Specifications for Foods (ICMSF) and the Food and Agriculture Organization of the United Nations (FAO). The HACCP system is based on seven principles that must be taken into account in the application (ARESP, 2006):

1. Identification of any hazards that should be avoided, eliminated or reduced to acceptable levels;
2. Identification of critical control points at the stage or stages where control is essential to avoid or eliminate a risk or to reduce it to acceptable levels;
3. Establishment of critical limits at critical control points that separate the acceptability from non-acceptability for the prevention, elimination or reduction of identified risks;
4. Establishment and implementation of effective monitoring procedures at critical control points;
5. Establishment of corrective measures where monitoring indicates that a critical control point is not under control;
6. Establishment of procedures to be carried out regularly to verify that the measures referred to in the 1st to 5th Principle work effectively;
7. Drafting of documents and records appropriate to the nature and size of enterprises in order to demonstrate the effective application of the measures referred to from the 1st to 6th Principle.

In Small and Medium Enterprises (SME), given the size of the business volume, the adoption of preventive measures is not always a priority, meaning that, not always the principles of hygiene and safety in the workplace and food safety are ensured, compromising the entire distribution chain, the quality of the product and the health or life of the workers themselves. Obstacles for the adoption of preventive measures in SMEs depend on internal factors, such as the level of knowledge or the availability of resources, or external factors, such as the availability of government support to industry.

All food products are subject to contamination by various agents that are sometimes imperceptible to the consumer, acting as a transport vehicle for substances harmful to human health. Contamination can occur through biological, physical and chemical pathways.

The biological contamination is due to the action of microorganisms, for example bacteria, viruses and molds. Physical contamination results from the deposition or introduction of an object outside the food, such as a screw, a hair or an insect, and chemical contamination occurs when food products come in contact with chemicals or their residues, such as lubricants, disinfectants or detergents.

The development of the bacterial population depends on several factors, such as (ARESP, 2006):

- Nutrients;
- Temperature;
- Humidity;
- Acidity;
- Oxygen;
- Time.

According to NP - 1524 of 25 March 1987 and Regulation 853/2004 of 29 April 2004 on the inland transport of perishable foodstuffs - characteristics and use, chilled fruit and vegetables, such as peaches and cherries, have the limitations set out in Table 1.

Table 1: Limit conditions on food transport, in particular, cherry and peach.

Product	Maximum food temperature	Maximum distance or time on vehicle transport
Cherry	+4 ºC	100 km or 2h
Peach	+7 ºC	100 km or 2h

The international distribution of food products consists of a worldwide network subject to the regulations of each intervening country, which proves to be another obstacle to food quality and safety, as seen in Figure 1 (Morais *et al.*, 2019).

One way of safeguarding the integrity of food products is by using monitoring systems, whether of temperature, humidity, ethylene and oxygen content or microbial growth, to measure quality at any stage of the cold chain.

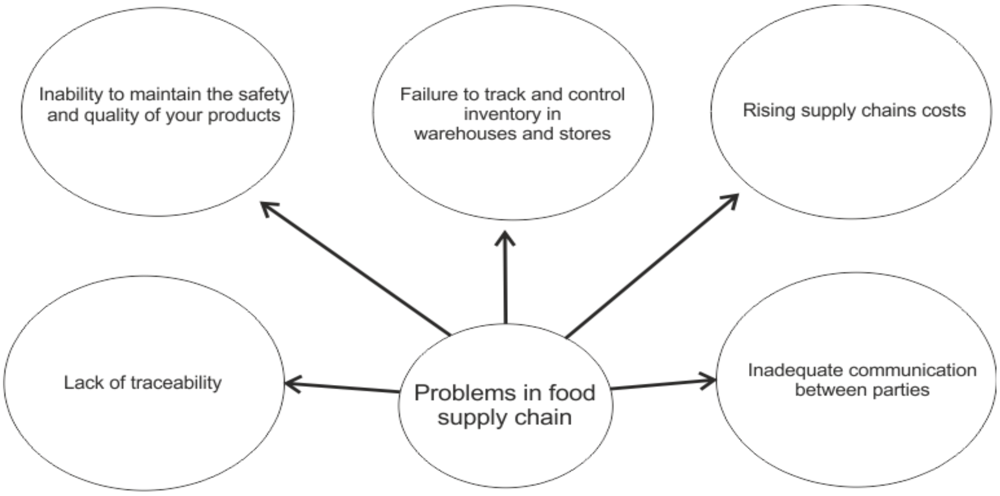


Figure 1: The main problems in the food supply chain.

Rediers et al. (2009) evaluated the cold chain of fresh-cut endive and observed that the global temperature profile revealed some critical points in the cold chain, mainly during the transportation from the farm to the processor and from the processor to the distributor, where small temperature rises were observed.

Ruiz-Garcia et al. (2010) evaluated the storage conditions inside a refrigerated transport vehicle and found that the temperature recorded was above the setpoint 98% of the time. Martinsdóttir et al. (2010) assessed the variation in temperature and deterioration in the quality of cod fillets depending on the type of packaging used and the position on the pallet in maritime transport containers. It was concluded that the temperature oscillation translated in a reduction of the validity of the product between 1.5 and 3 days. The highest temperature variations were recorded on the pallets placed in the corners of the container, resulting in the faster deterioration of the product and an increase in the microbial rate compared to the pallets that were in the center. Also, during the transportation of fresh cod loin fillets, it was observed that 35% and 18% of the time by air and sea transportation, respectively, the temperature was higher than recommended at around 1ºC.

In the United States, Pelletier et al.(2011) evaluated the transport conditions of strawberries by truck. It was found that the truck was unable to maintain the temperature of the pallets under study. After harvesting, the strawberries were cooled and before loading they were wrapped in plastic in a modified atmosphere (MA). Transport from producer to distribution center was monitored and temperature and relative humidity values were evaluated.

In Finland, Lundén et al. (2014) monitored the temperature of fish, meat, and ready-to-eat food in retail stores and found that about 50% of the temperature of these products were out of their controlled temperature range (i.e., above 1°C) for up to 24h. In addition, there was a significant deviation between the actual product temperature and the temperature indicated by the refrigeration equipment up to 6°C.

The implementation of monitoring systems has attracted interest from the cold chain actors, whether producers, distributors or consumers, and in recent years have been the subject of research and development by various authors in the framework of projects as shown in Table 2.

Table 2: Similar projects in traceability systems for food supply chain.

Project & Reference	Duration	Focus
Chill-On (Olafsdottir *et al.*, 2010)	2006-2010	TTI with chemical detection and RFID interface
PASTEUR (Hoofman, 2013)	2009-2012	RFID tag with multiple sensors (temperature, humidity and gas detection)
Intelligent container (Jedermann *et al.*, 2014)	2010-2013	Prototype container for QTT and FEFO
FRISBEE (Gwanpua *et al.*, 2015)	2010-2014	Simulation and creation of database for temperature mapping and models of lifetime
DANAHMAT (Jevinger *et al.*, 2014)	2013-2016	Concepts for dynamic labeling capable of determining validity

With the development and implementation of monitoring systems, it is possible to develop algorithms to predict the remaining life of the products. In this way, all players in the distribution chain benefit from either an increase in the value of revenues or an increase in product quality.

2.3 Packaging

For food to remain fit to be consumed, it is necessary to ensure its integrity throughout the stages prior to consumption. Packaging is one of the main processes that promote the preservation of the quality of food products during transport and storage. It consists of four basic functions (Ghaani, Cozzolino, Castelli, & Farris, 2016):

- **Protection:** keep food in a limited volume, protected from leakage, breakage, contaminants and other changes;
- **Containment:** keep the food inside for easy transportation, handling and storage;
- **Communication**: giving important information, such as shelf life, nutritional value and method of preparation;
- **Convenience:** allow to enjoy the food in a practical way according to the needs of the consumer.

Currently, food packaging only covers the basic needs of insulation, protecting food from chemical or microbiological contamination, oxygen, water vapor and light (K. A. Mane, 2016).

In the last decade, as a result of technological development, the profile of the final consumer has reached new and high requirements, demanding a higher quality of food and an access to its history. Thus, the packaging is no longer just a transport element and it has gained additional functions and status. This evolution reflects the need for new methods and efficient ways to optimize business processes, considering the existing problems with food safety and quality during the transportation process and also to reduce product loss (Vanderrost *et al.*, 2014). In addition to the importance of product packaging, environmental concern is also a variable to consider. A sustainable packaging has the potential to reduce the environmental impact by using recyclable materials of natural origin or nano materials (Han, Ruiz-Garcia, Qian, & Yang, 2018).

In Europe, there is a large interest in the development of active and intelligent packaging, translating into a growing number of research projects in the area. Some of these projects are presented in Table 3.

Table 3: Overview of different research projects concerning active and intelligent packaging.

Project name	Year	Project description	Reference
BioSmart	2017	Development of an active and smart bio-based and compostable packages to meet the needs of both fresh and pre-treated food applications.	http://biosmart-project.eu/
EasyFruit	2013	Develompent of a new packaging system that extends the shelf life of peeled and cut fruit 3-5 days longer than currently used technologies.	http://www.easyfruit.eu/
BioActiveLayer	2013	Development of a biodegradable, multi-layered packaging for dried food applications.	http://www.bioactivelayer.eu/
SUSFOFLEX	2012	Intelligent food packaging solutions to extend the use-by date of food products and protection against microorganisms.	https://cordis.europa.eu/
ISA-PACK	2012	Flexible and sustainable active and intelligent technological platform to pack fresh products aiming to extend the shelf life and quality, increase safety and reduce food and packaging waste.	https://cordis.europa.eu/
IQ-FRESHLABEL	2010	Promotion of implementation of new intelligent labels through research of expectations of consumers, retailers and the industry. Development of a new intelligent label to monitor over-temperature for frozen food and development of new intelligent label to monitor oxygen content in the modified atmosphere of packed products.	https://cordis.europa.eu/

The design of the packaging and the type of material used play an important role in extending the life of food products. Materials that have traditionally been used in food packaging include glass, metals (aluminum, foils and laminates, tinplate, and tin-free steel), paper and paperboards, and plastics (Marsh & Bugusu, 2007). In Figure 2, it is possible to analyze the market share of packaging material according to Food Packaging Forum.

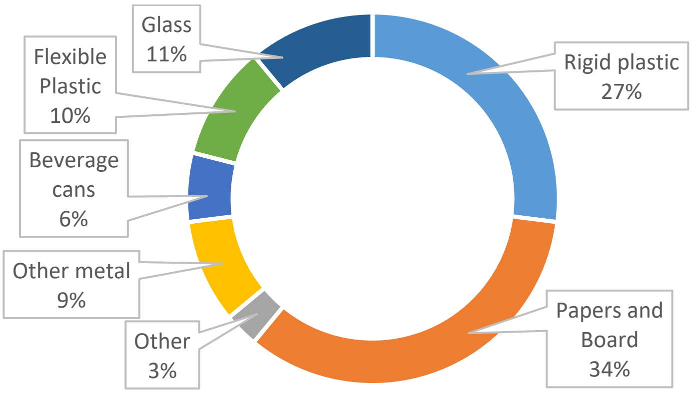


Figure 2: Market share of packaging material. (Source: Food Packaging Forum).

The paper and board packages have the biggest market share with 34%, while plastic packages have, in total, 37%.

In response to the demands of an increasingly modern society, food packaging is a constantly evolving technology, from the simple packaging function of products to the incorporation of aspects such as point-of-purchase marketing, material reduction, security, waterproofing and environmental issues (Han et al., 2018). For many years, the packaging design, composition and permeability, was viewed as the primary way of ensuring the cold chain integrity (Defraeye *et al.*, 2013).

2.3.1 Active packaging

The active packaging consists in the design of a package with the addition of certain components that release, absorb, activate or suppress substances for the product inside the package or the surrounding environment, aiming to extend the useful shelf life (Realini & Marcos, 2014). This change in the internal environment of the packaging can both maintain quality and extend the shelf life of the packaged product (Mane, 2016). The action of atmosphere modifiers in the package allows to increase the validity of products, improving their presentation and promoting the reduction of their waste. They also allow for more hygienic storage, free of leaks, liquids and odors, and also allow easy separation of sliced products and reduce the need for chemical preservatives (Biji *et al.*, 2015; Conte, Angiolillo, Mastromatteo, & Nobile, 2013; Gorny, 2003). Active packaging systems can be divided into active scavenging systems (absorbers) and active-releasing systems (emitters), as shown in Table 4.

Table 4: Examples of active packaging systems(Kaur & Puri, 2017).

Active Packaging System	Mechanisms	Food Applications
Oxygen absorbers	Iron-based, metal/acid, metal (e.g., platinum) catalyst, ascorbate/metallic salts, enzyme-based and nylon MXD6	Bread, cakes, cooked rice, biscuits, pizza, pasta, cheese, cured meats and fish, coffee, snack foods, dried foods and beverages
Carbon dioxide absorbers/ Emitters	Iron oxide/calcium hydroxide, ferrous carbonate/metal halide, calcium oxide/ activated charcoal and ascorbate/sodium bicarbonate	Coffee, fresh meats and fish, nuts and other snack foods and sponge cakes
Ethylene absorbers	Potassium permanganate, activated carbon and activated clays/zeolites	Fruits and vegetables
AM packaging	Organic acids, silver zeolite, spice and herb extracts, BHA/BHT antioxidants, vitamin E antioxidant, chlorine dioxide and Sulphur dioxide	Cereals, meats, fish, bread, cheese, snack foods, fruits and vegetables
Ethanol emitters	Encapsulated ethanol	Pizza crusts, cakes, bread, biscuits, fish and bakery products
Moisture absorbers	Poly (vinyl acetate) blanket, activated clays and minerals and silica gel	Fish, meats, poultry, snack foods, cereals, dried foods, sandwiches, fruits and vegetables
Flavor/odor absorbers	Cellulose triacetate, acetylated paper, citric acid, ferrous salt/ascorbate and activated carbon/clays/zeolites	Fruit juices, fried snack foods, fish, cereals, poultry, dairy products and fruits
Self-heating and self-cooling	Quicklime/water, ammonium nitrate/water and calcium chloride/water	Ready meals and beverages
Changing gas permeability	Side chain crystallizable polymers	Fruits and vegetables

Inhibition or release of certain gases will promote an extension of the shelf life of the product and decrease the growth rate of microorganisms. In a study carried out by Rodríguez et al.(2008) it was found that in an active packaging based on the incorporation of 6% w/w cinnamon oil to solid wax paraffin, completely inhibited the growth of *Rhizopus stolonifer* after 3 days storage at 25 °C. In another study, carried out by Gutiérrez et al. (2009) the effects of cinnamaldehyde, thymol and carvacrol in polypropylene films were tested at 2 and 4% against various moulds. It was shown that 2% cinnamaldehyde completely inhibited growth *of A. flavus* and *Penicillium commune*, whereas 2% carvacrol inhibited the growth of these species to a much lesser extent.

Essential oils (EOs) from aromatic plants have been the focus of extensive research not only because they are a natural product but also because they have shown benefits in food and human health without a high risk of food contamination (Ribeiro-Santos *et al.*, 2017). Active packaging incorporating EOs has been already applied to several foods such as: fresh beef, butter, fresh octopus and fish (Atrea, Papavergou, Amvrosiadis, & Savvaidis, 2009; Salgado *et al.*, 2013; Zinoviadou, Koutsoumanis, & Biliaderis, 2009)

2.3.2 Intelligent packaging

Intelligent packaging refers to the packaging equipped with electronic equipment that gives it the ability to monitor the environment and the product, allowing decision-making and optimization of transport and storage (Mane, 2016). Besides these points, the intelligent packaging also allows the improvement of HACCP and QACCP (Quality Assurance Critical Control Point) systems.

By definition, in Europe, is referred to as the material and equipment that monitor the state of the packaging or the environment that surrounds it (European Commission, 2004). From the academic point of view, it is a package capable of carrying out several functions (such as monitoring, tracking, recording information, communicating and applying scientific methods) to facilitate a decision making process concerning logistics and operations management as well as quality and safety purposes. Intelligent packaging can include different systems, both internal and external such as:

- Time – temperature indicator;
- Oxygen indicator;
- Carbon dioxide indicator;
- Microbial growth indicator;

- Pathogen indicator;
- Freshness indicator;

These indicators provide information regarding the conditions of conservation, microbial growth, development of specific pathogens, for example *Escherichia coli*, or whether the package was opened during the steps prior to consumption (Kaur & Puri, 2017).

But it is not just the indicators that smart packaging uses to evaluate the product. One of the most important elements is the sensors. In Figure 3, the different classes of sensors that can be implemented in this type of packaging are presented together with the operating principles.

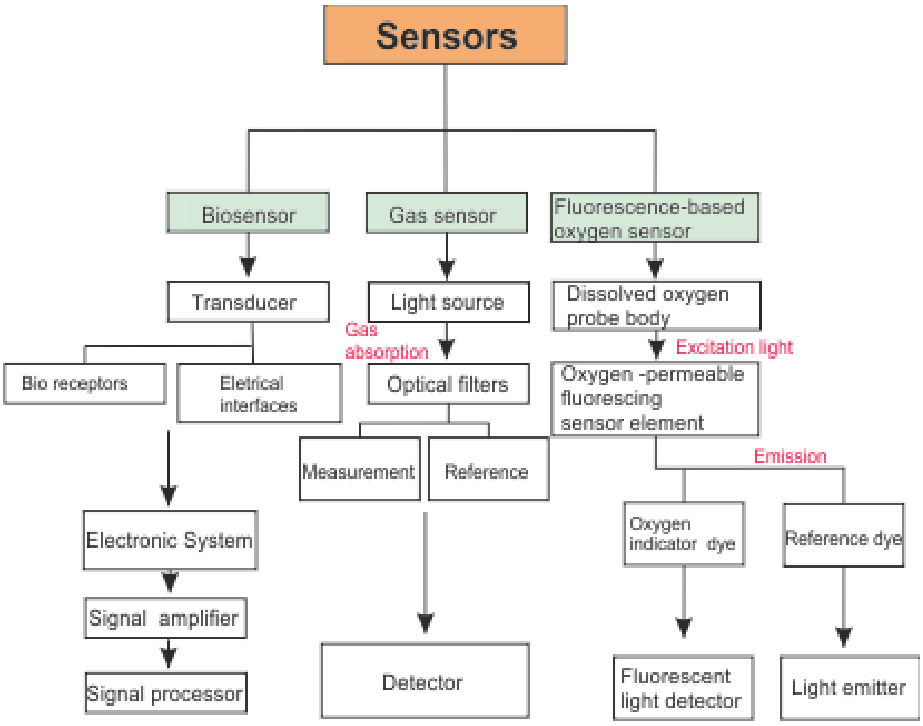


Figure 3: Different types of sensors used in intelligent packaging system (Lee, Lee, Choi, & Hur, 2015).

The fact of the packaging being intelligent does not prevent it from being active as well, since there are systems that can be classified as both. Until the beginning of the decade, this type of systems was not commercially viable due to packaging limitations and computer networks required for information processing to be costly and limited (Fang, Zhao, Warner, & Johnson, 2017). With the advances that technology has made and the reduction of the price of electronic components, intelligent packaging can become a reality and, coupled with active technologies, will be a means to optimize the production process and reduce food waste. Beside the sensors, the other tools used by the intelligent packages can include indicators, barcodes or RFID tags, as shown in Table 5.

Table 5: Summary of some intelligent packaging system in the food sector.

Type	Purpose	References
Freshness indicator	Determining freshness by showing color changes due to the presence of amines	(Zhai et al., 2017)
RFID system	Monitoring the product during supply chain	(Regattieri, Gamberi, & Manzini, 2007)
RFID + WSN	Tracking and tracing food product location along with temperature and humidity data	(Alfian et al., 2017)
Sensor	Theoretical wireless nanosensor network system that informs about food packaging condition	(Fuertes et al., 2016)
Gas Sensor	Measuring headspace CO2 in MAP storage	(Borchert, Kerry, & Papkovsky, 2013)
Chemical Sensor	Electrochemical nitrite sensor with high sensitivity, good selectivity and stability	(Li ,*et al.*, 2017)

The values recorded by the systems incorporated in the package can be stored in it or sent to a remote server using a communication method. The advantage of the latter is that it allows for almost immediate intervention in order to maintain an ideal conservation environment.

2.4 Communication technologies

To send data from one device to another wirelessly, it is necessary to use technology that allows it. This transmission can use technologies such as those presented in Figure 4. Each of these technologies has advantages and disadvantages over others, but all have the same purpose, sending data.

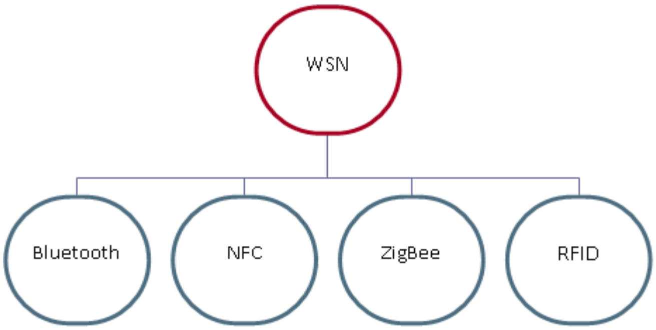


Figure 4:Different WSN communication technologies.

Designated by wireless sensor networks (WSN), they use the technologies referred to above for sending data. They are ideal systems for the monitoring and traceability of food products. (Kassal, Steinberg, & Steinberg, 2018) analyzed the 65 most relevant publications in the area of WSN systems and found that the predominant technologies are those found in Table 6.

Table 6: Most mentioned communication technologies in the literature.

Technologies	**Weight [%]**
Bluetooth	34
UHF	14
RFID	23
ZigBee	15
NFC	6
Others	8

By themselves, these technologies do not allow monitoring and sending data in real time to remote locations, but when they are combined, possibilities increase. Table 7 shows the main characteristics of each communication protocol.

Table 7: Main characteristics of different communication protocols.

Protocol	**Operating Frequency**	**Transmission rate**	**Range**
Bluetooth	2.4 GHz	1 Mbps	10 – 100 m
NFC	13.56 MHz	<424 kbps	< 10 cm
RFID	128-135 kHz, 13.56MHz, 860 – 960 MHz	<100 kbps	<15 m (depends on frequency)
Wi-Fi (802.11)	2.4, 3.6, 5 GHz 60 GHz	6-780 Mbps 6.75 Gbps to 60 GHz	100 m (can be affected by the building materials of buildings)

The digitalization and communication revolution named Internet of Things (IoT) has simplified the way we interact with the surrounding environment. The use of wireless technologies has enabled a kind of monitoring that was not so easily achieved before. Wireless technologies such as RFID, NFC or Bluetooth allow data obtained by an acquisition system to be sent to an operator anywhere in the world. The use of these technologies for the traceability of food products allows for a more rigorous control over their quality, since it allows parameters such as temperature, humidity, ethylene concentration, luminosity, among others, to be evaluated in real time at any time during transport or conservation.

When considering "smart" monitoring systems, end-to-end solutions must meet the needs of the customer and product to be tracked, but they must also be considered when scaling. This point is of great importance, as each technology can be affected by the environment in which it is. For example, the 2.4 GHz band which technologies such as Bluetooth and Wi-Fi use, is globally accepted and available, requiring a power never exceeding 1 mW. On the other hand, this frequency is affected by the resonant frequency of the water to be propagated, for example water colliding against the hull of a ship or inside a conservation chamber with a high relative humidity value (Badia-Melis *et al.*, 2018).

2.4.1 RFID

This technology emerged during World War II for the purpose of identifying aircraft as "Friend" or "enemy" (IFF) and consisted of wireless communication between a tag and a reader. Over the years, this technology has begun to be seen as one of those capable of monitoring a food product. Due to the possibilities that its implementation brings, there has been an increasing interest in different economic sectors in the tracing of objects, pallets or animals, toll gateways, and currently there are already 3000 applications where RFID is used (Bibi *et al.*, 2017). For an RFID tag to operate it is necessary to have a tag, consisting of an antenna to communicate, a chip for identification and, if necessary, a storage unit, as shown in Figure 5.

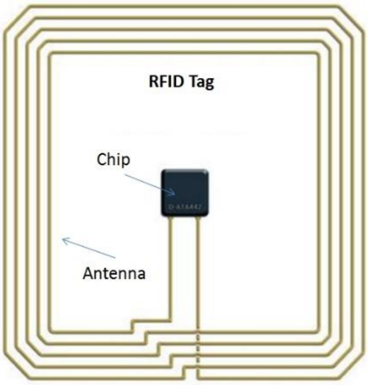


Figure 5: Components of an RFID tag.

In order to add value to this technology, several sensors have been developed for the implementation in the tags and thus to grant sensorial capacities to the same ones (Vergara et al., 2007; Steinberg & Steinberg, 2009; Abad et al., 2009; Bhadra, Bridges, Thomson, & Freund, 2011; Martínez-Olmos et al., 2013; Potyrailo & Surman, 2013). The combination of these systems enables the creation of databases accessible to merchants through a unique identification code.

Tags can be divided into three categories, depending on your power source:

- **Passive:** They do not have battery, being fed by the reader. The different mechanisms allow the exchange of energy and data. The energy transfer rate varies between 10 µW and 1 mW.

- **Semi-Passive:** Include a battery to keep the memory in the tag or to feed the different electronic devices that allow modulating the electromagnetic waves emitted by the reader.

- **Active:** They are powered by an internal battery that is used to run the microchip circuit and are therefore more expensive and larger than passive tags.

Despite the numerous possibilities it presents for food monitoring, it is a technology easily surpassed by Bluetooth technology when it comes to reading range. However, it still has a high potential.

2.4.2 Bluetooth

Bluetooth is a short-range, low-power data transmission method, proposed in 1994, operating in the 2400 to 2483.5 MHz band known as the ISM (Industrial, Scientific and Medical) band

(Chadha, Singh, & Pardeshi, 2013). Since its inception, it has undergone several upgrades, which have made it more secure and more efficient. More recently, the Bluetooth 5.1 version has been launched, which allows a greater range and speed of data transmission, with lower power consumption.

This version will equip the Low Energy Bluetooth controllers, specifically the receivers, with the ability to generate data that can be used to calculate the Angle of Arrival (AoA) and Angle of Departure (AoD) for the device transmission, which will enable a better location service. When associated profiles become available, it will be possible to create high-precision positioning systems, such as real-time location systems, such as Real-Time Locating Systems (RTLS) and Indoor Positioning Systems (IPS) (Woolley, 2019).

Bluetooth devices are managed through the star-type typology, in which a group of devices, Slaves, communicate with a single device, Master, which according to the specifications of this protocol is referred to as the piconet network. The structure can contain up to 8 devices, 1 Master and 7 Slaves, which communicate with each other. But although this technology structure only allows simultaneous communication between 8 devices, it allows up to 255 devices to pair in the network. The differences between the different versions of this technology are shown in Table 8.

Table 8: Comparison of the different versions of the Bluetooth protocol.

Function	Classic Bluetooth	Bluetooth 4.x	Bluetooth 5
Operation frequency (MHz)	2400 - 2483.5	2400 - 2483.5	2400 - 2483.5
Range (m)	<100m	<100m	<200m
Nominal transfer rate (Mb/s)	1 a 3	1	2
Lag (ms)	<100	<6	<3
Network Typology	Piconet, Scatternet	Star-Bus, Mesh	Star-Bus, Mesh
Nodes (Active slaves)	7	Ilimited	Ilimited

The protocol 5.1 supports a mesh-type network typology, as shown in Figure 6, giving the devices the ability to communicate with each other. The actors in this typology are designated by Nodes, which receive the data from the nodes that are in range (Line-of-Sight) and, if they are configured for this, will relay the received messages, thus increasing the communication reach (Woolley, 2019). This type of network is functional in the Bluetooth versions Low Energy (LE) and versions 4.2 and later.

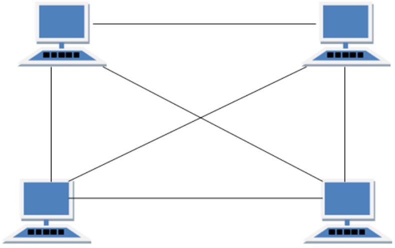


Figure 6: Network type Mesh type.

This communication technology has increased its presence in our daily lives. From wireless headphones to smartbands, Bluetooth technology is used to connect our devices (Suárez, Lozano, Arroyo, & Herrero, 2018) and is seen as the preferred way to integrate monitoring systems due to their low power consumption.

2.4.3 WiFi

This technology is extremely present in everyday life and consists of a radio and wireless communication technology on a local area network (WLAN) that is based on the IEEE 802.11 protocol.

Radio signals are transmitted from antennas and routers, whose signals are picked up by Wi-Fi receivers, such as computers and mobile phones that have Wi-Fi module. The range of this network depends on the characteristics of the location where it is being implemented. Wi-Fi is the most versatile and effective technology within the RF range for wireless data transmission (Kuppusamy, 2016).

There are several versions of this technology.

- Wi-Fi-802. 11a.
- Wi-Fi-802. 11b.
- Wi-Fi-802. 11g.
- Wi-Fi-802. 11n.
- Wi-Fi-802. 11ac.

The number of wireless devices has increased dramatically in recent years, which has made the 2.4 GHz band spectrum congested. It was then necessary to extend the operating band to the 5 GHz. In this version, the signal range is lower, since the frequency is higher, it cannot penetrate solid objects such as the walls of a building. However, when operating at higher frequencies, data transmission occurs at a higher speed.

2.4.4 NFC

In a first approach, its mode of operation may resemble to RFID. However, the NFC is a wireless interface system that resembles Bluetooth technology. NFC is a short-range wireless technology, typically requiring separation of 10 cm or less, operating at 13.56 MHz in the ISO 18092 protocol and at rates ranging from 106 kbit/s to 424 kbit/s, depending on the mode of communication. To work, it needs a primer and a target. The initiator actively generates an RF field that can feed a passive target. Peer-to-peer communication is also possible as long as the two devices are powered (Rinner, Witschnig, & Merlin, 2008).

This technology has one big advantage: faster connectivity between devices. This occurs because of the use of inductive coupling and the absence of manual pairing, taking less than a tenth of a second to establish a connection between two devices (NFC-Forum, 2018).

2.4.5 GSM

The GSM (*Global System for Mobile Communications*) is a second generation (2G) digital network communication method used by devices such as mobile phones or tablets that operates in different bands. The GSM networking is based on the superposition of a distributed star type network architecture on the existing fixed landline telephony.

The telephony network consists of a communication infrastructure divided into three major systems: the switching system (SS), the base station system (BSS), and the operation and support system (OSS) (Rahnema, 1993):

- The switching system **(SS)** is responsible for performing call processing and subscriber-related functions;

- Base station subsystem **(BSS),** through which the mobile users access the network over radio links.
- The MSC acts as the nerve center of the system. It controls call signaling and processing and coordinates the handover of the mobile connection from one base station to another as the mobile roams around. Each MSC is in turn connected to the local public switched telephone network (PSTN, or ISDN) to provide the connectivity between the

mobile and the fixed telephony users, as well as the necessary global connectivity among the MSCs of the cellular mobile network.

- The operation and support system **(OSS)** is the functional entity from which the network operator monitors and controls the system.

The structure of a GSM network is illustrated in Figure 7.

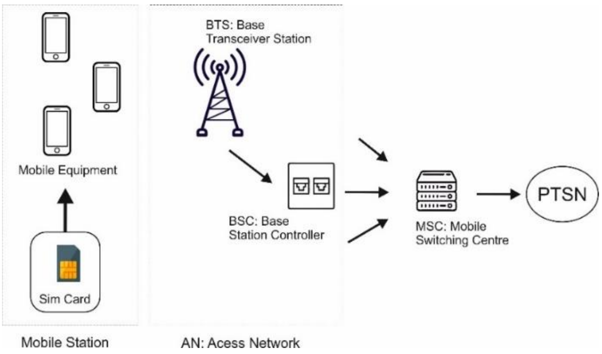


Figure 7: Structure of a GSM Network.

To operate, this technology requires a subscriber identity module (SIM Card), which is where the assigned personal number is located. This technology is also a pioneer in low-cost applications because it enables long-distance data sending, making them ideal for monitoring systems in special locations.

Several studies were carried out on systems using GSM to send information, as presented in the Table 9.

Table 9: Monitoring systems using GSM for communication.

Objective	Reference
Remote pest monitoring system oriental fruit fly, *Bactrocera dorsalis*	(Jiang et al., 2008),
Beef farming quality traceability system based on the PDA, with RFID module and GSM Modem	(Bao & Yang, 2011)
System for tomato ripening stages monitoring	(Thengane & Gawande, 2018)
Arduino based device for the determination of the respiration rate of fruits and vegetables in a closed system.	(González-Buesa & Salvador, 2019)

2.5 Conclusive notes

Packaging is the essential element in the cold chain because it accommodates, ensures safety and most importantly, accompanies food products from the producer to the final consumer. Consumer interest nowadays concerns interaction with objects through technology, and the development and implementation of a package that allows both producer control over the product and consumer access to history will be an advance well accepted by society. Active packaging has the best characteristics in maintaining product quality but fails to achieve the traceability that smart packaging has. Packaging with active and intelligent features is the best choice for international use. But the disparity in regulation of cold chains and other factors will remain the major obstacle.

The presence of technologies, such as WiFi or GSM in society's daily life, demonstrates the habituation we all have, and the implementation of these technologies in a package would make it easier for consumers to be aware of temperature history, path and state of conservation through an application on the smartphone. The benefits are not just for consumers. Through the data obtained from sensors and the use of machine learning and predictive models of product life, the cold chain and all inherent steps will be more precisely controlled, benefiting producers through a reduction in lost product.

In this dissertation a monitoring system that allows access to information through the internet will be developed. The data obtained will be the parameters to which the products are subjected, such as temperature and relative humidity, as well as the GPS location. In the first stage of development it is necessary to understand the environment in which it will operate, and what values it will have to monitor, and for this purpose two conservation condition tests were carried out inside a conservation chamber installed on producers. These tests aim to evaluate the parameters that directly affect the quality of the food product, the temperature and relative humidity of the conservation environment, but also the way the conservation is done, by detecting events that affect the conservation environment, such as prolonged opening the doors of the chambers or the variation of the thermal load inside them. Based on the values obtained from the tests on food products, namely Cereja do Fundão and Pêssego da Cova da Beira, the air temperature and relative humidity range to which the device to be developed will be subject was be defined.

3 Experimental Evaluation of Conservation Conditions

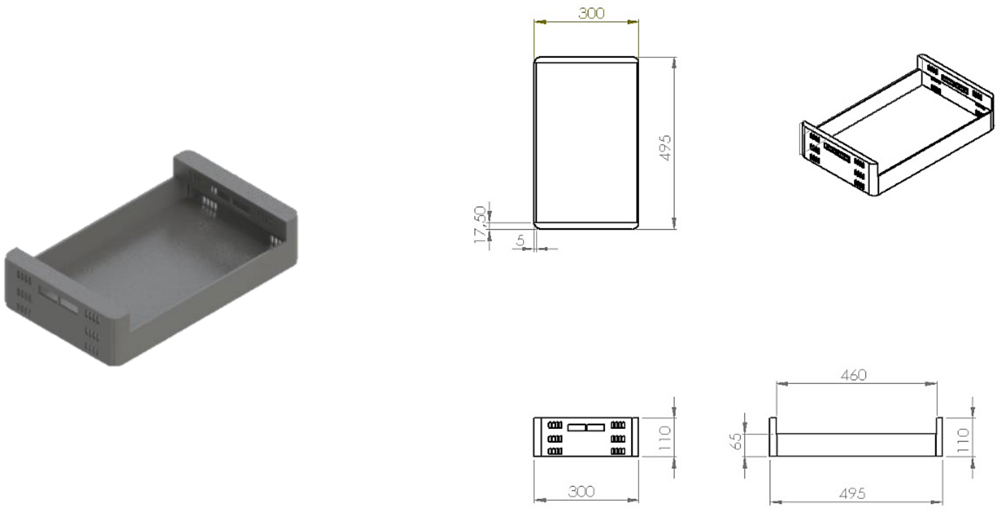
In order to proceed with the development of the monitoring system, it was first necessary to evaluate the conservation conditions to which the fruit products are subjected. This evaluation was carried out inside the refrigeration chambers of the producers and intended to monitor the temperature and the relative humidity of the air. This study was carried out in partnership with the producers CerFundão and Sociedade Agrícola Quinta dos Lamaçais and with the CATAA (Associação Centro Apoio Tecnológico Agro-Alimentar), where the fruit products were kept in a normal atmosphere and controlled atmosphere. The fruits used in the experimental tests were peach and cherry.

For the measurements to be carried out, it was necessary to use equipment that would allow the collection and storage of data and that did not affect the food safety of the product. We used the LASCAR ELETRONICS "EL-USB-2-LCD +" datalogger, shown in Figure 8.

Figure 8: Datalogger "EL-USB-2-LCD+" Lascar Eletronics.

Two experimental tests were performed for the acquisition of air temperature and relative humidity values inside the producers' chambers, one in 2018 and one in 2019. From the first to second test, the time of each acquisition and the number of dataloggers changed, from 2 dataloggers at 60 second each acquisition in 2018, to 4 dataloggers at 5 minutes each acquisition in 2019.

To place the control lots inside the producers' conservation chambers, it was necessary to place them in standard boxes, as shown in Figure 9. The use of this type of transport box facilitates the placement on pallets, which are also standardized and designated by EURO-PALLET, whose dimensions are as shown in Figure 11.



(a) Sketch of the control box.

(b) Dimensions of the control box [mm].

Figure 9: Control box used to place the products in both assays.

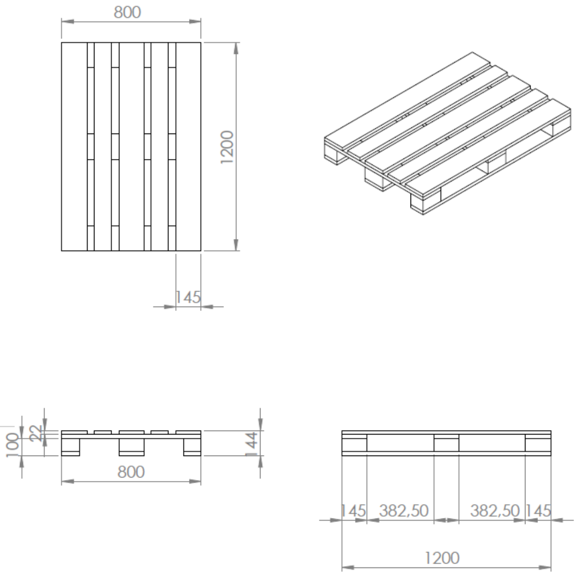


Figure 10: Dimensions of the pallet used in the assays, in millimeters.

3.1 Cherry

The cherry is cultivated in Cova da Beira since the beginning of the 19th century, being the main reason for the development of agriculture in the region. Considering data from the Planning, Policy and General Administration Office (GPP) in 2016, the Beira Interior region had 11% of the agricultural population and 12% of the farms, compared to the national territory. The year 2017 was a year favored to the production of cherries, reaching 19.6 thousand tons, the highest of the last three decades, with 54 tons for exportation (INE, 2017). According to the producers, 2018 was a bad campaign year due to the late rains and warm weather out of season. Agricultural forecasts on 31 May of 2019 point to a very productive prunus campaign, with unit yields (3.2 tons per hectare for cherry) at the best of decades (INE Instituto Nacional de Estatística, 2019). In Figure 11 is presented the harvest time of the cherry.

Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
								▨	▨	▨	▨	▨											

Figure 11: Harvest time of the cherry, varying annually depending on the climatic conditions. (Source: A SATIVA).

Cova da Beira’s cherry is recognized nationally and internationally as a cherry with specific characteristics, whose market price is generally higher than its competitors. This difference is justified by the quality provided by the region's soil and climatic conditions. Recognized by the Institute of Agricultural Markets and Agri-Food Industry, Cova da Beira cherries have the following characteristics:

- **Color** - bright red to purple red, with some irregular spots on the epidermis;
- **Shape** - cordiform, long peduncle green lettuce;
- **Flavor** - very sweet;
- **Consistency** - firm and fleshy;
- **Calibe**r - on average, each fruit weighs between 6 and 7g and has a diameter between 24 and 26mm.

Cherries are considered a highly perishable food product due to its high content in water, nutrients, and favors, that promote the development of microorganisms. To maintain their freshness and quality it is necessary to keep them in a controlled environment.

Several studies were carried out to determine the cherry conservation parameters that considered the extension of the shelf life and the development of cold damages, as shown in Table 10.

Table 10: Temperature, relative humidity and controlled atmosphere for cherry conservation conditions.

Temperature [°C]	Relative humidity [%]	Conservation time	Reference
0 to 4	90 – 95	14 days	Baptista (2007)
-0.5 to 0.5	90 – 95	-	Mitcham et al. (2000)
-1 to -0.5	90 – 95	-	Silva (2002)
-1 to -0.5	90 – 95	2 to 3 weeks	“APPENDIX III: Temperatures and Compatibility of Fruits and Vegetables”
-1 to 0	>95%	2 to 4 weeks	Gross et al. (2016)
≈1	≈95%	27 days	Palma et al. (2012)
0 to 2	>95%	up to 3 weeks	Wang and Vestrheim (2002)
≈1	≈95%	60 days	Tian et al. (2004)
0 to 5	-	28 to 35 days	Ben-Yehoshua et al. (2005)
≈1	-	6 weeks	Mattheis et al. (1997)

The loss of moisture is one of the critical factors affecting the fresh appearance of the fruit and the peduncle, the so-called cherry leg. For example, if the value of relative air humidity is too low, the peduncle will dry and darken.

3.1.1 Methodology of 2018 experimental work

For the cherry, after reception, samples were prepared for later placement inside the chamber, taking the following steps:

1. Place a sample of 50 cherries in each grid box, verifying if the samples were homogeneous;
2. For each sample, 20 cherries were sequentially numbered with a white marker;
3. For each numbered cherry, the weight was determined and recorded;
4. For each numbered cherry, the color was determined by positioning a colorimeter in the area below the number;
5. Record the weight of each box with the total of 50 cherries;

6. Each box with the sample was placed in the center of a plastic box and cherries were placed all the way around, approaching the actual situation in the storage chambers.

Table 11 shows the modalities of the control lots, which include the atmosphere at the producer's organization, normal atmosphere and four different modified atmospheres tested in CATAA.

Table 11: Cherry testing modalities.

OP	Preserved in the chambers of the Producers' Organization
AN	Preserved in normal atmosphere
AC	Conserved in Controlled Atmosphere **A** -Preserved in Controlled Atmosphere (3% O2 / 10% CO2) **B** - Preserved in Controlled Atmosphere (3% O2 / 15% CO2) **C**- Preserved in Controlled Atmosphere (10% O2 / 10% CO2) **D**- Preserved in Controlled Atmosphere (10% O2 / 15% CO2)

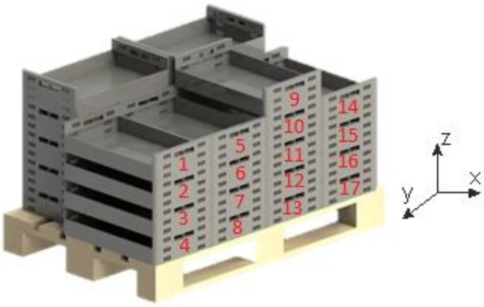
Table 12 shows the coding used for the control lots, which includes the month and the day in which each one was collected, to be later delivered to the CATAA where the chemical composition of the cherry was analyzed. The test was run for 21 days.

Table 12: Conservation time to which it was subject.

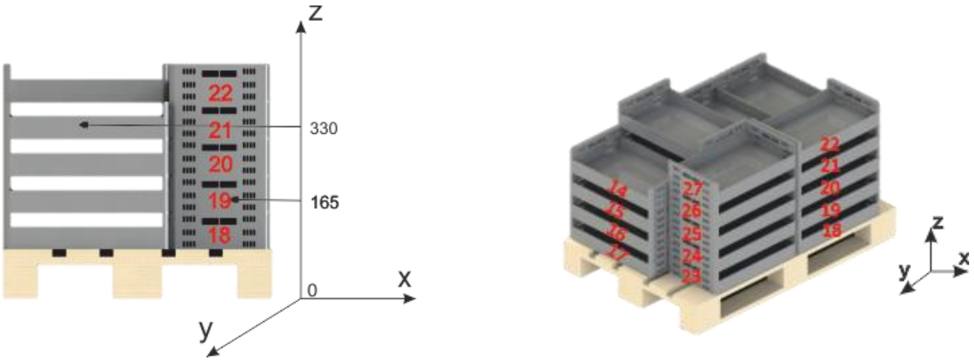
Lot		**Collection data [days]**
OP-0629	0629-1 0629-2 0629-3	3
OP-0703	0703-1 0703-2 0703-3	7
OP-0710	0710-1 0710-2 0710-3	14
OP-0717	0717-1 0717-2 0717-3	21

The control lot of cherries used for the experiment is present in Figure 12. The dataloggers were placed at the top of the pallet and at the bottom, in control lot number 5 and 19, as shown in Figure 13 b).

Figure 12: Control lot in the initial state of the experiment.



a) Perspective view of the control pallet.



b) Left side view of control pallet and datalogger position, in milimeters.

c) Right side view of control pallet.

Figure 13: Arrangement of the cherry boxes on the control pallet.

Table 13 shows the correspondence between each number and the control lot shown in Figure 13.

Table 13: Numbering assigned to each box of cherries.

Number	Lot	Number	Lot	Number	Lot	Number	Lot
1	0703-3	8		15	0717-3	22	0717-1
2	0710-1	9	0710-3	16		23	0717-2
3		10	0717-2	17		24	
4		11	0629-1	18		25	
5	0703-1	12		19		26	
6	0710-2	13		20		27	0629-2
7		14	0629-3	21			

3.1.2 Methodology of 2019 experimental work

In 2019, the methodology used was the same used in 2018, except on conservation time to which it was subject, as shown in Table 14. The change of methodology was performed to improve the details of the results.

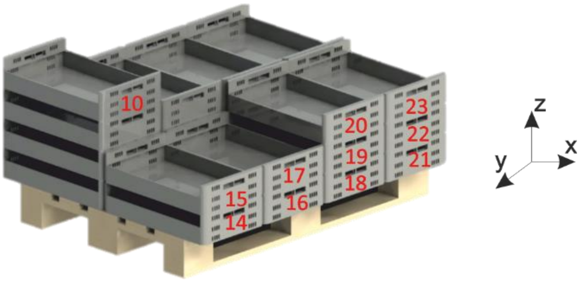
Table 14: Conservation time to which it was subject.

Lot		Collection data [days]
OP-0629	0629-1 0629-2 0629-3	7
OP-0703	0703-1 0703-2 0703-3	14
OP-0710	0710-1 0710-2 0710-3	21
OP-0717	0717-1 0717-2 0717-3	28

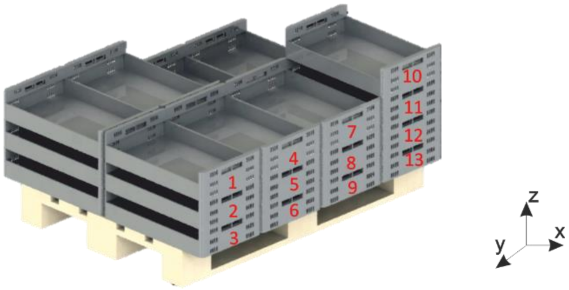
The control lot of cherries used for the experiment is present in Figure 14.

Figure 14: Control lot in the initial state of the experiment.

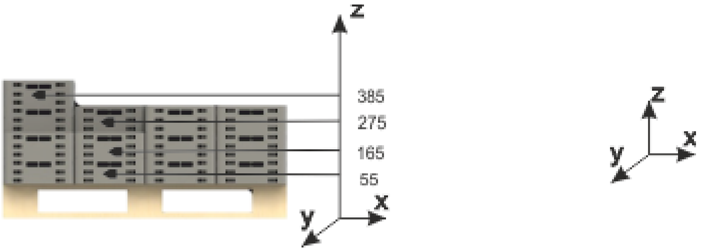
Figure 15 shows the arrangement of all cherry boxes in the control pallet, as well as the dataloggers location, in Figure 15 c).



a) Perspective view of the control pallet.



b) Perspective view of the back of the control pallet.



c) View of the back of the control pallet, and datalogger position, in milimeters.

Figure 15: Arrangement of the cherry boxes on the control pallet.

Table 15 shows the correspondence between each number and control lot shown in Figure 15.

Table 15:Numbering assigned to each box of cherries.

Number	Lot	Number	Lot	Number	Lot	Number	Lot
1	OP-0626-2	7		13		19	OP-0710-3
2	OP-0710-1	8	OP-0703-2	14		20	
3		9		15	OP- 0619-1	21	OP-0703-3
4	OP-0619-2	10	OP-0619-3	16		22	OP-0626-1
5	OP-0710-2	11	OP-0703-1	17	OP-0626-3	23	
6		12		18			

The four dataloggers were placed in four different boxes, as show in Table 16.

Table 16: Dataloggers position during the assay.

Unit	Lot	Number
1	OP-0626-2	1
2	19	19
3	OP-0626-3	18
4	OP-0619-3	10

3.2 Peach

The Cova da Beira peach is not characterized by a single cultivar, but by its quality, a result of the region's soil and climatic conditions. Data from the Agricultural Census of 2009 indicated that there were 1584 farms engaged in peach production in Cova da Beira, with an area between 5 to 20 ha (35.2%) and 20 to 50 ha (30.8%) (+Pêssego, 2016). In Portugal, the central region accounted for 57% of the national peach production, with 12 tons for export. The increase in demand for this product from the foreign market led to an increase in export values that doubled from 2016 to 2017 (INE, 2017). Agricultural forecasts on 31 May of 2019 point to a very productive prunus campaign, with unit yields (12.5 tons per hectare for peach) at the best of decades (INE Instituto Nacional de Estatística, 2019). Figure 16 shows the usual peach harvest season.

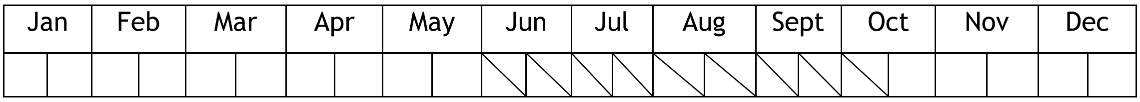


Figure 16:Peach harvesting time, varying annually depending on the weather conditions (Source: GPPAA/SIMA).

Peaches perish rapidly after harvesting when stored at room temperature. Thus, low temperature storage is required to extend shelf life and attenuate ripening and decomposing agents (Andrade et al., 2019). Several studies were carried out to determine the peach conservation parameters taking into account the extension of the shelf life and the development of cold damages, which will be presented in Table 17.

Table 17:Temperature values suggested by several authors.

Temperature [°C]	RH [%]	Conservation time	Reference
-1 to 0	90-95		(Sargent & Moretti, 2016)
-0.5 to 0	90-95	14 to 28 days	(Bachmann & Earles, 2000)
-0.5 to 0	90	2 to 4 weeks	("APPENDIX III: Temperatures and Compatibility of Fruits and Vegetables 1.," n.d.)
-1 to 0	90-95	1 to 5 weeks	(Crisosto, Mitcham, & Kader, 1996)
1.5	90-95	30 days	(Cantillano, Treptow, & Schünemann, 2010)
-0.5 to 0.5	≈97	46 days	(Ceretta, Antunes, & Brackmann, 2000)
-0.5 to 0.5	87 to 93	35 days	(Girardi et al., 2005)
0	90-95	30 days	(Eris, Türkben, Özer, & Henze, 1994)
1.1	95-100	4 weeks	(Brecht, J K, Kader AA, Heints AM, 1982)

3.2.1 Methodology of 2018 experimental work

For the peach test, the following procedure was required.

1. Place in each box a sample of 24 peaches, verifying if the samples were homogeneous;
2. For each sample 24 peaches were sequentially numbered with a white marker;
3. For each peach numbered the weight was determined and recorded;
4. For each numbered peach, the color was determined by positioning a colorimeter in the equatorial zone;
5. The weight of each box with the total of 24 peaches was recorded;

Table 18 shows the modalities of the control lots, which include the atmosphere at the producer's organization, normal atmosphere and four different modified atmospheres tested in CATAA.

Table 18:Peach testing modalities.

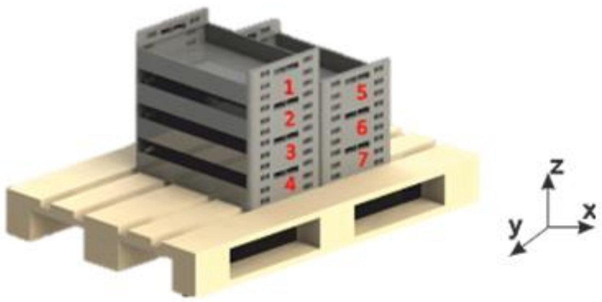
OP	Preserved in the chambers of the Producers' Organization
AN	Preserved in normal atmosphere
AC	Conserved in Controlled Atmosphere **A** -Preserved in Controlled Atmosphere (4% O2 / 5% CO2) **B** - Preserved in Controlled Atmosphere (2% O2 / 3% CO2) **C**- Preserved in Controlled Atmosphere (2% O2 / 5% CO2) **D**- Preserved in Controlled Atmosphere (2% O2 / 10% CO2)

Table 18 shows the coding used for the control lots, which includes the month and the day in which each one was collected, to be later delivered to the CATAA where the chemical composition of the peach was analyzed. The test ran for 28 days.

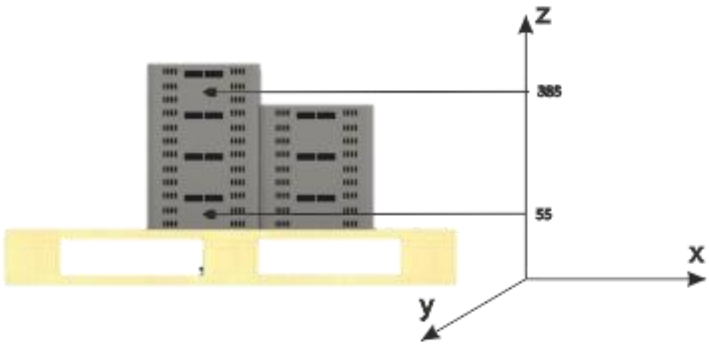
Table 19:Conservation time to which it was subject.

Lot	Collection data [days]
OP- 0907	7
OP- 0914	14
OP- 0921	21
OP- 0928	28
OP- 1004	35

Control lots were placed on the pallet as shown in Figure 17 a), and datalogger position in Figure 17 b).



a) Arrangement of the peach boxes on the control pallet.



b) Left side view of control pallet and datalogger position, in milimeters.

Figure 17: Arrangement of the peach boxes on the control pallet.

The dataloggers were placed in boxes 1 and 4. Two repetitions of the control lots were placed, namely OP-1004 and OP-0914, which were used for chemical analysis in CATAA. To the control boxes was attributed the coding presented in Table 20.

Table 20: Numbering assigned to each box of peaches.

Number	Lot
1	OP-0921
2	OP-0928
3	OP-1004
4	OP-1004 (2)
5	OP-0907
6	OP-0914 (2)
7	OP-0917

With the completion of the necessary initial procedures, the batches corresponding to the OP (Producers Organization) were taken and placed inside the producer's chamber, as shown in Figure 18.

(a) 1st control lot OP-0906.

(b) 2nd control lot OP-0913.

(c) 3rd control lot OP-0920.

(d) 4th control lot OP-0927.

(e) 5th control lot OP-1004.

Figure 18: Control lot boxes used for the assay on peach.

3.2.2 Methodology of 2019 experimental work

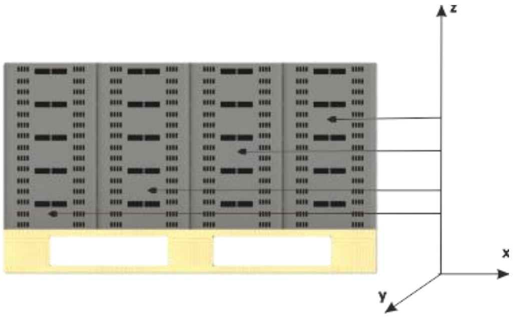
In 2019, the methodology used was the same used in 2018, except on conservation time to which it was subject, as shown in Table 21.

Table 21: Conservation time to which it was subject.

Lot	Collection data [days]
T1-7d	7
T1-14d	14
T1-21d	21
T1-28d	28

Figure 19 shows the arrangement of all peach boxes in the control lots, as well as the location of the dataloggers during the test.

a) Arrangement of the peach boxes on the control pallet



b) Front side view of control pallet and datalogger position, in milimeters.

Figure 19: Arrangement of the peach boxes on the control pallet.

Table 22 shows the correspondence between each number and control lot shown in Figure 19.

Table 22: Numbering assigned to each box of peaches.

Number	Lot	Number	Lot	Number	Lot	Number	Lot
1		6		11		16	
2		7		12		17	
3	T1-7d-3	8	T1-14d-3	13	T1-21d-3*	18	T1-28d-3
4	T1-7d-2	9	T1-14d-2*	14	T1-21d-2	19	T1-28d-2
5	T1-7d-1*	10	T1-14d-1	15	T1-21d-1	20	T1-28d-1

The four dataloggers used in this assay were placed in boxes number 5, 9, 13 and 17.

A definition of a methodology is crucial to ensure a procedure and the authenticity of the results and in this essay was a complicated process. Preparing an experimental trial inside a producer's conservation chamber requires that it allows a space that could be occupied with the product for sale. Forklift maneuvers inside the chamber or arrangements in the control pallet were some of the problems faced but solved: by wrapping the control pallet with signaling tape, it allowed employees to easily identify the pallet corresponding to the assay. Notify the employees about the realization of the experimental test was also a means of preventing changes in the control palette.

During the trial, on data collection days, to download data logger information to the computer, it was first necessary to enter the storage chamber and remove the pallet. In this procedure, a control panel inspection was performed, where the positions and the number of control boxes were compared with the information from previous captures. This way allows maintaining the pallet under control, ensuring the integrity of the collected values.

With the conclusion of the experimental test, it was necessary to follow the data processing that allowed a clearer and more objective analysis of the conservation environment over the days after the start of the trial.

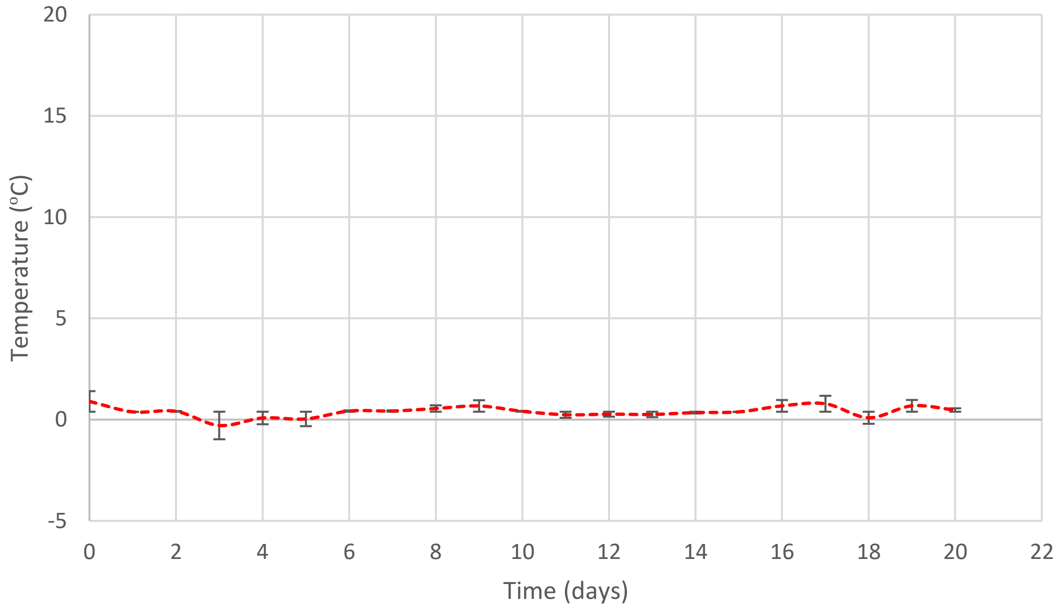
4 Results

With the end of the monitoring tests and the data collected, it was possible to analyze the conservation environment over the weeks to which the fruit products were subjected. Manipulation of the datalogger from inside the chamber to the outside and vice-versa induced values that should not be considered in the test. For example, when removing the datalogger from the control pallet, contact with the human hand caused the value of temperature to rise and the value of humidity to decrease. Therefore, a period of 1h was set after initialization and before data collection in each run where values would be despicable.

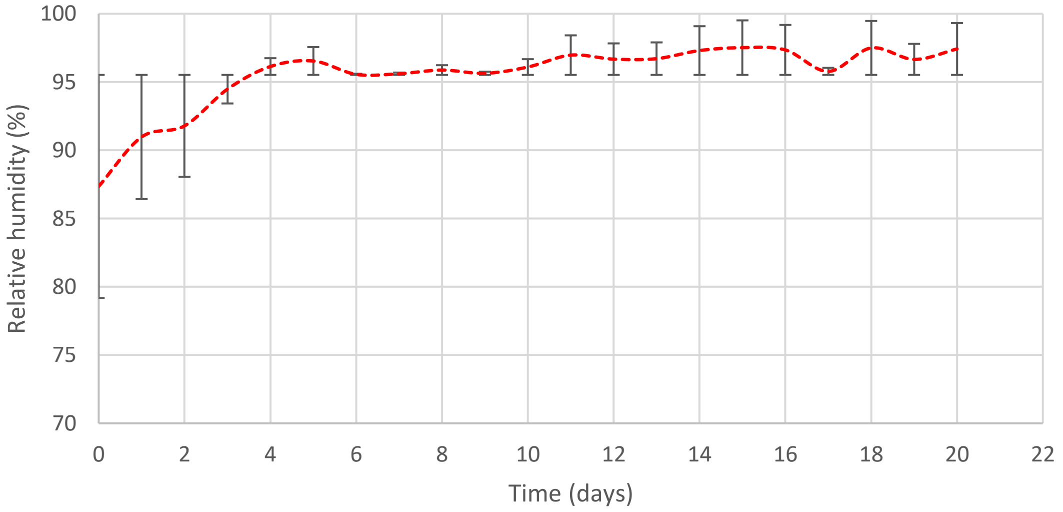
When representing the conservation environment, it was necessary to group the data to make the analysis clearer and more objective, but without covering up worrying events. When representing the test, a time scale was chosen in days where the maximum and minimum values recorded during the day were also applied, objectively expressing the test day. But not every day presented the same variance, requiring a more detailed analysis of the values that stand out. Thus, for each test performed, two days were chosen that had a higher variance and which were neither near the beginning nor the end, and their analysis was done per hour.

4.1 Experimental Results of the Conservation Conditions of Cherry

Figure 20 shows the variation of air temperature and relative humidity within the producer's refrigeration chamber during the test. The results for the year 2018 are presented first, followed by the values for 2019. In 2018, the air temperature presented adequate values, in the range between -1ºC to 1.5ºC and the air relative humidity between 90% and 100%. Based on the reference values suggested by the literature in Table 10, we conclude that the conservation environment was adequate for the product in question.



a) Variation of air temperature.

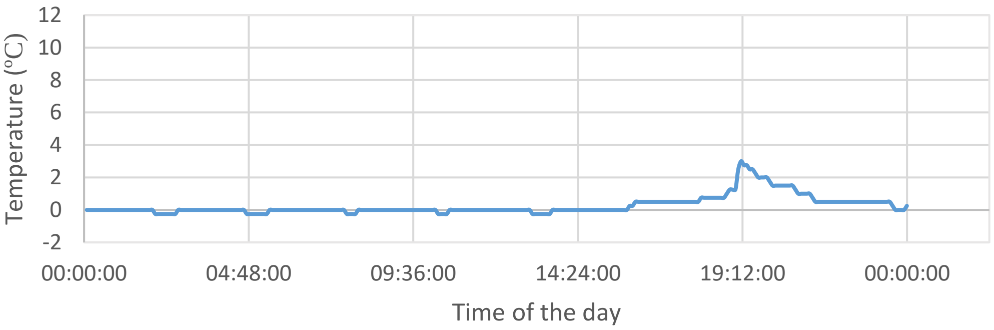


b) Variation of air relative humidity.

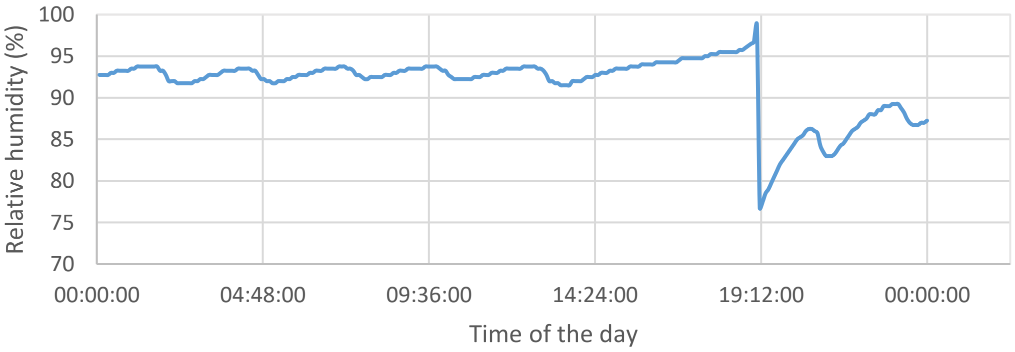
Figure 20: Environmental parameters recorded inside the producer's conservation chamber - 2018 experimental test of conservation conditions of cherries.

On day 3, the variance from the average air temperature value is higher compared to the other days, indicating that there was a high range of temperature values. Looking more closely at day 3, it can be seen that the temperature during dawn and day fluctuated on average between -0.25 °C and 0 °C, rising to much higher values in the late afternoon. From 18h onwards there is a rapid increase in the temperature value reaching 3 °C. After this peak the temperature gradually decreased near to 0 °C. Relative humidity values in Figure 21 b), showed a sudden decrease at the same time and also gradually normalized. During the rest of the day, the humidity values ranged from 90% to 95%.

This change in values indicates that products have been added to the refrigeration chamber as air temperature increases and relative humidity decreases.



a) Air temperature variation.

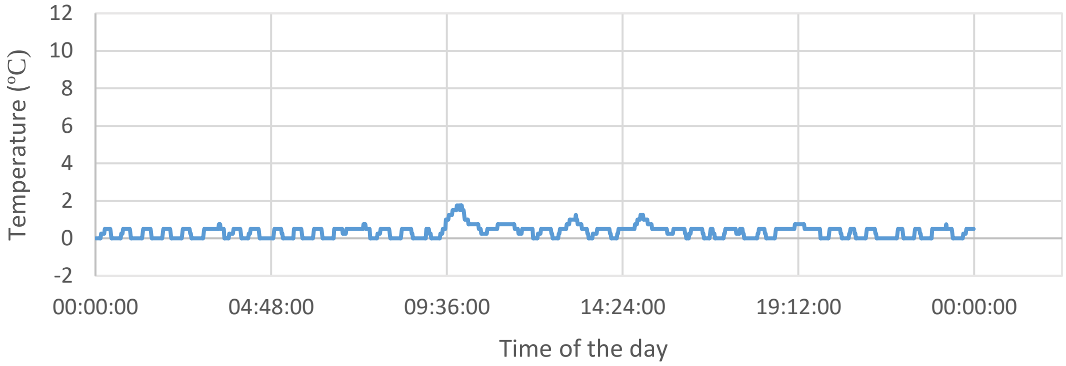


b) Air relative humidity variation.

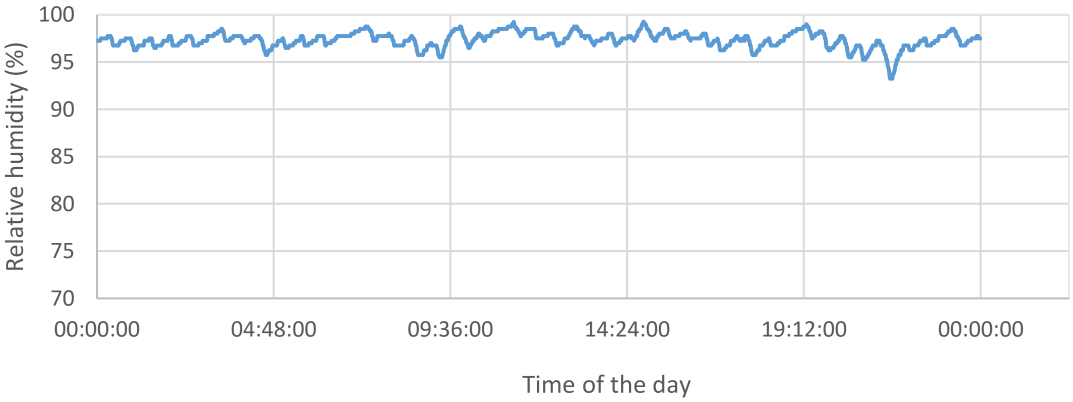
Figure 21: Air temperature and relative humidity during the 3rd day - 2018 experimental test of conservation conditions of cherries.

On the 11th day, shown in Figure 22, it can be seen that in the morning (09h:30m), the air temperature increased from an average value of 0.5ºC to 2ºC, where it remained a short time. At the same time, air relative humidity increased by 2%. This event is associated with the conservation chamber's door opening, as it allowed the increase of thermal energy exchange with the exterior, which affected the air temperature. The average values of air temperature and relative humidity recorded were 0.2 ºC and 97%, respectively.

In the afternoon there are two small increases in air temperature (12h:50m and 15h:00m), but without influence on the air relative humidity values. At 21h:30m there is a decrease in the air relative humidity values inside the chamber, which indicates the action of the exchanger defrosting system (the air temperature remained stable at 0 °C and the air humidity decreased).



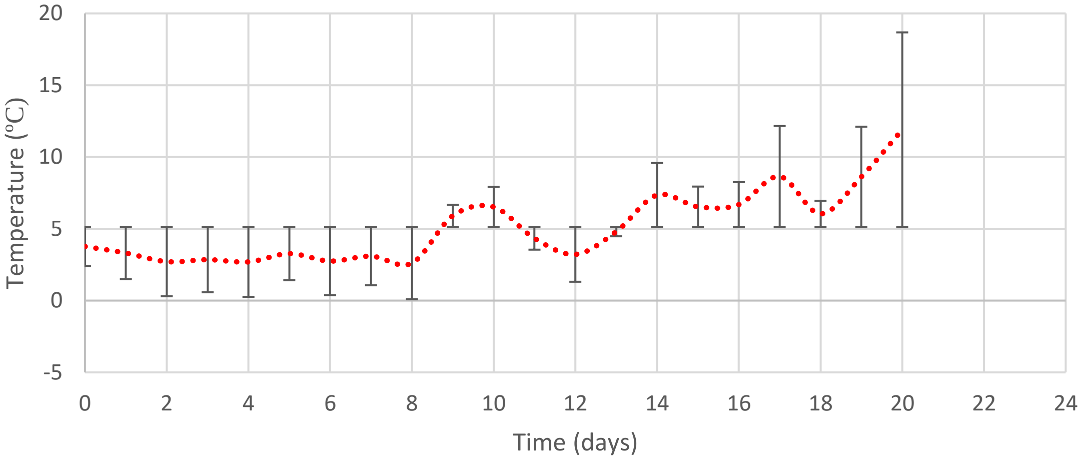
a) Air temperature variation.



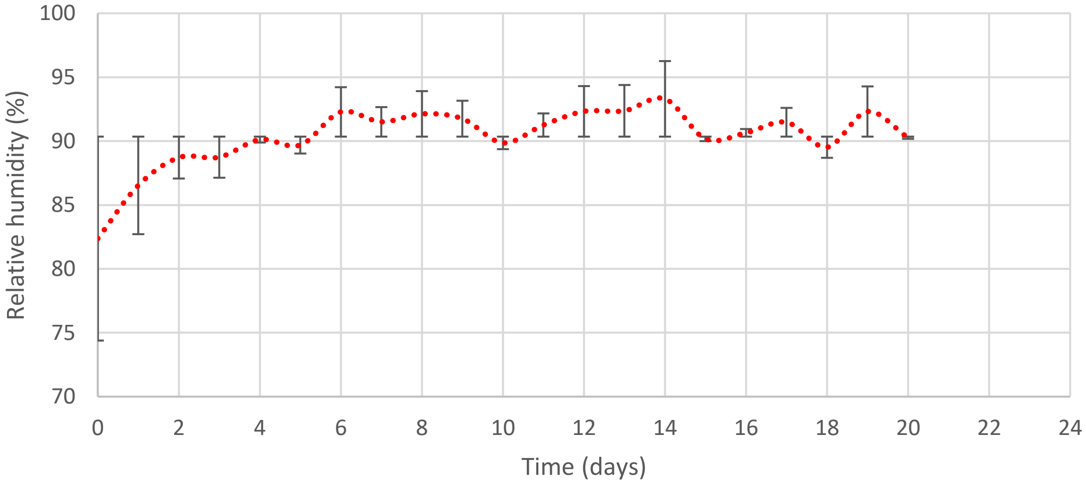
b) Relative humidity variation.

Figure 22: Air temperature and relative humidity during the 11th day – 2018 experimental test of conservation conditions of cherries.

In the 2019 test, the average values of air temperature and relative humidity were higher from the beginning to the end of the test (see Figure 23). The variance of the values per day was also higher than in 2018, which means that the conditions under which the cherry was subjected were not the most appropriate.



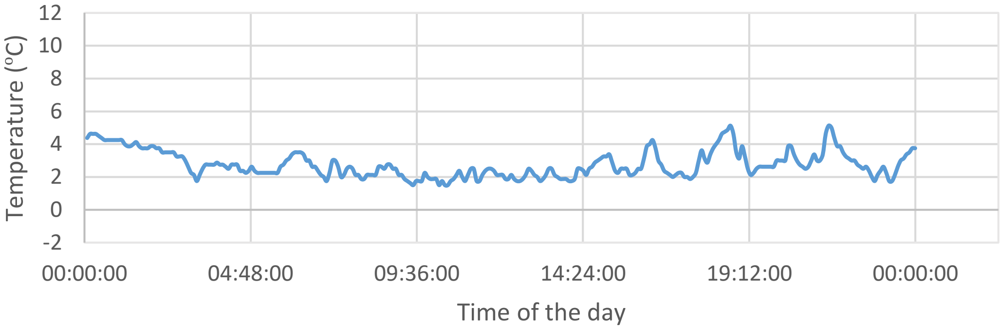
a) Air temperature inside the conservation chamber.



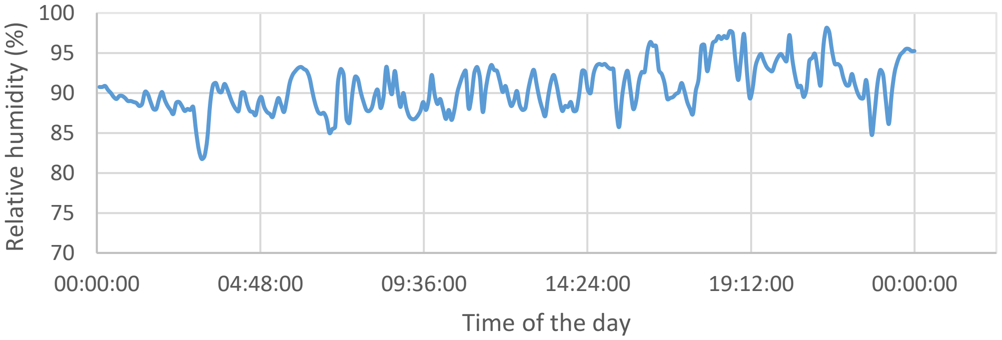
b) Relative humidity inside the conservation chamber.

Figure 23: Environmental parameters recorded inside the producer's conservation chamber – 2019 experimental test of conservation conditions of cherries.

On the sixth day, shown in Figure 24, the air temperature inside the chamber fluctuates during the day until the end of the day (15h:00m to 23h:00m) there is a greater irregularity in the values. Given the time when these oscillations were recorded and considering the information provided by the producer, these oscillations correspond to door opening periods of the conservation chamber.



a) Air temperature during the day.

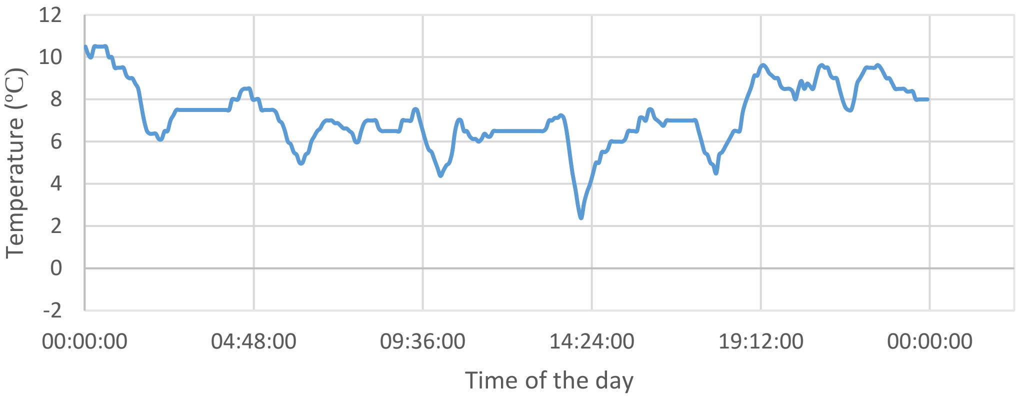


b) Air relative humidity during the day.

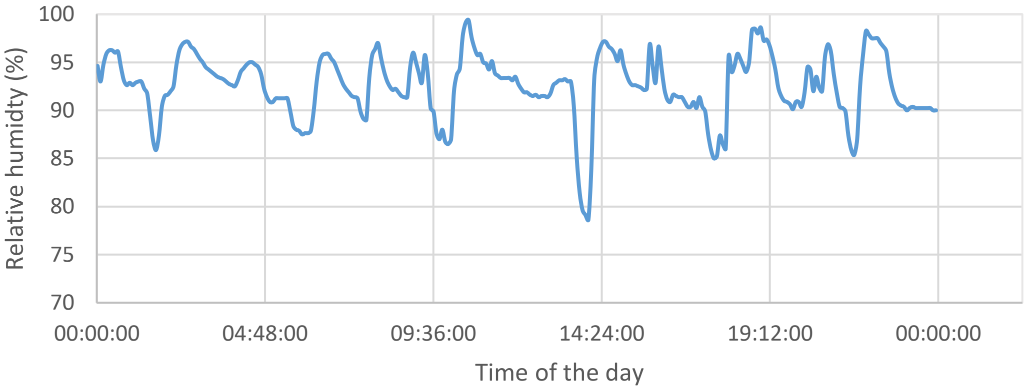
Figure 24: Temperature and relative humidity during the 6th day - 2019 experimental test of conservation conditions of cherries.

Air relative humidity values gradually increased throughout the day, shown in Figure 24 b), where it goes from (85-90%) in the morning to (90-95%) in the afternoon.

On the fourteenth day of the test, the air temperature recorded was higher than the values suggested by the literature, which favors the loss of cherry quality, as shown in Figure 25. The average air temperature recorded, 7.4 °C, was higher than the previous days. It is also observed that throughout the day, there were 5 moments in which the air temperature decreased rapidly, but gradually returning to previous values.



a) Air temperature variation.



b) Air relative humidity variation.

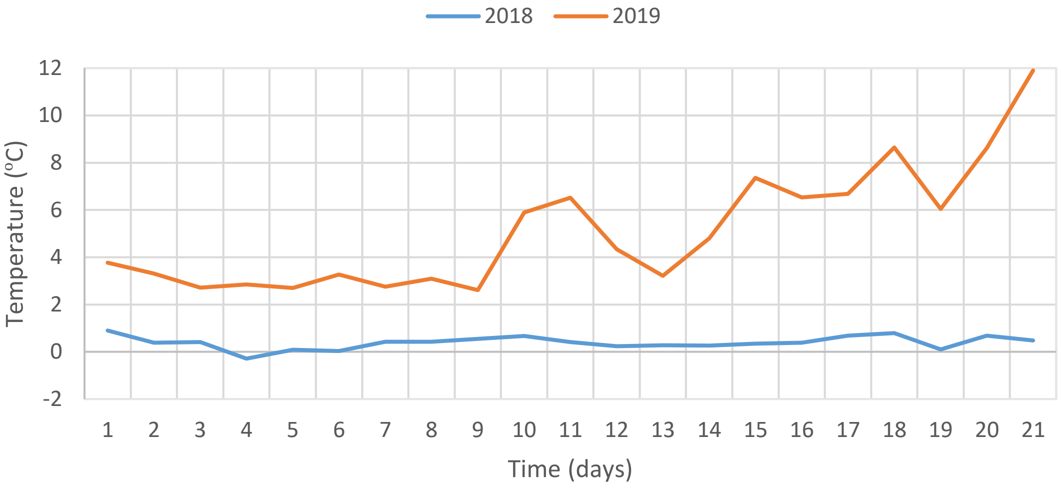
Figure 25: Air temperature and relative humidity during the 14th day - 2019 experimental test of conservation conditions of cherries.

Air relative humidity on this day also showed 5 moments when its value suddenly decreased. The sharp decrease visible at 14h:24m is common to the temperature graph, indicating that there was a variation in the thermal load of the chamber, i.e., added and/or removed products from inside the chamber.

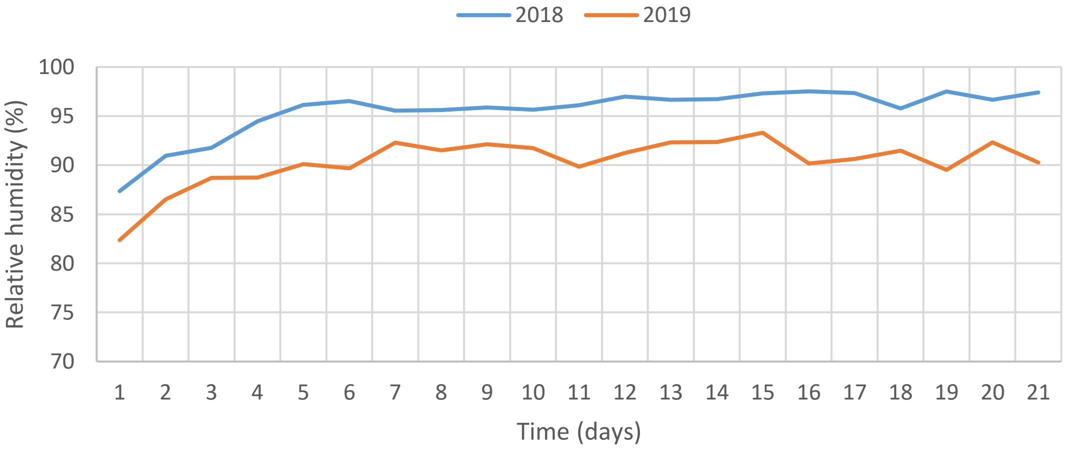
4.1.1 Comparison of results from both experimental tests for conservation conditions of cherries

The following figures compare the values of the year 2018 and 2019, where the average air temperature value obtained in Figure 26 a) in 2019 was higher than the year 2018. This fact also occurs in the air relative humidity values, with an average value of 95% in 2019, while in 2018 was 90%.

When comparing the two trials and keeping in mind the values suggested by the literature in Table 10, it is concluded that in 2019 the cherry conservation was not as effective as the previous year. This incorrect product preservation results in reduced product life and loss of quality.



a) Average air temperature values obtained from both tests.



b) Average values of relative humidity obtained in both tests.

Figure 26: Parameters recorded inside the cherry's conservation chamber.

Tables 23 and 24 show the average values of each experimental test of the conservation conditions of cherries.

Table 23: Values obtained in the field work on cherry conservation.

Values	Temperature [°C]	Relative humidity [%]
Average	0.4	95.5
Maximum	0.9	97.5
Minimum	-0.3	87.4
Standard deviation	0.3	2.5

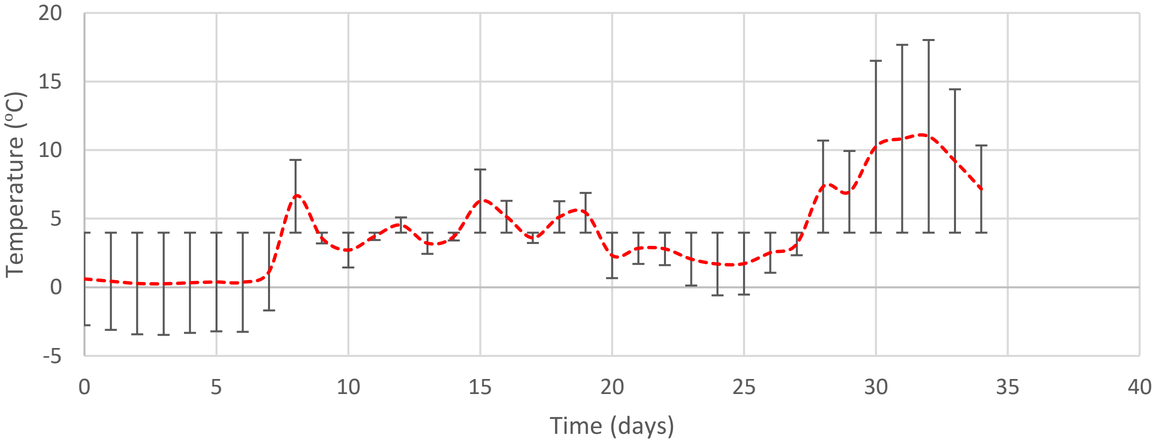
Table 24: Values obtained in the second field work on cherry conservation.

Values	Temperature [°C]	Relative humidity [%]
Average	5.1	90.3
Maximum	11.9	93.3
Minimum	2.6	82.4
Standard deviation	2.5	2.3

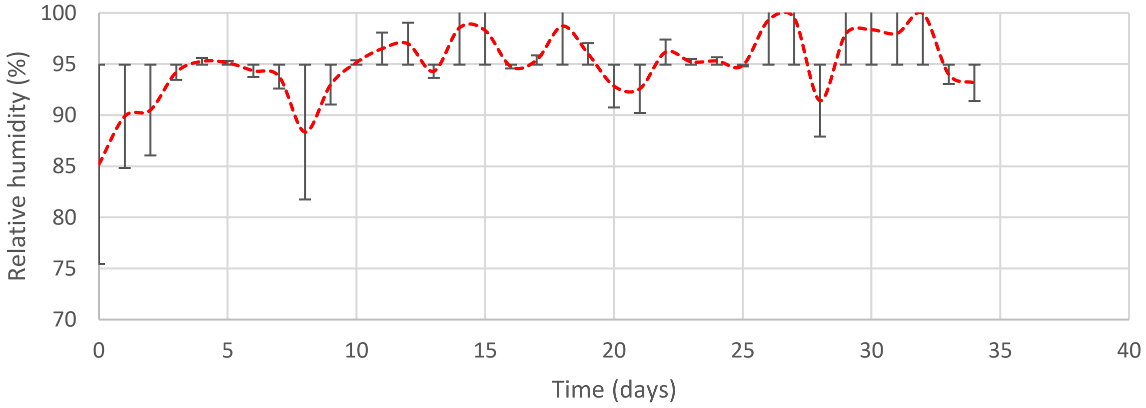
4.2 Experimental Results of the Conservation Conditions of Peach

The following figures show the relationship between each sample obtained as a function of time. In the first experimental test, in the evaluating of the conservation conditions of peaches shown in Figure 27, it was found that there were 3 different temperature periods.

In the first period, beginning at the onset of the test and extending until day 7, the air temperature remained below 2 °C, while in the second period, between day 7 and day 20, the average values of air temperature were closer to 5 °C. It should be noted that in the 2018-year experimental test for the evaluation of peaches' conservation conditions, in the last week of the test, due to malfunctions in the conservation chamber, caused air temperature values to exceed normal values.



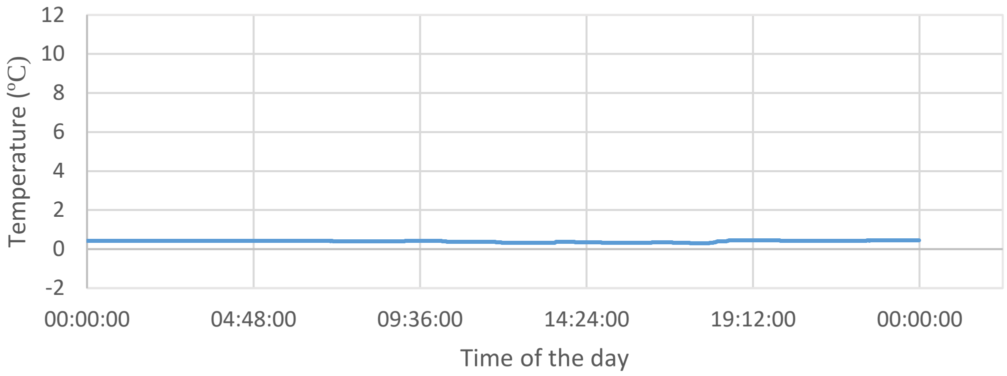
a) Variation of air temperature during the test.



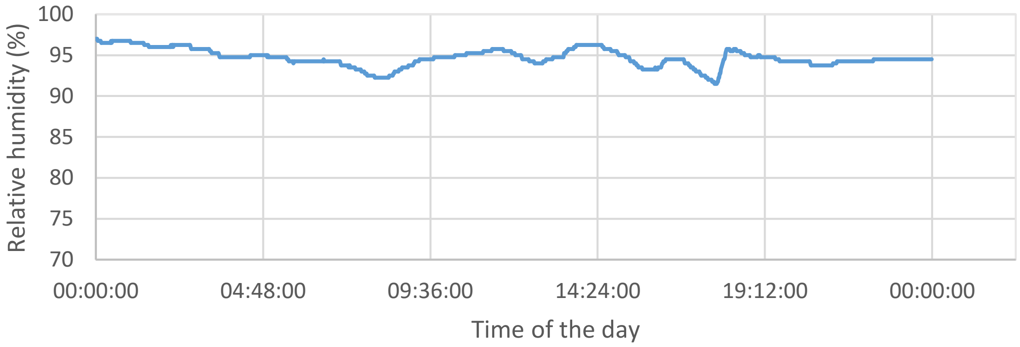
b) Variation of relative humidity during the test.

Figure 27: Environmental parameters recorded inside the producer's conservation chamber - 2018 experimental test of conservation conditions of peaches.

On the sixth day of the test, the average air temperature inside the chamber was 0.4 ° C, while the relative air humidity was 94.3%, as shown in Figure 28. Compared to the average test value, the variation of the air temperature was lower by 3.6 ° C, while relative air humidity was by 0.6%, indicating inadequate storage air temperature during the test. During this test day, no fluctuations in the air temperature and relative humidity values occurred inside the chamber, indicating that there were no door openings or thermal load variation.



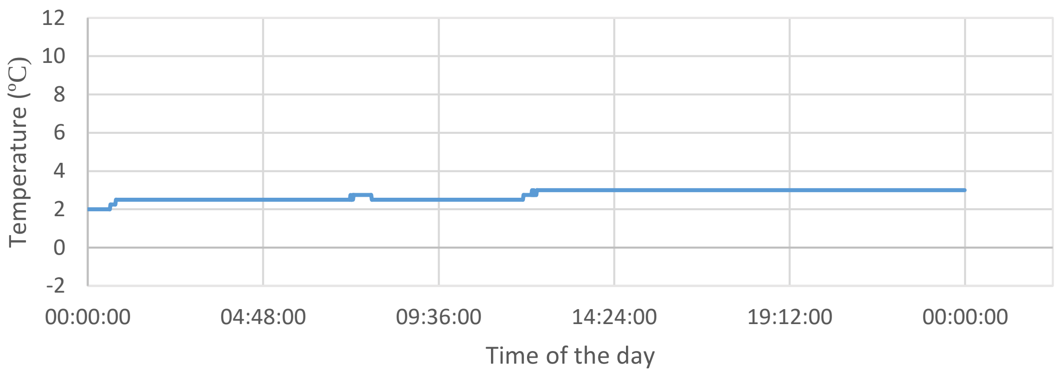
a) Air temperature during the day.



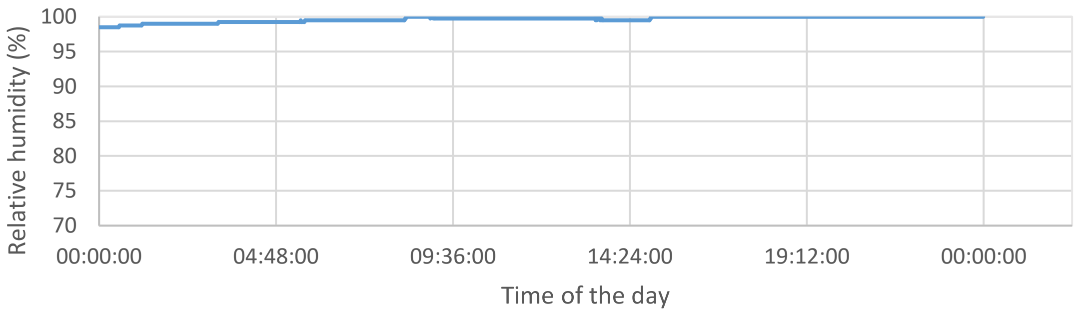
b) Air relative humidity during the day.

Figure 28: Air temperature and relative humidity during the 6th day – 2018 experimental test of conservation conditions of peaches.

This day presented a high variance compared to the other days, which indicates that the average air temperature was closer to the average value. There were no significant changes throughout the day, as shown in Figure 29. Air relative humidity remained virtually constant throughout the day, with an average value of 99.5%.



a) Air temperature during the day.

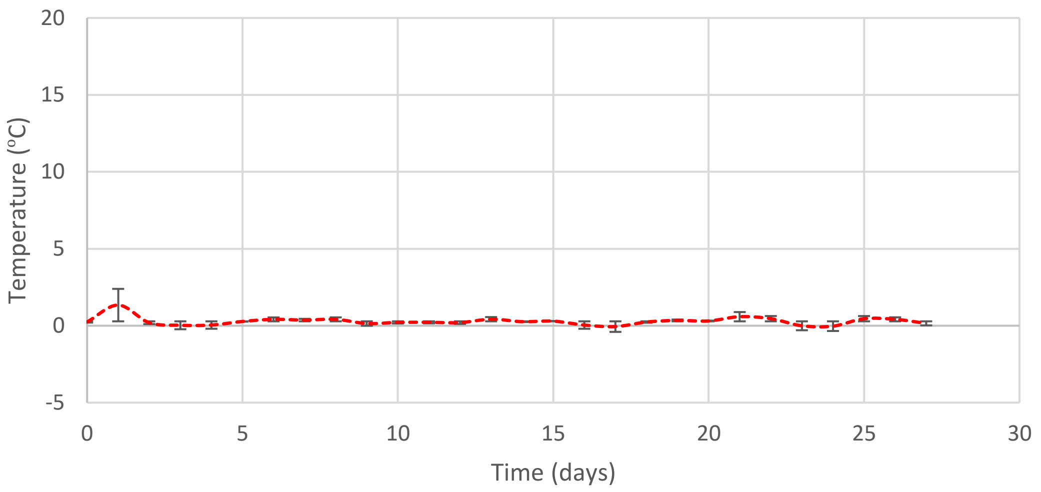


b) Air relative humidity during the day.

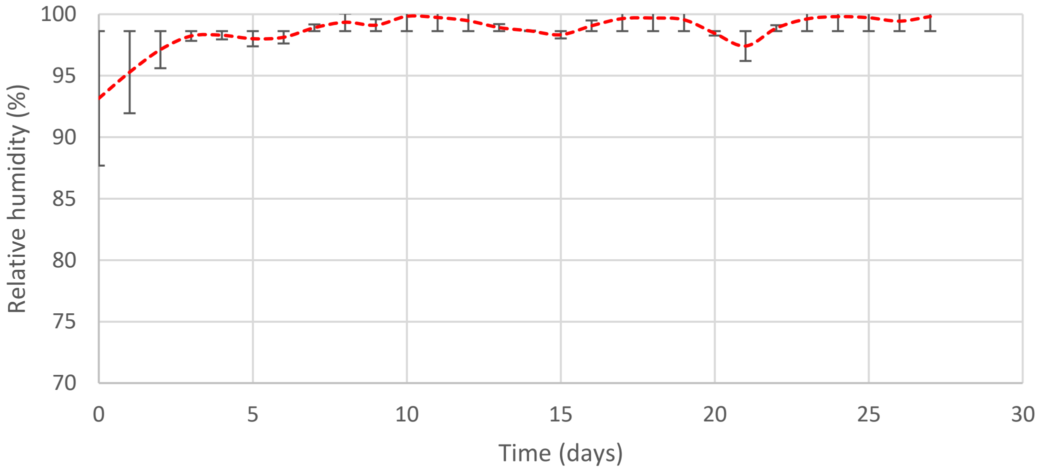
Figure 29: Temperature and relative humidity during the 27th day – 2018 experimental test of conservation conditions of peaches.

This day preceded a series of high air temperature variances, which reached 7 ºC. These peaks resulted from the failure of the conservation chamber.

In the second experimental test, the air temperature and relative humidity values obtained were better than those of the year 2018. The decrease of values made the conservation environment improved and thus promoted the extension of the peach's life-time. These results are described in Figure 30.



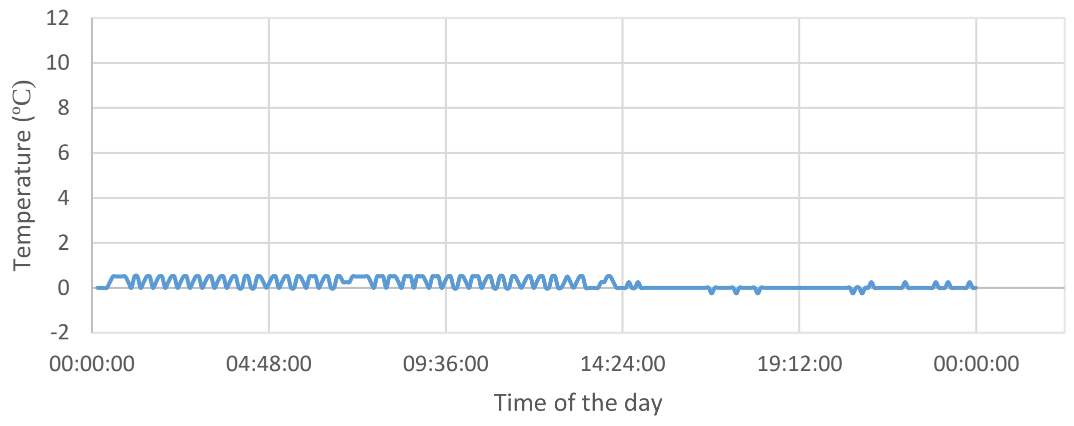
a) Variation of air temperature during the test.



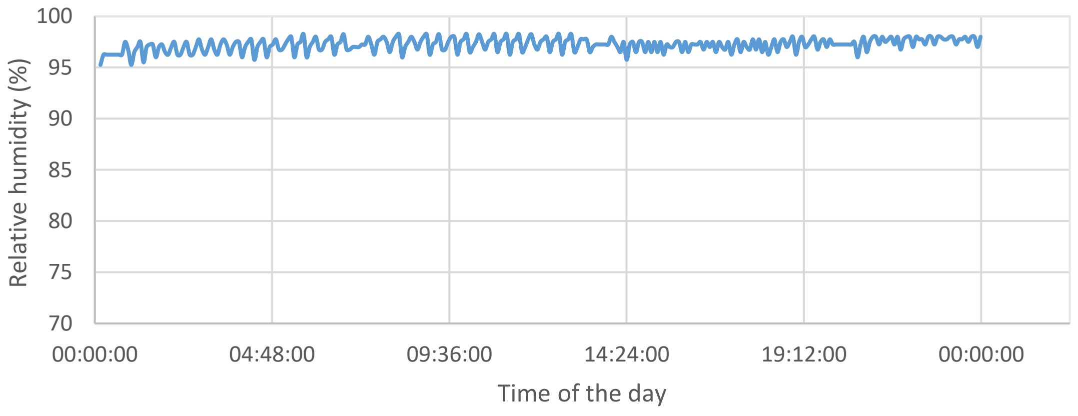
b) Variation of air relative humidity during the test.

Figure 30: Environmental parameters recorded inside the producer's conservation chamber day – 2019 experimental test of conservation conditions of peaches.

During the initial period of the experimental test, the day with the highest variance was the third. Figure 31 shows the graphs corresponding to the values obtained during that day.



a) Air temperature during the day.

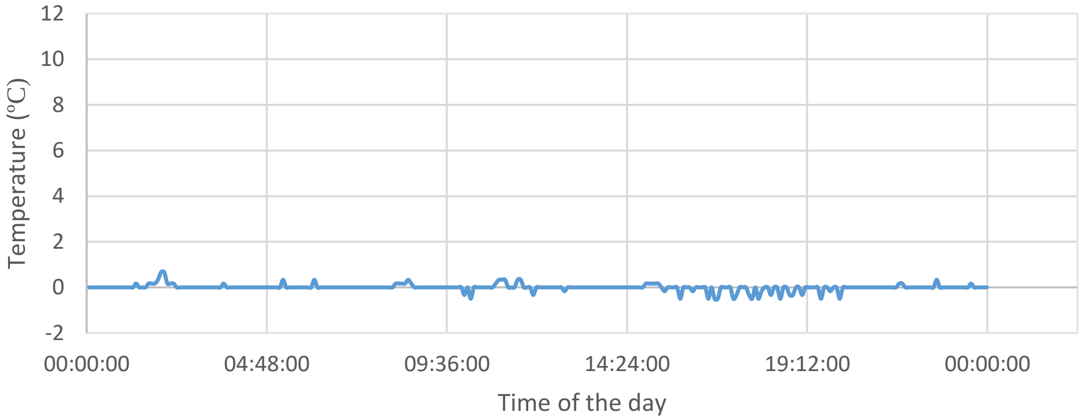


b) Air relative humidity during the day.

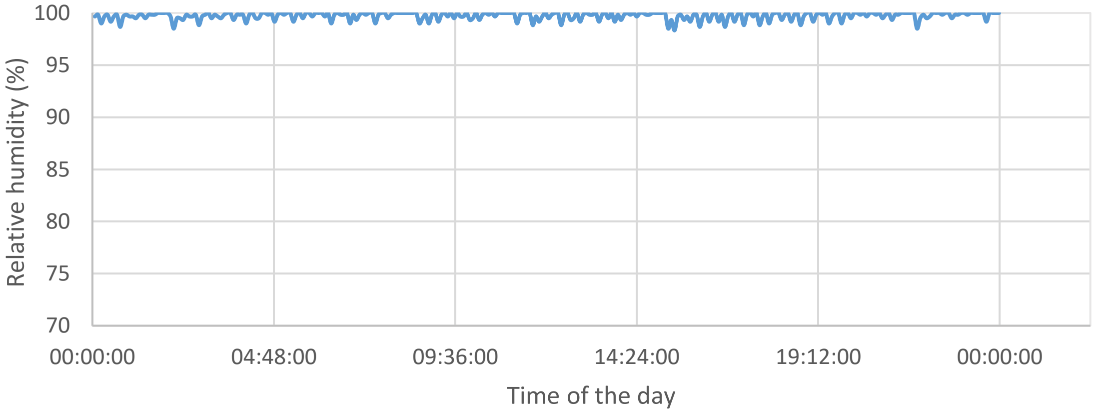
Figure 31: Air temperature and relative humidity during the 3rd day - 2019 experimental test of conservation conditions of peaches.

As can be seen from the analysis of Figure 31 a), the average air temperature presented two periods, one with positive values and one with negative values. In the morning, the average temperature was between 0 °C and 0.5 °C, and after 14h:24m, the values tended to 0 °C. Over the same period, the air relative humidity values reduced the value range. During this day, there were several doors openings of short duration, which caused the values to fluctuate. In the afternoon, the operations inside the conservation chamber were reduced reflected in more constant values.

Figure 32 shows the graphs of the values obtained during the twenty-third day after the start of the test. The temperature was practically constant throughout the day, with a sequence of negative values in the late afternoon.



a) Air temperature during the day.



b) Air relative humidity during the day

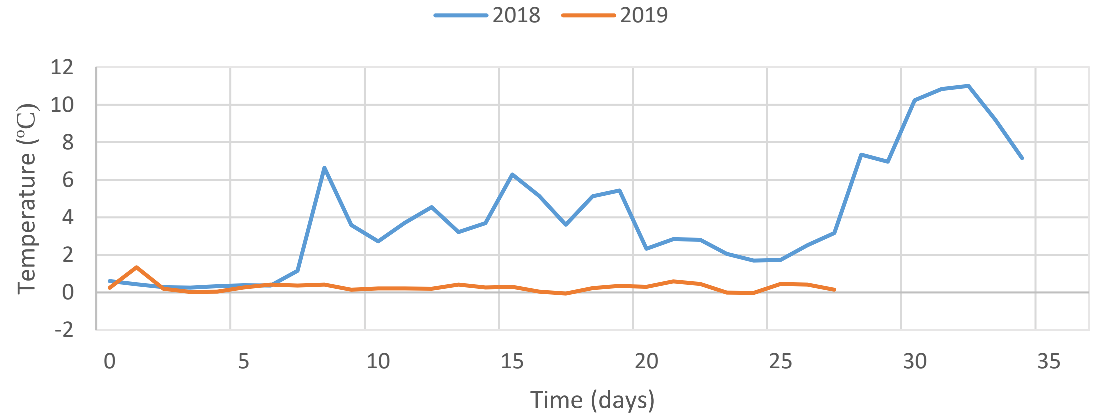
Figure 32: Air temperature and relative humidity during the 23th day - 2019 experimental test of conservation conditions of peaches.

The air relative humidity values recorded were normal, with a very small range between 98.5% and 100%.

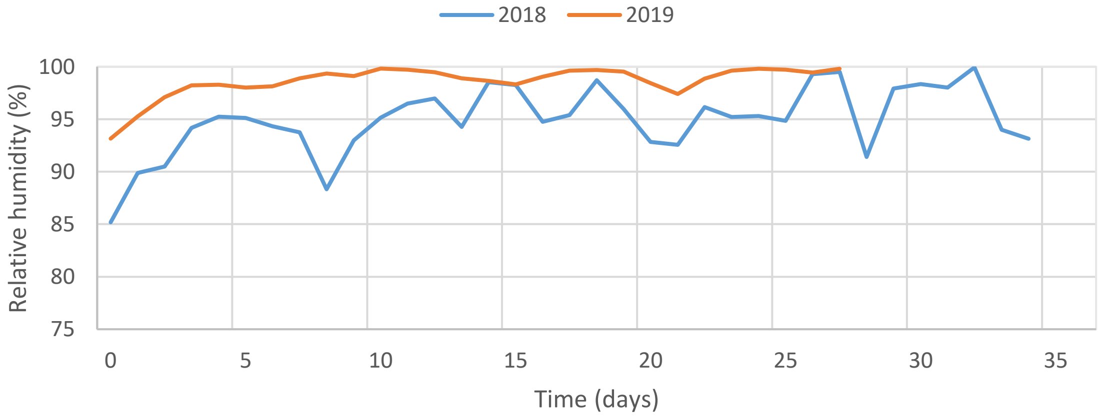
4.2.1 Comparison of results from both experimental tests for conservation conditions of peaches

As shown in Figure 33 and Tables 25 and 26, in 2018, the average air temperature inside the chamber was 4.0 ˚C, while in 2019 was 0.3 ˚C, meaning a decrease of 3.7 ˚C. Regarding the conservation environment, since in 2019, the air temperature was lower than in 2018 and, according to the literature, the ideal air temperature for conservation is between 0 ºC and 2 ºC, it can be concluded that in the second test the environment was more favorable. Air relative humidity also fluctuated, with an averaging value of 94.9% in 2018, while in 2019 it was 98.6%. The variance of the daily values concerning the average value was also lower in 2019, which means that the air temperature remained similar to the averaging.

The main difference between each experimental test was the duration. In 2018 was 5 weeks (35 days), while in 2019 was 4 weeks (28 days).



a) Average air temperature values obtained from both tests.



b) Average values of relative humidity obtained in both tests.

Figure 33: Parameters recorded inside the peach’s conservation chamber.

Table 25: Values obtained in the field work on peach conservation.

Values	Temperature [ºC]	Relative humidity [%]
Average	4.0	94.9
Maximum	11.0	99.9
Minimum	0.3	85.2
Standard deviation	3.1	3.2

Table 26: Values obtained in the second field work on peach conservation.

Values	Temperature [ºC]	Relative humidity [%]
Average	0.3	98.6
Maximum	1.3	99.8
Minimum	-0.1	93.2
Standard deviation	0.3	1.5

4.3 Conclusive notes

After analyzing the results presented, it was concluded that both fruits in the study had a year with an ideal conservation environment and a year in which the conservation values reduced their life span.

In the first experimental trial, the cherry was conditioned in an environment with an average air temperature of 0.4 °C with an average relative humidity of 95.5%. The conservation environment of the peach presented an adequate average air temperature during the first 7 days, with 0.4 ºC, increased after that to an average value of 5ºC and later to 10 ºC. These values are inadequate to promote the extension of the life span of peaches.

In the second experimental trial, the cherry from day one was conditioned to a conservation environment with an average air temperature of 3 °C during the first 8 days, gradually increasing to 10 °C, while the average relative humidity was 90.3%. Unlike the year 2018 campaign, peach recorded an average air temperature of 0.3 ° C and relative humidity of 98.6%, which promoted shelf life by slowing down the ripening process.

Based on the results of the preservation environments to which cherries and peaches were subjected, it was possible to observe the impact that the opening moments of the chamber door or the variation of the amount of fruit product had on the preservation environment inside the chamber. With the experimental evaluation performed, the values of temperature and relative humidity in which the system to be developed would have to operate were stipulated.

Defining the range to which the traceability device would be subjected allows a correct choice of electronic equipment.

5 Prototype

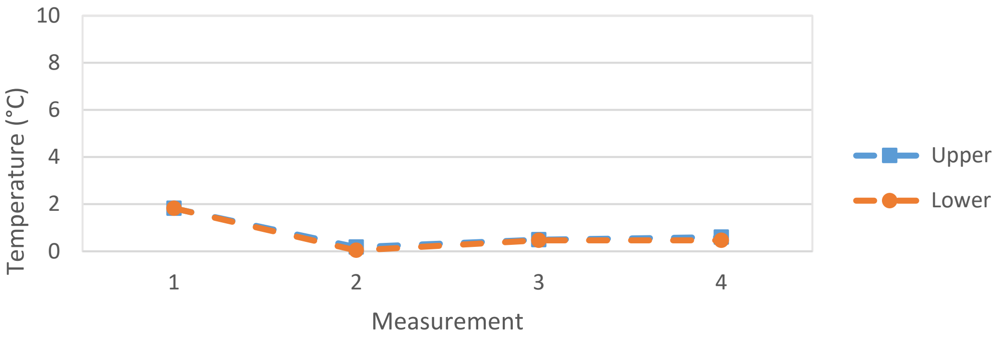
5.1 Introduction

With the analysis of results provided by the experimental tests and the characterization of the conservation environment, it was possible to establish the technical specifications desired for the traceability system to be developed, i.e. the air temperature and relative humidity at which it would have to work, the time interval between each acquisition and the energy autonomy required.

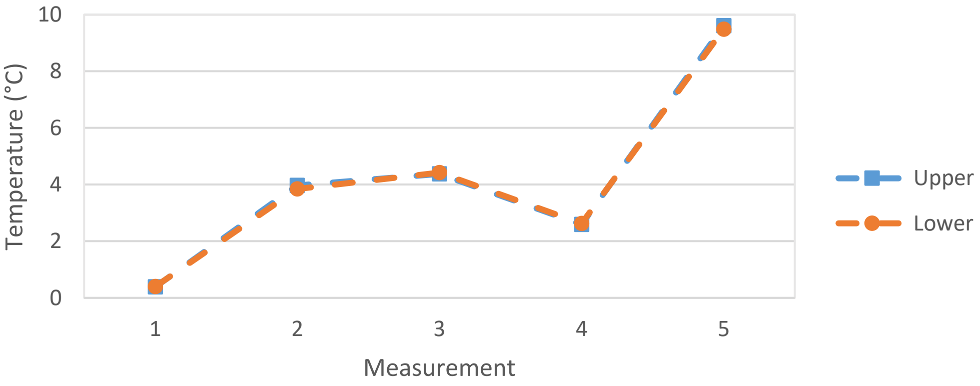
When placed on a pallet and stored in a chamber, the packaging is not subject to the same temperature. A study by Goransson et al. (2018), using data from 83 sensors installed in a 26 m^3 conservation chamber, aimed to evaluate the thermal inertia at which the pallet was subjected and how it affected the shelf life of packaged smoked ham. The pallet was placed in a corner of the chamber, with a set point of 2 ºC and subject to temperature variation when withdrawing it to the outside. Intrinsic to the results, it was shown that the location of a product on the pallet did not influence its validity.

As more than one datalogger was used, it was also possible to evaluate the difference in air temperature and relative humidity between the upper and lower part of the pallet, allowing the evaluation of the number of sensors required to monitor it. Figure 34 shows the difference in average air temperatures of the top and bottom of the pallet during the first experimental test.

Based on the data obtained from the experimental tests, it is noted that the air temperature variation between the top of the pallet and the base is practically insignificant so that the number of sensors required for monitoring is reduced to 1 per pallet.



a) Temperature values recorded in cherry control lot.



b) Temperature values recorded in peach control lot.

Figure 34: Evaluation of the temperature difference between the top and the bottom of a pallet.

5.2 Device operation requirements

When choosing technologies to include within a traceability system, the first that one needs to know is the function to choose and the relevance of the data. Previously several wireless communication technologies were presented, showing their strength in a particular field.

The idea of the traceability device is to be placed or inserted in a packaging box with fruit products along the distribution chain, acquiring and communicating the state of the conservation environment and the location. Given the fruit product under test, it is concluded that a 5-minute acquisition rate would be ideal.

Refrigeration systems equipped in food transport vehicles do not always ensure constant air temperature and relative humidity values or the range considered optimal due to external factors such as sun exposure of vehicles, low-efficiency refrigeration systems, among others. Table 27 presents the characteristics of the traceability system to be developed.

Table 27:Acquisition characteristics necessary for the traceability device.

Number of devices	1 device per pallet
Maximum value	+ 30 °C / 90% HR
Minimum value	0 °C / 30 % HR
Acquisition time	5 min
Communication	GSM

Besides the requirements presented in the previous table, there is another extremely important factor, namely the energy autonomy of the system. Since monitoring is done in real-time, the time interval between acquisition and the dispatch is reduced. Thus, it requires more power from the system, especially during communication. So, the ideal system would be functional up to 3 days (60 h) with a 3.7V, 2400 mAh battery.

5.3 Traceability device

In WSN's design, there are three major requirements (Nurellari & Srivastava, 2019):

- **Low Power Hardware:** The biggest design problem is the power consumption of these systems even when using low power microcontrollers.
- **Resource Constraints:** Being battery-powered devices with limited power, system life and communication bandwidth (BW) are restricted. When designing algorithms, both signal processing and communication must be carefully designed to consume as little power as possible to extend the life and improve the overall reliability of the WSN.
- **Network Security:** As the purpose of sensor networks is to be placed in a large outdoor area, their maintenance is not always assured, making them vulnerable to computer attacks or hardware problems. The overall detection and estimation performance strongly depends on the reliability of these SNs (Sensors Network) in the network.

According to the literature, several monitoring systems can be applied to both transport and cultivation process monitoring. Jagadesh et al. (2018) developed a system for field monitoring. This system consists of an Arduino, a Raspberry and a ZigBee, the latter being used for sending data. Soil humidity, temperature, pH and water level sensors were coupled, allowing to characterize the environment in which the system is located.

Tang et al. (2019) also used an Arduino and ZigBee for the development of a monitoring system to track maritime cargo containers, allowing the control of air temperature and relative humidity values inside. Badia-Melis et al. (2015) combined two technologies, RFID and WSN, to develop a system that would follow perishable products during transportation, storage, and distribution globally. The analysis of the environment was performed using sensors in passive RFID tags, and the values were sent later with the aid of a ZigBee. Venkatesh et al. (2017) present a system that combines BLE (Bluetooth Low Energy) with IoT. The system includes gas sensors, which detect gas from the food product, temperature and humidity sensor. The data obtained is transferred via BLE or GSM/GPRS to a remote server.

The traceability system developed is based on an Arduino. This microcontroller enables faster development and application on a prototyping board (Patnaikuni, 2017). Table 28 presents the main characteristics of the microprocessor used.

Table 28: Microprocessor characteristics.

Processor	ATMEGA328-PU
Operating voltage	5V
GPIOs	14
Flash memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock frequency	16 MHz

After choosing the microcontroller, it had to be programmed to make automatic acquisition and shipping processes. To program the microcontroller, the Arduino Integrated Development Environment (IDE) and the corresponding sensor and communication module libraries were used. The code is in flowchart form as shown in Figure 35.

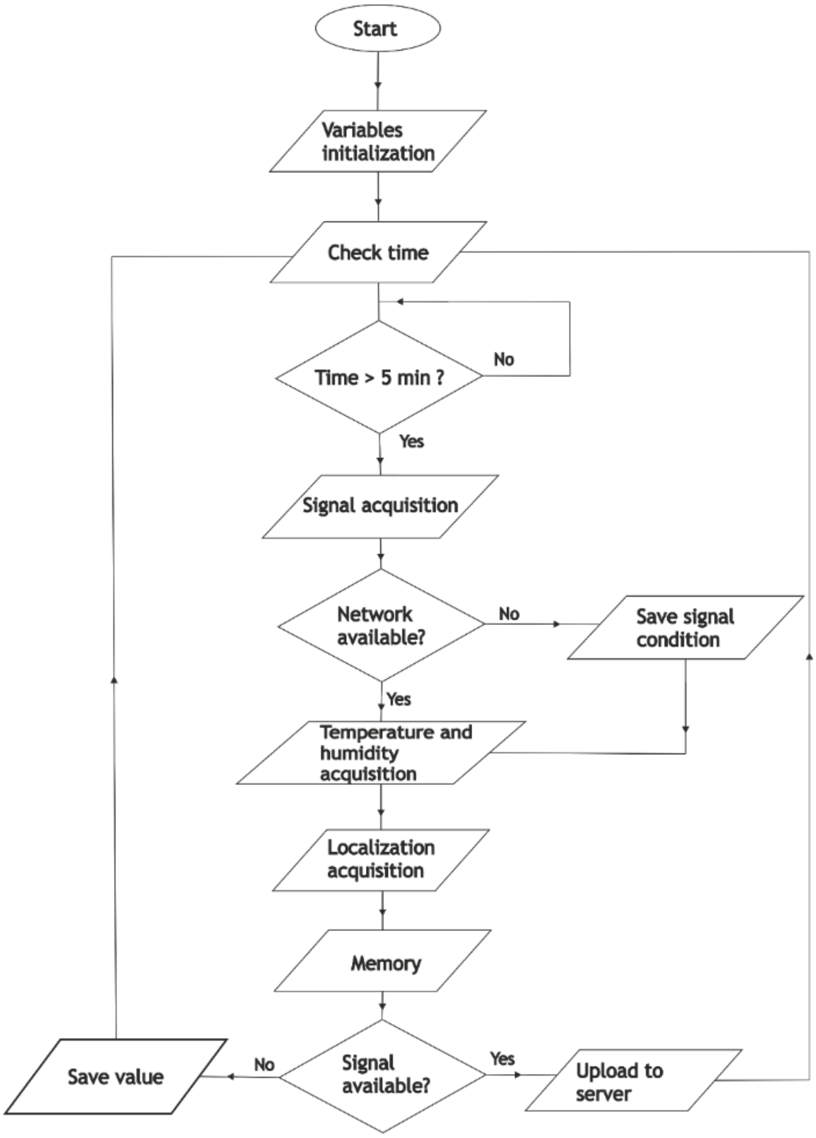


Figure 35: Flowchart of monitoring device operation.

When enabled, the variables are initialized so that there is no overlap in memory allocation. This part is the code setting. It is also in this process that the timer value setting a variable and the corresponding sensor off-set variables were set.

At the end of the setup, the code enters the loop, where the actions that will perform indefinitely are defined. In the second line is coded the condition that is always in progress, the timer check. If the timer does not have a value of 5 minutes, it does not check the condition and retries the timer check. The instant it is verified, the system goes to the next step.

The third line is to analyze the value of the signal strength of the network. Signal strength, called RSSI, is the unit that allows evaluating the strength of a signal. If the signal condition is found to be good, air temperature and relative humidity values are acquired using the DHT11 sensor. For low RSSI value, the system will acquire the air temperature, relative humidity, and sample number value. Thus, when the system has a favorable signal again, it will send the values obtained previously.

Then, triangulation is performed to obtain the location using the GSM module. By sending AT commands to the operator, the Longitude and Latitude are returned to and then stored in memory. Triangulation is based on the telecommunications antennas closest to the device.

After these operations, and based on the value of the signal strength, the system either sends the data via GSM to a remote server or stores the air temperature value and sends it only in the next cycle. In this condition, only the temperature value is sent, as it is the parameter that most affects the quality of perishable products.

The data obtained is sent to an online platform, ThingSpeak, which allows the storage of data from IoT platforms. In addition to storage, MATLAB Online is available which allows data processing on the platform itself. Data is sent to ThingSpeak via the Transmission Control Protocol/Internet Protocol (TCP/IP). The process is described in Figure 36.

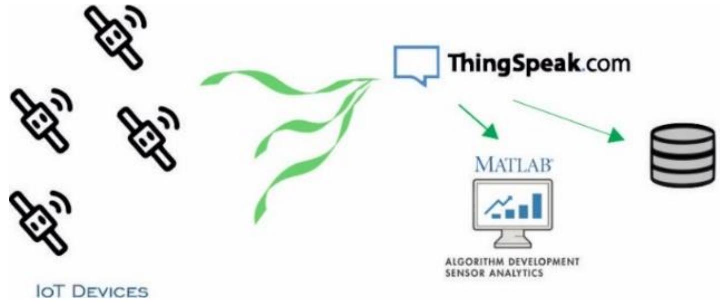


Figure 36: Illustration of communication flow between data sent by IoT devices and ThingSpeak server.

Subsequently, the data is converted to a display and sent to the website allowing the location and values obtained every five minutes, as shown in Figure 37.

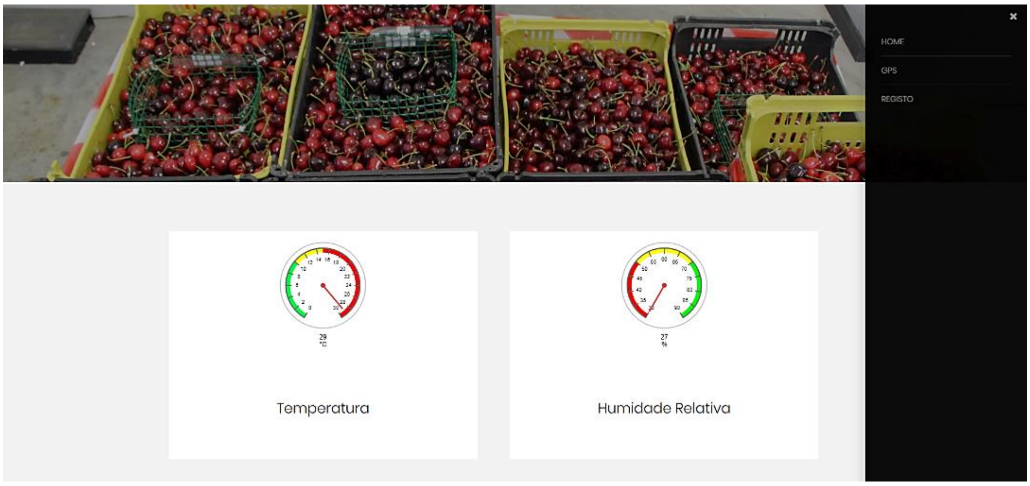


Figure 37: Viewing informational apps on the device page.

For the elaboration of the map that allows the visualization of the location, a code was written in HTML that incorporates the values read in ThingSpeak and overlaps them with the map of Google Maps. In Table 29 are presented all the components used and their main electrical characteristics.

Table 29: Electrical specifications of the components used.

<table>
<tr><td>Component</td><td colspan="6">Characteristics</td></tr>
<tr><td rowspan="6">Sim800L</td><td colspan="2">Voltage</td><td colspan="4">3.7V - 4.2V</td></tr>
<tr><td colspan="2">Recommended Voltage (V)</td><td colspan="4">4V</td></tr>
<tr><td colspan="2" rowspan="4">Current (mA)</td><td colspan="4">sleep mode < 2.0mA</td></tr>
<tr><td colspan="4">idle mode < 7.0mA</td></tr>
<tr><td colspan="4">GSM transmission (avg): 350 mA</td></tr>
<tr><td colspan="4">GSM transmission (peek): 2000mA</td></tr>
<tr><td rowspan="5">ATMEGA328P</td><td colspan="2">Crystal</td><td colspan="4">16Mhz (external)</td></tr>
<tr><td colspan="2">Voltage (V)</td><td colspan="4">3.3</td></tr>
<tr><td colspan="2">Current (mA)</td><td colspan="4">6.6</td></tr>
<tr><td colspan="2">Power (mW)</td><td colspan="4">21.8</td></tr>
<tr><td colspan="2">5V, 16Mhz</td><td colspan="4">81.8 mA</td></tr>
<tr><td rowspan="5">DHT11</td><td colspan="2">Conditions</td><td>Minimum</td><td>Average</td><td>Maximum</td><td>S.I</td></tr>
<tr><td>Voltage</td><td>DC</td><td>3</td><td>5</td><td>5.5</td><td>[V]</td></tr>
<tr><td rowspan="3">Current</td><td>Measure</td><td>0.5</td><td></td><td>2.5</td><td>[mA]</td></tr>
<tr><td>Average</td><td>0.2</td><td></td><td>1</td><td>[mA]</td></tr>
<tr><td>Standby</td><td>100</td><td></td><td>150</td><td>[μA]</td></tr>
</table>

The electrical circuit assembled for the tests is shown in Figure 38. In addition to the elements listed in Table 29, it was also necessary to use two 33μF capacitors for the 16 MHz crystal, a voltage divider to ensure the 3.3V input value of the SIM800L module RX pin and a 10K resistance for the DHT11 sensor.

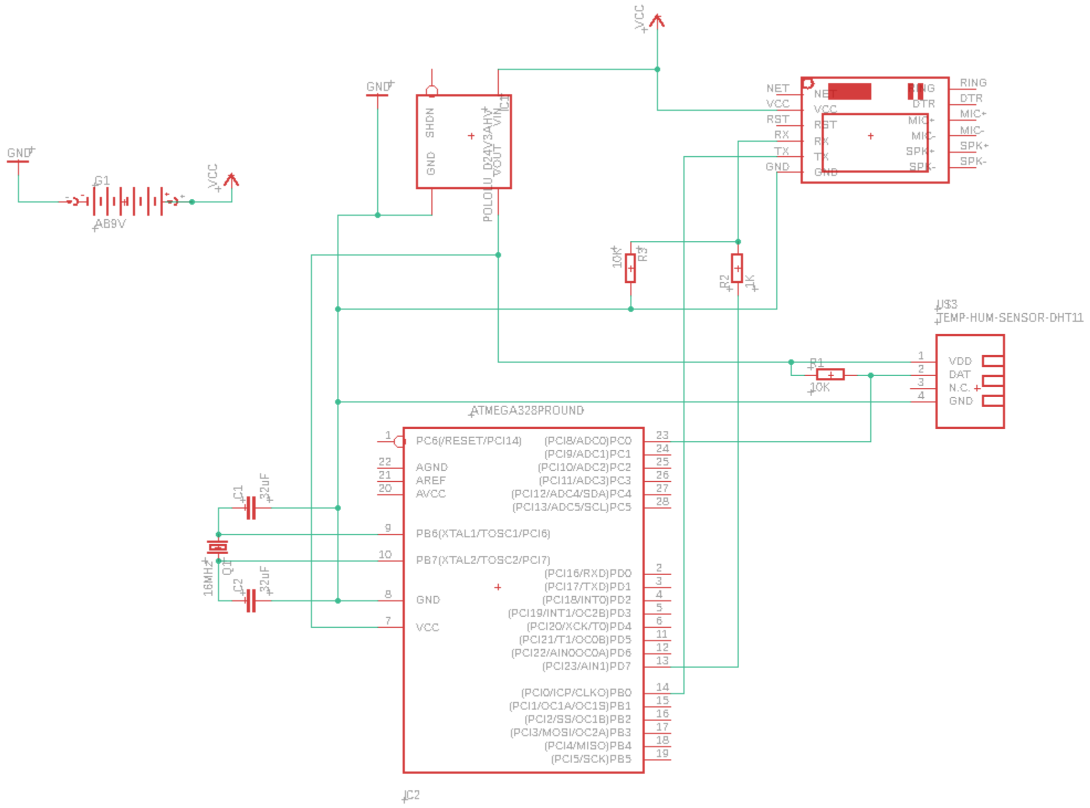


Figure 38: Schematic of the connections of the traceability device.

To assemble the prototyping board, it was first necessary to mount the circuit on a breadboard to test it, as shown in Figure 39.

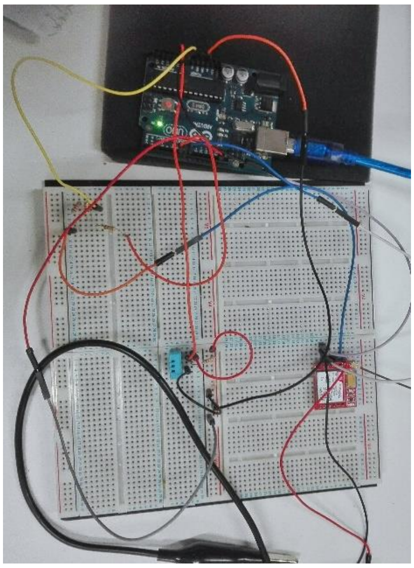
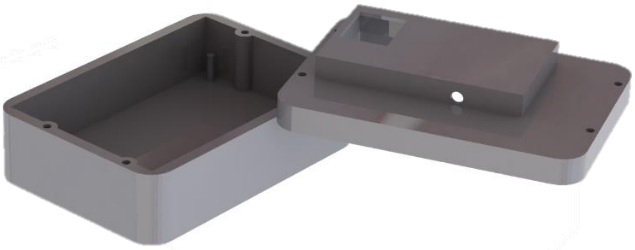


Figure 39: Breadboard circuit with all components.

After mounting the system on a development board, a 3D printer was used to print the package, with the final result shown in Figure 40.

(a) Prototyping board with system.

(b) Printed box.



(c) Model used for printing.

Figure 40: Prototype of the packed traceability system.

The box designed for the prototype has the dimensions shown in Figure 41.

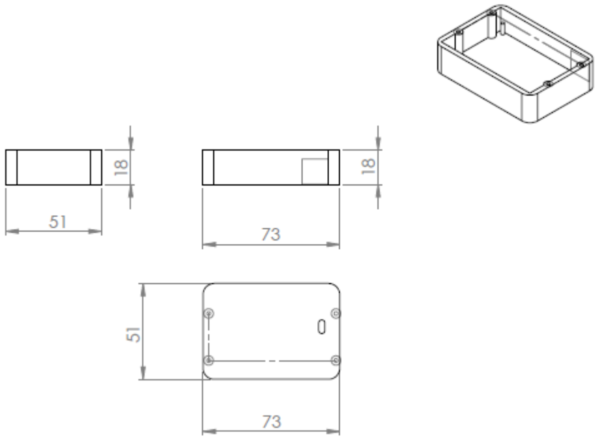
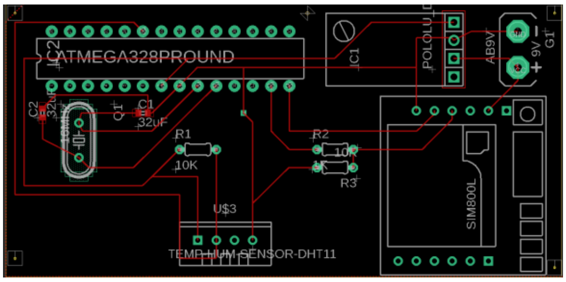
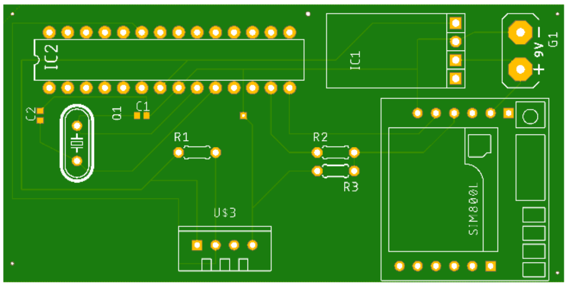


Figure 41: Dimensions used in the prototype box [mm].

With the conclusion of the experimental tests on the monitoring system, the circuit for printing was designed. The circuit design is shown in Figure 42.



a) Schematic of the printed circuit board.



b) Printed circuit board used for the monitoring system.

Figure 42: PCB scheme used for final system version.

5.4 Results

To validate the experimental results, two experimental tests were performed, each divided into two parts. The first set of tests was performed inside the laboratory at Universidade da Beira Interior (UBI) to validate the operation and adjustment of the offsets.

In the second set of tests, the operation during the transport of fruit products from the producer (Covilhã) to the distribution center (Albufeira) was assessed. The trip took approximately 5h and 470 km. Thus, it was possible to test the operation of the monitoring system in a situation similar to that it would have to face, from signal losses, vibrations, and excessive temperatures.

5.4.1 Experimental validation test #1

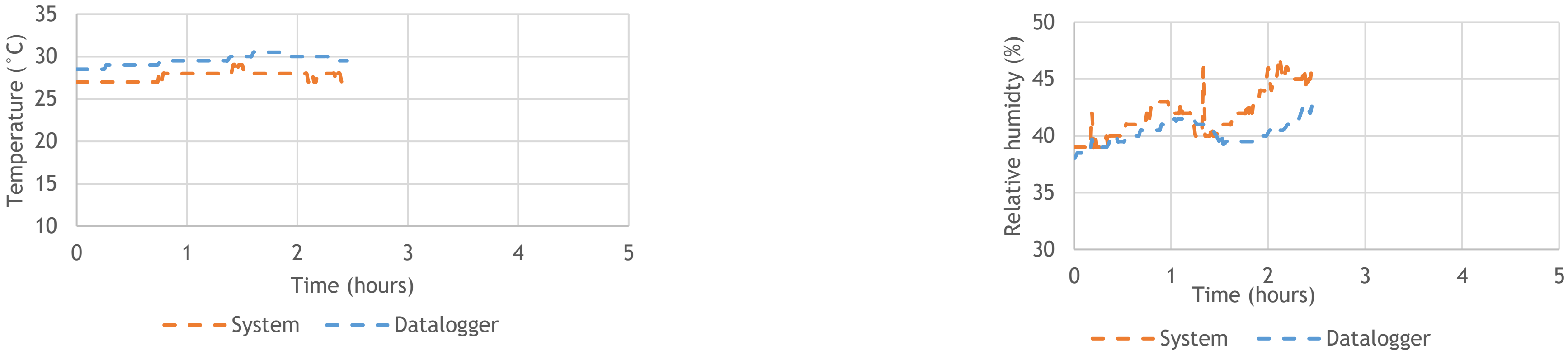
The validation test #1 was performed inside the laboratory to verify the functioning of the communication module and the sensor. Both experimental tests were performed under the same laboratory conditions.

The results are shown in Figure 43, where it is possible to analyze the difference of the tests without offset and considering a posterior offset to improve accuracy. The offset is a value used to calibrate the sensor value in order to improve the measurement. The duration of the experimental test in the first validation was shorter than in the second validation because of the values obtained by the prototype were bigger than datalogger values, so was preferer to stop the validation and adjust the offset. The offset was made so that the monitoring system values were closest to the datalogger values since the accuracy of the datalogger sensor is higher than the DHT11. The overall values do not show a significant difference, approaching the datalogger values. DHT11's response to parameter variations appears to take longer than the datalogger's built-in sensor. The values for the test performed are shown in Table 30.

Table 30:Values resulting from the first test using the monitoring system and the datalogger

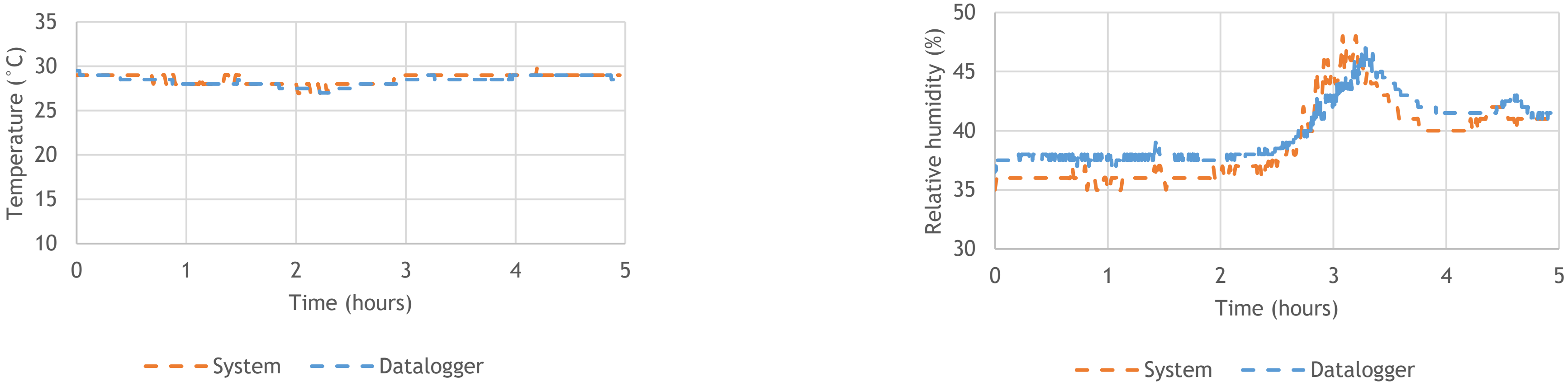
Device	Test	Acquisition (min)	Temperature [°C]			Relative humidty [%]		
			Max	Min	Avg	Max	Min	Avg
Datalogger	1	1	30.5	28.5	29.5	44.0	38.0	40.6
System		5	29.0	27.0	27.7	47.0	39.0	42.0
Absolute Error			-1.5	-1.5	-1.8	-3.0	-1.0	-1.3
Datalogger	2	1	34.5	24.0	28.5	51.5	30,5	40,8
System		5	39.0	24.0	28.7	50.0	21.0	39.5
Absolute Error			-4.5	0.0	-0.2	1.5	9.5	1.3

After applying an offset to the system, the accuracy of the acquired samples was higher. The air temperature error reduced from -1.8 ºC to -0.2 ºC. With this validation test, it was possible to proceed to the next step: to test operation under normal conditions.



a) Air temperature monitoring values (without offset).

b) Air relative humidity monitoring values (without offset).



c) Air temperature monitoring values (with offset).

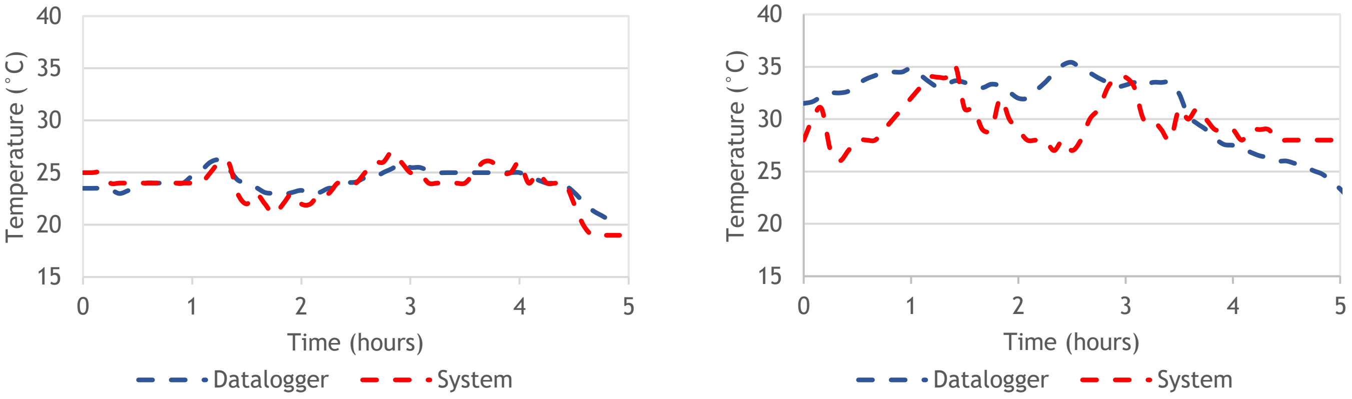
d) Air relative humidity monitoring values (with offset).

Figure 43: Values resulting from the first test using the traceability system and the datalogger.

5.4.2 Experimental validation test #2

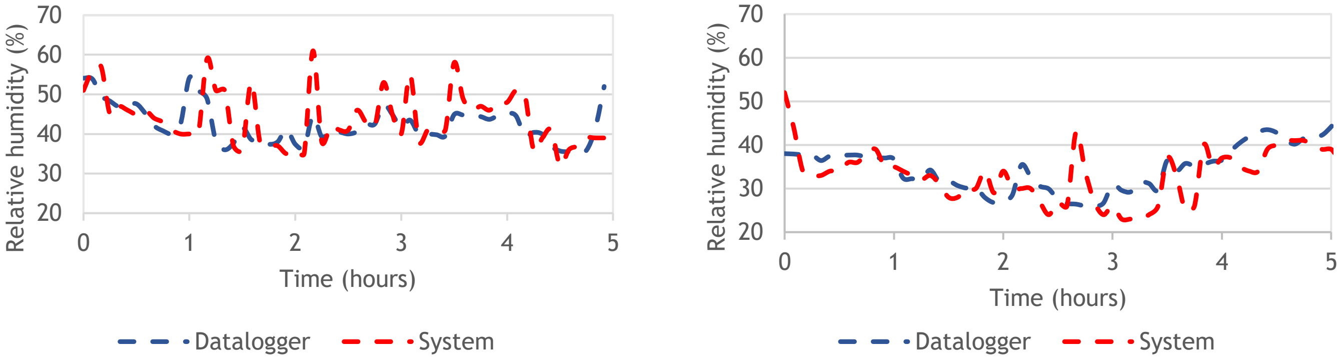
The experimental validation test #2 simulates a real situation, and it allows us to understand how the traceability system will acquire locations and store data when the mobile network power is small or inexistent. During a trip, these situations may occur. Its asset a round trip from Covilhã to Albufeira to analyze the operation of the traceability system. The maximum period in which the traceability system did not communicate was 10 minutes. In a normal situation, depending on the speed of the vehicle, the communication blackout period would be longer. However, the values acquired and not sent due to lack of signal were sent later as soon as the connection is obtained.

As shown in Figure 44, the temperature values measured by the data logger and the system showed no meaningful difference. Despite the second test, the difference was greater due to the temperature variation being used.



a) Air temperature during first test.

b) Air temperature during second test.

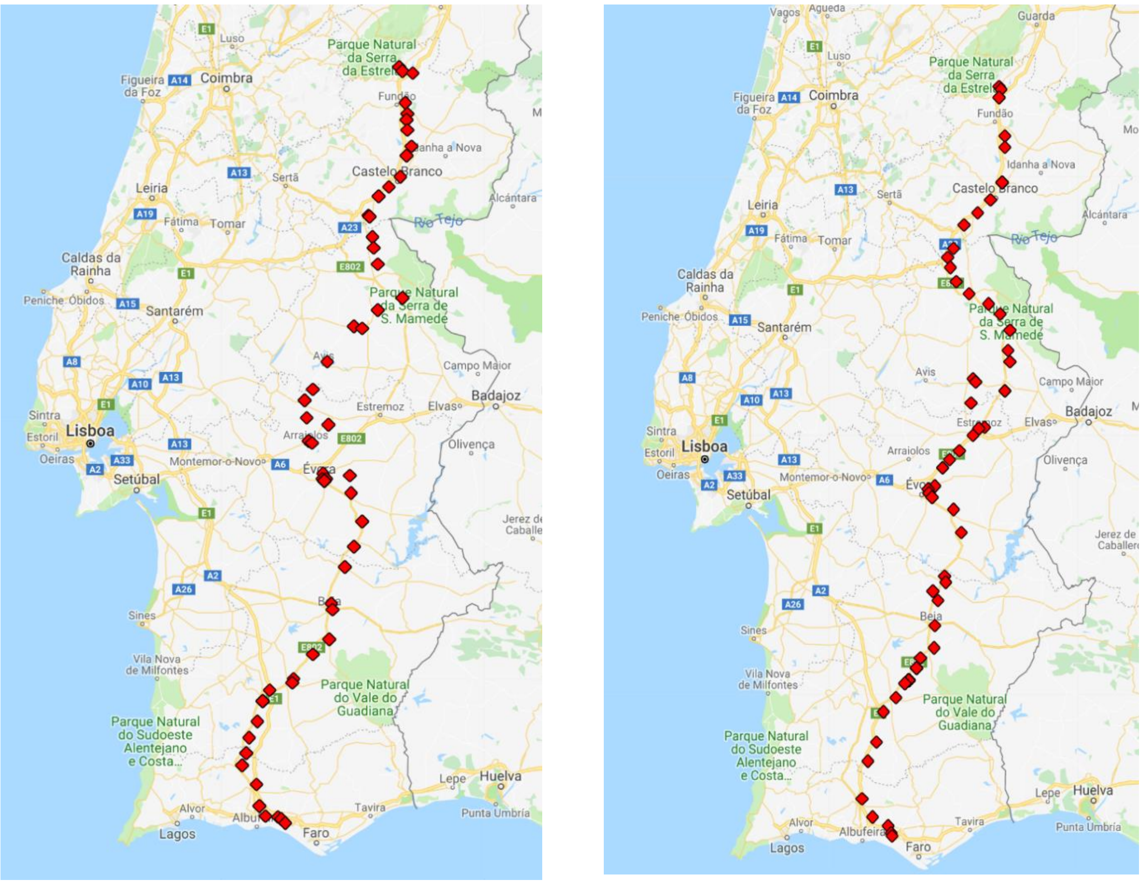


c) Air relative humidity during first test.

d) Air relative humidity during second test.

Figure 44: Values resulting from the second test using the traceability system and the datalogger.

Latitude and Longitude values were also analyzed to verify the difference with the actual route. Later, through the Google Maps platform and as shown in Figure 45, the coordinates were associated with points on the map to better represent the route obtained by the system.



a) Locations from the trip Covilhã-Albufeira.

b) Locations from the trip Albufeira-Covilhã.

Figure 45: Conversion of the geographic coordinates obtained by the system into a map.

As shown in Table 31, the average values obtained by both the datalogger and the traceability system showed a difference of 0.2 °C on the first trip and 1.7 °C on the second trip. Relative humidity values differed by 1.4% on the first trip and 1.3% on the second trip.

Table 31: Values obtained during the trips.

Device	Assay	Acquisition (min)	Temperature [°C]			Relative humidity [%]		
			Max	Min	Avg	Max	Min	Avg
Datalogger	1	1	26.2	20.5	24.0	54.2	35.5	42.5
System		5	27.0	19.0	23.8	61.0	32.0	43.9
Absolute Error			0.2	-1.5	-0.2	6.8	-3.5	1.4
Datalogger	2	1	35.4	21.4	31.1	47.8	26.0	34.9
System		5	35.0	25.0	29.4	52.0	23.0	33.6
Absolute Error			-0.4	3.6	-1.7	4.2	-3.0	-1.3

Regarding signal losses, as mentioned above, there were small sections along the path where mobile coverage was scarce or nonexistent. The mechanism employed in the code allowed sending the values, as shown in Table 32.

Table 32: Values sent by the monitoring system.

Time(h)	Temperature (°C)	Relative humidity (%)	Latitude	Longitude	Backup
16:59:02	28.00	26.00	38.950806	-7.662195	
16:59:56					
17:09:11	31.00	37.00	39.053886	-7.652961	
17:10:05					
17:15:09					
17:19:20	30.00	33.00	39.040543	-7.636255	
17:20:16					
17:30:52	31.00	25.00	39.000008	-7.471332	
17:31:48					31/31/31/31

After the data acquisition at 16h:59m, the system misses sending at 17h:04m, 17h:14m, 17h:24m and 17h:29m. The values are backed up only at 17h:31m.

The tests performed allowed us to gauge the quality of the measurements made by the traceability system both in controlled conditions and in real situations. The assays were all performed in conjunction with a commercial datalogger.

Overall, the difference in values between the two devices is enough for monitoring conditions, although sometimes the difference is considerable. Considering that it is a low-cost prototype, the values were satisfactory due to the traceability it allowed. In a real situation, it would be possible for the producer to evaluate the air temperature and relative humidity irregularities and to associate them with a point on the map and thus with the event that originated it.

6 Conclusions

6.1 General conclusions

Along cold chains, there are numerous times when temperatures suffer irregularities, such as an open door on a conservation chamber or even a poorly closed door of a transport truck. All these events influence the quality of the product when they are purchased by the end consumer, evidencing, for example, the reduction of product life or the occurrence of damage by the cold. These irregularities also have consequences on hygiene and food safety.

Experimental testing in collaboration with the Producer Organization (PO) improved data accuracy as it was collected in a normal operating environment, allowing for the analysis of conservation environments, in particular, the air temperature and humidity values, which were decisive later for prototype development. In 2018, the average storage temperature was more adjusted for cherry than peach, while in 2019 the opposite was observed, with peaches being conserved at more appropriate average air temperatures than cherries. In cherry, the observed temperature variations were partially caused by periods of the opening of the conservation chamber door and/or by the variation of the thermal load inside the chamber. The average values of temperature and relative humidity in 2018 for cherry were 0.4 ºC and 95.5 % and 5.1 ºC and 90.3% in 2019, respectively. During the peach campaign, the average values of temperature and relative humidity were 4.0 ºC and 94.9% in 2018, while in 2019 it was 0.3 ºC and 98.6 % respectively. Experimental tests carried out on the controlled atmosphere cherry carried out at CATAA in Castelo Branco showed an extension of the cherry lifetime up to 49 days when stored in a 10% O_2 and 10% CO_2 atmospheres (Andrade *et al.*, 2019). This test allows to evaluate the difference in the conservation conditions under different atmospheres.

The development of a traceability system that goes within a pallet of perishable goods during transport from the producer to a distribution center was a challenge from the outset, as it was based on the evaluation of a real problem and needed providing a solution. The integration of IoT technologies in agriculture, and in all related sectors, is a promising area as it allows, for example, food traceability, which could be one of the solutions to reduce food waste. Monitoring and control of the packaging atmosphere itself through active components may be key in the development of packaging with the ability to interact with the producer, the product and the consumer. Aspects such as the use of biodegradable or environmentally friendly materials will also need to be considered and taken into account. The developed prototype consists of an ARDUINO UNO Rev3 microcontroller that acquires temperature and relative humidity every 5 minutes using a DHT 11 sensor and uses the SIM800L module that provides real-time communication data via GSM. It also incorporates a 3.7V - 2600mAh battery, which provides approximately 60 hours of autonomy (Morais *et al.*, 2019)

Comparing the temperature and relative humidity values obtained by the prototype or the data logger, it is concluded that after the applied offset, the error decreases, increasing the accuracy of the monitoring system. During the transport between Covilhã and Albufeira, there were times when the coverage was not enough to send the temperature, relative humidity, and geographic coordinates. The data stored in the system were sent to the remote server, verifying that the discrepancy between the values obtained during the blackout and in the moments before and after it presented at most a difference of 1 ºC.

The final values obtained by the monitoring system fluctuated from those of the datalogger that was used as a reference but proved to be suitable for a low-cost traceability device. The use of a traceability monitoring system allows the producer to track the goods during the journey between production and the distribution center. With the geographic information of each sample sent, it allows the producer to know which irregularities occurred and where the event took place. Data sent to a website makes it easier for users to access and analyze all the values.

Thus, the developed device is capable of monitoring perishable products throughout transport and transmitting data of air temperature, relative humidity, and geographical coordinates, being an asset for traceability operations.

6.2 Suggestions for future work

From the work developed there are numerous possibilities for future work, particularly in the development of the traceability system.

-The use of other microcontrollers that enable an energy-saving mode to reduce system power consumption;

-The use of gas sensors, such as O_2, CO_2 or ethylene, which allow the analysis of the atmosphere in ppb, and predict the product respiration (in the case of horticultural products) that may be used to evaluate product quality. Additionally, air temperature and humidity sensors with greater precision could be included in the system;

-The creation of a product lifetime prediction software based on the values collected from the conservation conditions from the producer's conservation chamber until the retail, i.e., along the food chain, can relate the shelf life with the organoleptic losses, and thus be used to reduce food waste and increase profitability. Additionally, the development of a transport route optimization algorithm, using the geographic coordinate values collected by the traceability system can also contribute to that objectives;

-The implementation of Bluetooth modules that allows the creation of a network of sensors that communicate with each other through Bluetooth and whose data is transmitted to a central device that uploads the data, can be a technical solution that provides larger autonomy and reduced dimensions of the system.

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