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Food Packaging and Storage Guide

"INCREASING FOOD LITERACY COMPETENCIES OF ADULTS"

2020-1-TR01-KA204-092828

2022

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"INCREASING FOOD LITERACY COMPETENCIES OF ADULTS"

FOODTR

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Introduction

The EU Strategic Partnership project titled **"**Increasing Food Literacy Competencies of Adults **[FOODTR]"**, supported by the European Commission under the Erasmus+ Program, is coordinated by Central Research Institute of Food and Feed Control (CRIFFC) and is carried out with the project stakeholders from 4 countries. Turkish project stakeholders are General Directorate of Agriculture and Research Policies (TAGEM), Bursa Provincial Directorate of Agriculture and Forestry (Bursa Il Tarim), Bursa Metropolitan Municipality (TARIM A.Ş.) and Bursa Technical University (BTU). The National Technological Centre for the Food and Canning Industry (CTNC) from Spain, Food and Fermentation Technologies Center (TFTAK) from Estonia and Széchenyi István University (SZE) from Hungary are other project stakeholders.

Food industry is one of the biggest and the most complex business sectors in the world. With the world's population increasing daily, food producers must constantly make efforts to provide the best possible quality. The supply chain of the global food network is versatile. It includes the links between producers of raw materials, suppliers, final product producers, distribution and retail, with the aim of transforming raw materials into consumer-ready food products. All of these activities have to ensure the safety and quality of food products before finally reaching the last part of the supply chain, the customer.

To ensure the highest quality and safety of food products during storage, proper packaging solutions are one of the most important factors having a crucial impact. The right packaging materials that fulfill the needs of the product can delay possible quality degradation processes, extending the shelf-life of packaged goods. Next to that, the implementation of well-characterized packaging environments helps to slow the spoilage mechanisms.

In addition to the proper packaging solutions, right storage conditions help to achieve the expected shelf-life that has been determined in the product development phase. Various food products have different needs regarding storing and it is vital that these conditions are stable throughout the retail chain in order to maintain the quality and safety of food. Therefore, achieving the expected shelf-life to meet the highest demands of quality is a complex tackle which needs to involve different steps.

Food packaging and storage guide will give important information about packaging and storage of food materials to adults.

1. Shelf-life of food products

Shelf-life is the period of time during which a food maintains its acceptable or desirable characteristics under specified storage and handling conditions. These acceptable or desirable characteristics can be related to the safety or quality of the product and can be microbiological, chemical or physical. European Union regulation 1169/2011 requires that the shelf-life of food products are indicated by either a date of minimum durability ("best before") or a "use by" date (Regulation EU nr 1169/2011).

The date of minimum durability or best before date, is the date until which a food product maintains its specific, mainly quality based properties like organoleptic and nutritional properties which stand for the expectations of the consumers. Foods that are highly perishable, mostly prone to microbial spoilage and therefore have short shelf-lives are defined as "use by date". This is the date up until which a food may be used safely, consumed, cooked or processed, once it has been stored correctly. After this date the food is unsafe and cannot be sold (Figure 1) (Regulation EU nr 1169/2011; Singh et al., 2017).

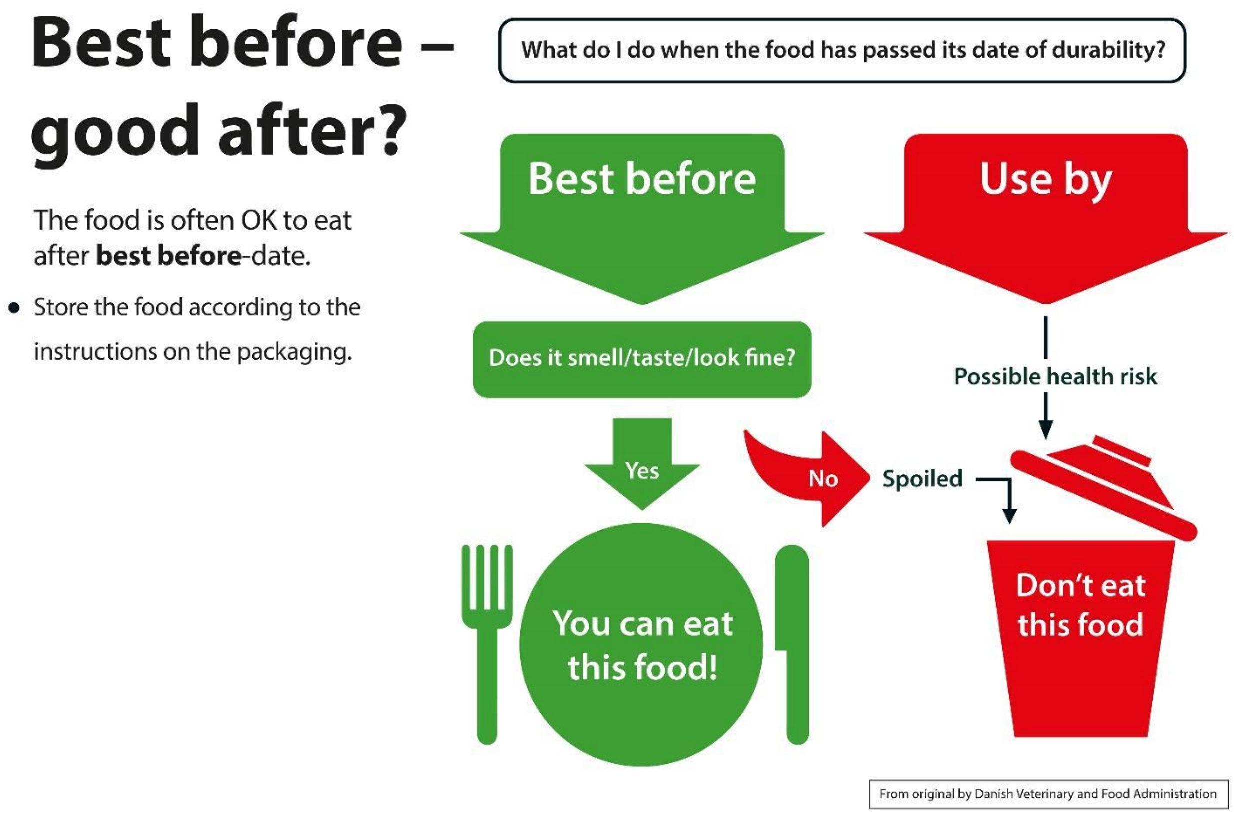


Figure 1. Illustration of "best before" and "use by" dates (Danish Veterinary and Food Administration)

To define the correct shelf-life of a specific food product which is safe to eat and has an acceptable quality, a food business operator needs to think about two aspects. Firstly, it is important to know if the product is safe to eat throughout its intended shelf-life and secondly, how long will the product last before it becomes unacceptable to the target consumer. To answer these questions, a food producer needs to have an overview about the product, its raw materials, manufacturing processes and possible deterioration and spoilage mechanisms (Man, 2016).

The shelf-life of a product is determined by conducting shelf-life studies which should include a legally required food safety management procedure based on the Hazard Analysis Critical Control Points (HACCP) principles. Shelf-life tests are storage trials where the durability and stability of products quality is experimented under defined conditions. Defined shelf-life is expressed as required by EU food law, either as a "use by" or "best before" date (Man, 2016).

A shelf-life study consists of multiple steps (Fıgure 2). Firstly, it is important to describe the product of interest. This expects a profound overview of the product properties as detailed as possible. Secondly, it is necessary to identify what may cause food spoilage or quality degradation. This can be done based on available literature. After having this information, the proper choice of packaging materials, environments and storage conditions is crucial. Thirdly, to correctly assess the duration of storage, the right analysis needs to be chosen. Usually, food producers assess the quality of products whether with sensory or microbiological analysis. Sensory analysis is conducted based on organoleptical sensations like appearance, texture, odor, taste, sound or touch. Microbiological tests analyse the amount of molds, yeasts and/or bacteria in the product. After choosing the right analysis to test the product, shelf-life study can be done which determines the product's shelf-life (FSAI, 2019; NZFSA, 2005).

Food products can have different shelf-lives based on their properties. Short shelf-life products are mainly prone to microbial spoilage and have a "use by" date (Singh et al., 2017). Microbiological processes are caused by the activity of specific groups of microorganisms like molds, yeasts and bacteria. These processes make foods unsafe to eat and therefore cause food waste (Lianou et al., 2016). Some examples of short shelf-life food products are dairy, meat, poultry, fish, cooked ready-to-eat meals, some fruits, vegetables and bakery products.

Foods that are mostly sensitive to chemical and physical processes like oxidation or moisture absorption have intermediate or long shelf-lives and are not typically prone to microbial spoilage. The main quality changes in these products are the loss of characteristic organoleptical attributes and the development of off-tastes and off-odors. Next to that, loss of nutritional value is usually the case because the degradation of vitamins and bioactive compounds may result in concentrations below the claimed content (Corradini, 2018). Food products that have intermediate or long shelf-life are for example potato chips, flours, breakfast cereals, grains, pasta, powdered milk, meat jerky, pasteurized and canned foods.

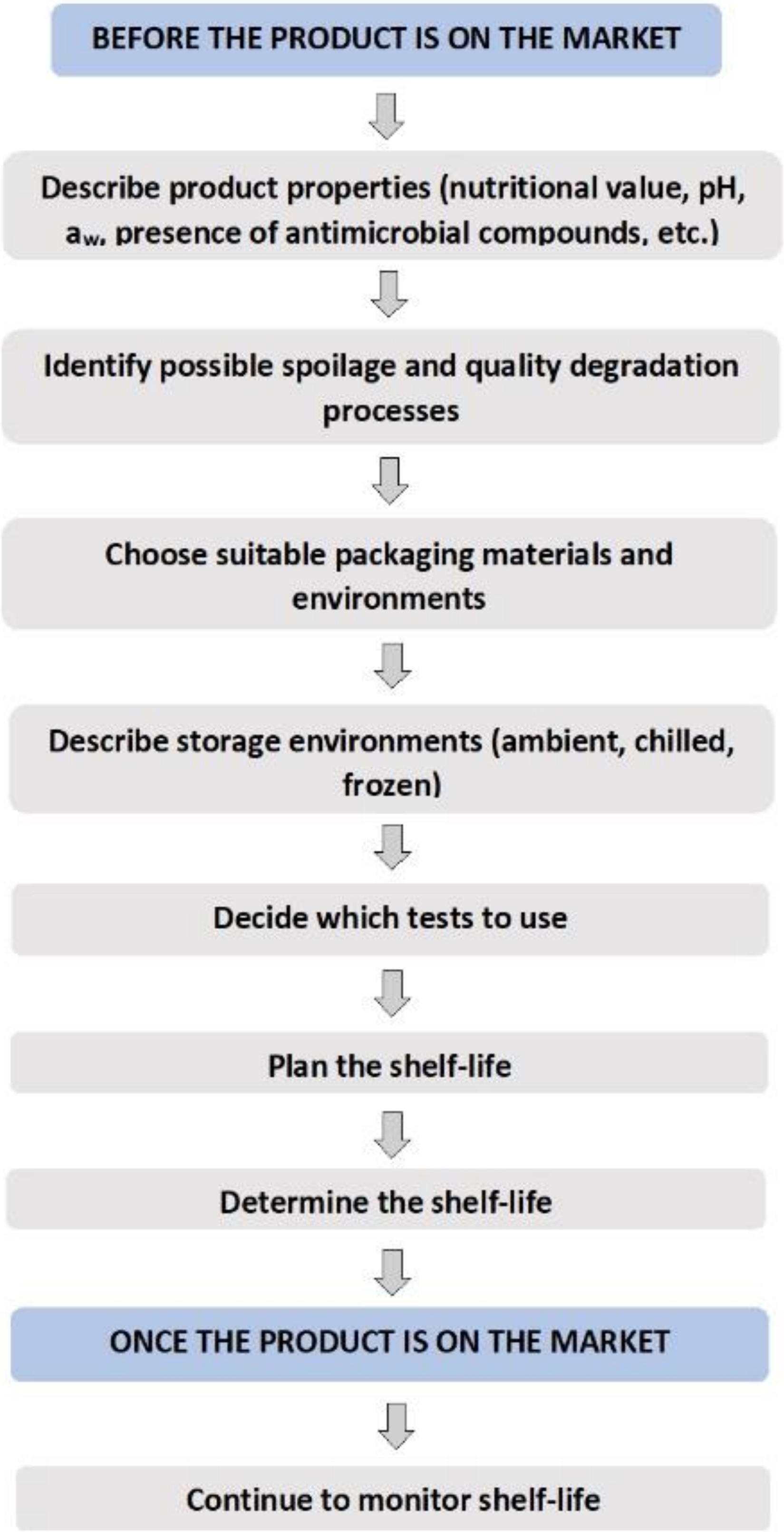
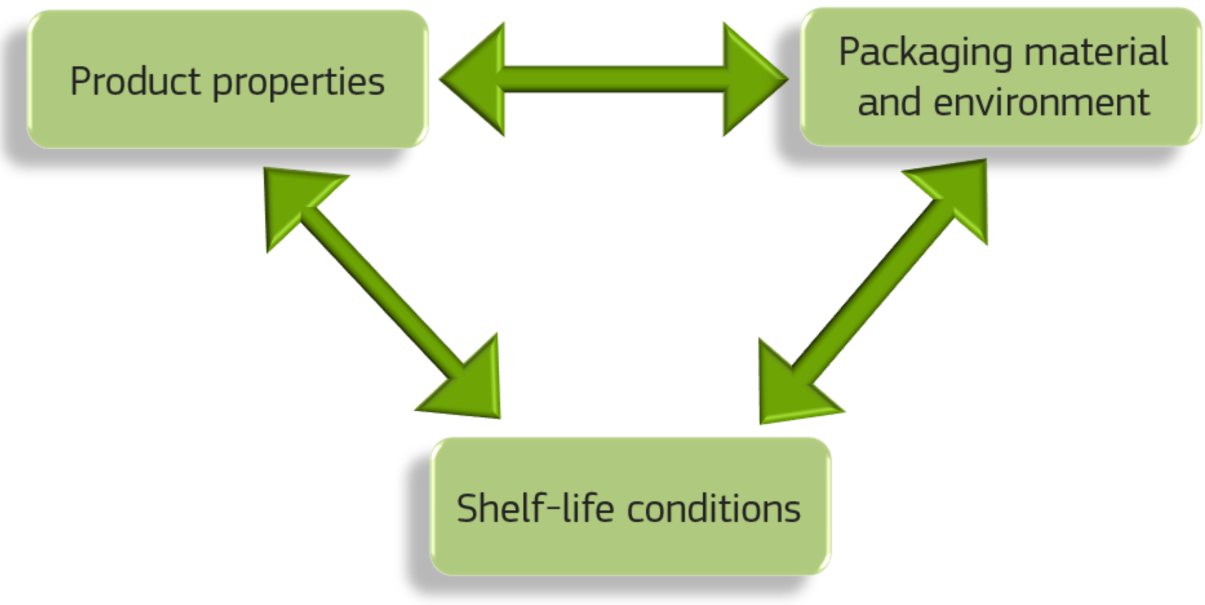


Figure 2. Steps for determining the shelf-life of food products (Modified from NZFSA, 2005)

In addition to product properties, factors affecting the shelf-life include also the choice of packaging materials, packaging environments and conditions of storage. For example, products that are sensitive to moisture absorption during storage, need packaging that protects the product from becoming moist. This requires the right choice of material composition, including water barrier giving materials. To enhance the shelf-life of fatty foods, packaging materials which have oxygen barriers are often used. Next to that, to maintain the safety and stabile quality of a food, packaging environments, like the use of different gases is applied. For example, to prolong the shelf-life of fresh meat, a mixture of oxygen, carbon dioxide and nitrogen is applied. But to enhance the shelf-life of fatty foods, oxygen is pushed out of the package by the use of nitrogen as a filler gas. Storage conditions are another factors that can influence the shelf-life of a food. For instance, fresh flesh produce like meat, poultry and fish is recommended to keep refrigerated when consumed within days, but shelf-stable foods like cereals and confectionary can be stored in ambient conditions. Frozen foods include different products, storing them in cold temperatures and therefore prolonging their shelf-life (Robertson, 2013; Singh et al., 2017; Lianou et al., 2016; Sancho-Madriz, 2003). More detailed aspects of packaging materials, environments and recommended storage conditions will be given in chapters 3, 4 and 5.



2. Quality degradation processes

Different processes affect the quality of food products during shelf-life. These include chemical, biochemical, physical and microbiological changes. These processes can happen individually, being the dominant change, or simultaneously, causing a multidimensional loss of quality in food products. However, in most cases, a particular type of process is likely to be dominant, being the limiting change of shelf-life. Microbial quality means that the amount of microorganisms does not exceed the allowed maximum level. Although, when microbiological processes happen, the number of microorganisms increases, ending the shelf-life of a product. Chemical and physical changes contribute to the overall quality decrease, developing of off-odors and off-flavour, causing loss of nutritional value and even the development of possible toxic compounds (Corradini, 2018; Man, 2016). The visualization of these processes happening during storage is given on Figure 3.

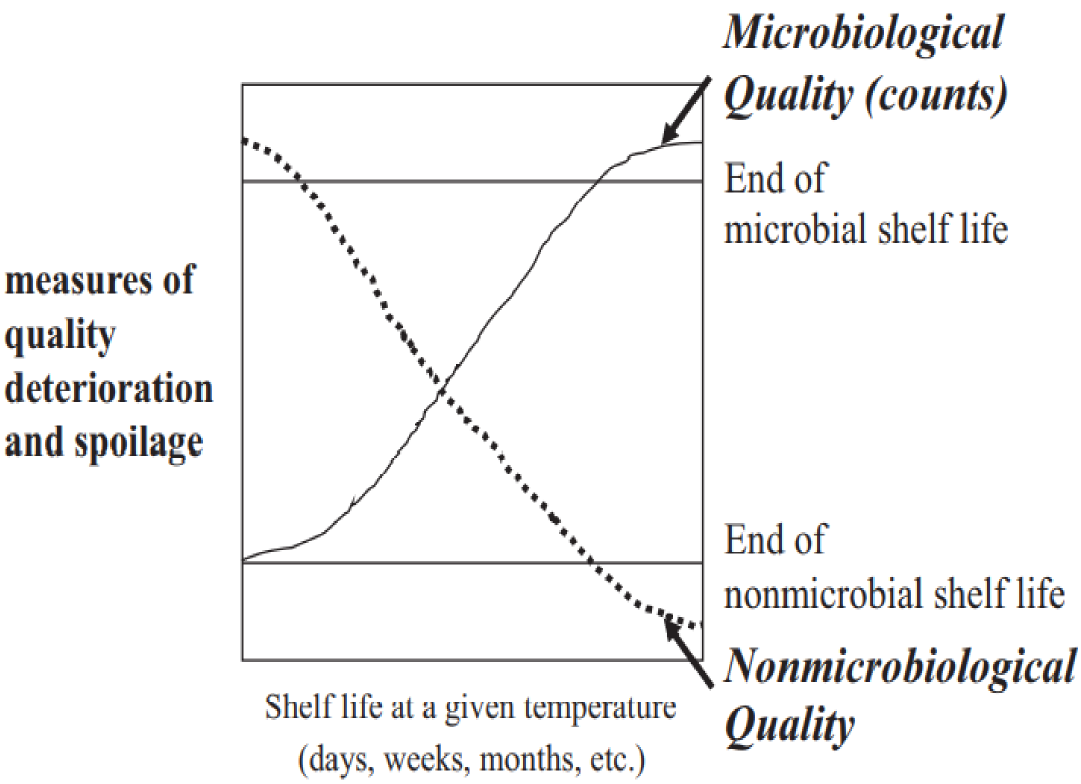


Figure 3. Changes in food during storage (Man 2016)

2.1 Microbiological processes

Microbiological processes are the cause of food spoilage which makes the product unacceptable and unsafe to eat. These processes take place with the biochemical activity of specific groups of microorganisms like molds, yeasts and bacteria which dominate in foods and beverages (Lianou et al., 2016).

The range of spoilage microorganisms is wide. For example, bacteria cause rapid spoilage processes for different foods such as meat, poultry, fish, shellfish, milk and some dairy products. Molds and yeasts are usually visible on the surface of foods such as bread and other dairy products, and their growth is slower than that of some bacteria. However, they can degradate different compounds and be tolerable to more extreme conditions than bacteria (Petruzzi et al., 2017).

The profile and growth of microorganisms in foods is dependent on different internal and external factors. Internal factors are the properties of the foods themselves. For example, these include pH, water activity values, nutrient content, the structure of the surface and the presence of antimicrobial compounds (Lianou et al., 2016). Each microorganism has specific requirements and conditions both of the food itself and of the environment that must be met in order to grow (Singh and Anderson, 2004).

Firstly, the structure of the food plays an important role. Foods like fruits, nuts, eggs, brans, etc. have shells or skins which avoid the microorganism penetrating to inner parts of the food. In this case, the microorganisms only spread on the surface. In fluid foods, microorganisms can spread through the food, causing more rapid spoilage (Petruzzi et al., 2017).

Moisture content and the type of water in the food influences the characteristics of a product (such as shape, color, texture, weight, etc.) and affects the growth of microorganisms. In food products, moisture can occur in two forms. Firstly, the water can be bound to ingredients present in the food such as proteins, salt and sugars. Secondly, water can be free of unbound that is available for microbial growth. A value describing the first option is water activity (a_w) which is defined as the equilibrium relative humidity for a product divided by 100. More simply, it states the amount of free water in the food that can be used by microorganisms (Singh and Anderson, 2004). Water activity is given on a scale from 0-1 (Figure 4).

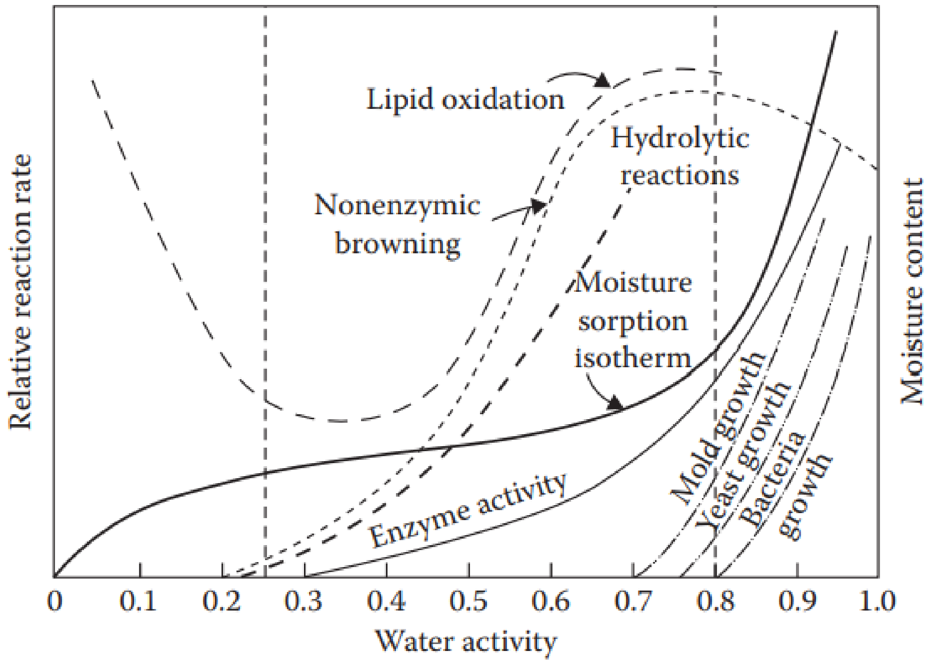


Figure 4. Water activity stability map (Robertson, 2013)

The relationship between total moisture and water activity is complex. Foods with higher moisture content might be expected to have higher water activity than dry foods but it may not always be like this. This depends on how much of the water in the product is bound to other compounds. In addition, products with the same water content may have different water activities. Most fresh foods have water activities above 0.95, hence they are susceptible to microbial growth. Virtually no microbe can grow at water activities less than 0.6, but almost all can grow at water activities above 0.9. Most bacteria cannot grow below an a_w of 0.91, though there are some bacteria growing in high-salt content foods that can grow down to an a_w of 0.75. Most yeasts in food products also cannot grow below an a_w of 0.88, however some yeasts that are viable in high-sugar foods can grow down to an a_w of 0.6. In addition, most molds don’t grow below an a_w of 0.8, even though some molds that have high durability in dry foods can grow at 0.65 (Singh and Anderson, 2004). The water activity values of some common food products are given in Table 1.

Table 1. Water activity values and moisture content of common food products (Schmidt and Fontana, 2020)

Food product	a_w value	Moisture content, %
Bread	0.96	37.0
Cookies	0.2-0.5	2.0-8.0
Crackers	0.1-0.4	1.0-5.0
Muffins	0.84-0.95	21.0-40.0
Granola bars	0.21	1.5
Tortillas	0.92	30.8
Breakfast cereals	0.10-0.40	1.0-7.0
Nuts	0.20-0.40	0.5-3.0
Potato chips	0.09-0.26	0.3-1.3
Pasta	0.30	5.4
Ranch dressing	0.97	75.0
Chocolate	0.60	1.2
Maple syrup	0.90	29.0
Honey	0.50	15.0-21.0
Butter	0.90	15.9
Cheese	0.96	40.0
Mayonnaise	0.93-0.96	14.0-29.0
Milk	0.98	89.2
Apples	0.98	84.6
Lemons	0.98	90.8
Juices	0.97	87.0
Potatoes	0.93	79.1

Tomatoes	0.98	94.9
Beef chops	0.96	66.5
Ground beef	0.99	71.2
Beef jerky	0.69	16.6
Chicken breast	0.97	74.6
Salmon fillet	0.95	68.3

Another factor affecting the growth and profile of microorganisms is the nutrient composition of the product. For example, protein foods like meat, fish and eggs are prone to organisms that degradate protein molecules. High-carbohydrate foods like bread, flour, pasta, syrups and jams are sensitive to fermentative organisms and fatty products are prone to microorganisms which degradate lipid molecules (Nychas and Panagou, 2011; Petruzzi et al., 2017).

The pH value of food largely limits what organisms are dominant in them. The pH scale is defined from values 1 – 14, where 7 is the neutral area, above this is the alkaline and below acid area (Figure 5). Most microorganisms are viable at a neutral pH near 7.0. However, there are bacteria that can tolerate pH values outside this range. For example, in very low pH products (<3.7) such as most citrus fruits, *Lactobacillus* (lactic acid bacteria) and *Acetobacter* (acetic acid bacteria) can grow. Yeasts grow best in the range of 4.5-7.0 and molds in 3.5-8.0 (Singh and Anderson, 2004; Petruzzi et al., 2017).

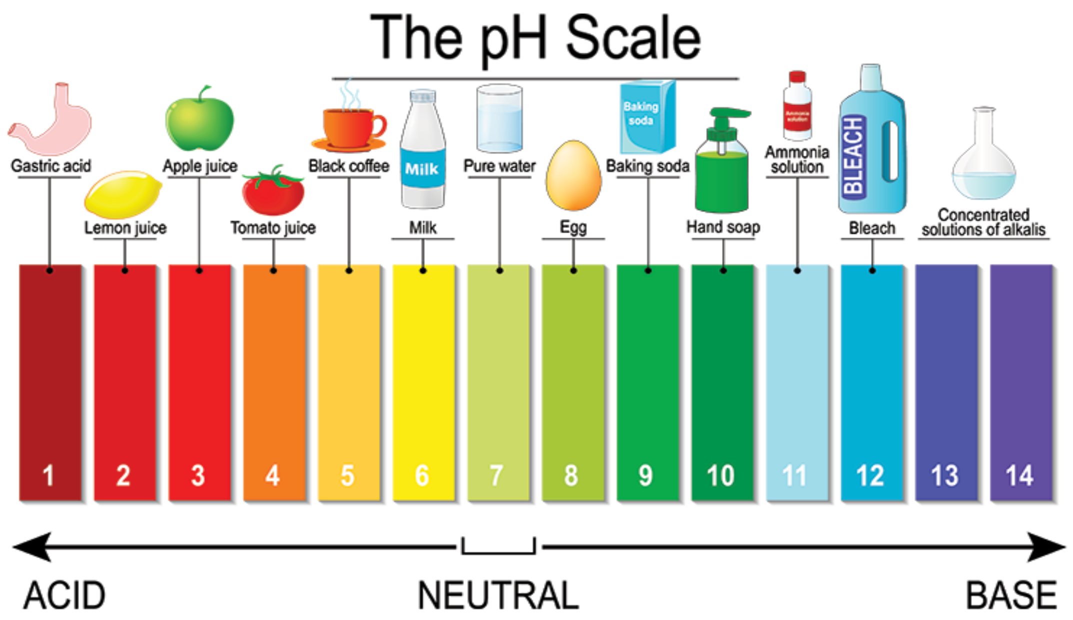


Figure 5. The pH scale of different products (Source: Science News for Students webpage)

Temperature during transportation, retail and storage is an external factor affecting the growth of microorganisms. There are three main classes of microorganisms depending on the temperature at which they grow best. Mesophilic organisms can grow between 10°C and 45°C, however the best conditions for them to grow is between 30°C and 40°C. Psychrotrophs are viable between 20°C and 30°C but they can also grow in colder temperatures below 10°C. Thermophiles are organisms that prefer warmer conditions and frow best between 45°C-65°C. In higher temperatures, the microorganisms are killed (Singh and Anderson, 2004). Examples of some common microorganisms in foods and beverages causing spoilage are given in Table 2.

Table 2. Examples of some common spoilage causing microorganisms in foods and beverages (Singh and Anderson, 2004)

Name	Type of microorganism	Examples of products
Candida spp.	Yeast	Meats, poultry, seafood dairy
Saccharomyces spp.		Fermented beverages like wine, beer and cider
Zygosaccharomyces spp.		Mayonnaise, pickles, ketchup
Aspergillus spp.	Mold	Grains, fruits, vegetables, nuts
Fusarium spp.		Vegetables, fruits, grains
Mucor spp.		Fruits, vegetables, cheese
Penicillium spp.		Meats, fruits, vegetables, grains
Rhizopus spp.		Breads, vegetables, fresh meats
Bacillus cereus	Bacteria	Fish, fresh meats, water
Campylobacter spp.		Meats, milk
Clostridium botulinum		Improperly canned foods
Escherichia coli		Vegetables, meats, poultry, milk
Listeria monocytogenes		Poultry, dairy, meats, vegetables
Salmonella spp.		Poultry, meats, dairy
Staphylococcus aureus		Meats, poultry
Vibrio parahaemolyticus		Fish, seafood

Yersinia enterocolitica		Fresh meats, milk, seafood
Lactic acid bacteria		Fruits and vegetables, beer, milk, vacuum packed meats
Acetobacter spp		Fruits, beer, wine
Bacillus subtilis		Vegetables, fresh meats, poultry, bread, milk
Enterobacter spp.		Fresh meats, poultry
Pseudomonas spp.		Vegetables, meats, poultry, eggs

When storing packaged foods, the gas composition is an important factor affecting the growth of microorganisms. Aerobic organisms are growing in the presence of oxygen, including bacteria like *Bacillus*, *Pseudomonas* and molds. Anaerobic organisms do not need oxygen to grow, therefore they can rapidly grow in tight-sealed cans and vacuum-packs. Examples of anaerobic organisms are *Clostridium* and *Bifidobacterium*. Facultative organisms can grow in both conditions, for example most yeasts (Petruzzi et al., 2017).

2.2 Physical processes

2.2.1 Mechanical injury

The mechanical damage of foods is an action which degrades the quality of products by changing their appearance. This includes bruising fresh fruits and vegetables and crushing or breaking dried snack foods like potato chips (Kong and Singh, 2016).

Physical injuries cause the most loss of fruits and vegetables which happens during harvesting, packing, handling and transport. When fruits start bruising, they lose water and change in color due to enzymatic and microbiological processes. Other physical damages include crackling and breaking. For example, dry and brittle products can break down to little pieces during transportation and distribution which makes their quality unacceptable. These products are for example potato chips, crackers, ready-to-eat cereals and some frozen foods (Kong and Singh, 2016).

2.2.2 Moisture changes

Moisture change is one of the most important physical processes happening with food during storage. Whether they be dry or moist, all foods can be affected by moisture loss or gain. Moisture changes in packaged or un-packaged foods can increase or decrease the water content of the product, influencing the properties of the food. For example, the texture of the food can be altered through softening, toughening, swelling or shrinkage (Roudaut and Debeaufort, 2010).

Dry products like breakfast cereals and potato chips lose their crispness after gaining moisture to above the 0.35 to 0.5 a_w range, while dried fruits and bakery goods become unacceptably hard on losing moisture to below 0.5 to 0.7 a_w (Kong and Singh, 2016).

In addition, fresh vegetables can start wilting with drying, biscuits may soften and lose crunchiness when gaining moisture, dressed salads like coleslaw could develop changes in the texture of vegetables or in the consistency of dressing with moisture migration from vegetables to the dressing and chilled layered desserts could start developing loss of visual layers with the migration of moisture (Man, 2016).

Therefore, it can be said that the control of initial moisture content and moisture migration during storage is critical to the quality of foods.

2.3. Chemical processes

Another processes causing quality degradation in food products are chemical processes. Some of the most important of these processes are lipid oxidation and the degradation of bioactive compounds like vitamins, minerals, dietary fibres and phytochemicals.

2.3.1 Lipid oxidation

Lipid oxidation is one of the major chemical processes in foods that affect the quality of products during shelf-life. Lipids are high-energy nutrients in food, providing the body with nine calories per gram (USDA), serving as a source of energy. In addition, they contain substances like essential fatty acids or lipid-soluble vitamins in food (Olsen, 2009). However, next to these important properties, lipids may also affect the quality degradation of foods through oxidation processes influenced by different factors (Kong and Singh, 2016).

One of the main components in lipids playing an important role is the fatty acid compound. Fatty acids are the building blocks of lipids and determine their physico-chemical and physiological properties (Shahidi and Zhong, 2009). Naturally occuring fatty acids are usually saturated or unsaturated. Saturated fatty acids contain only one carbon-carbon (C-C) bond and other available bonds are taken up by hydrogen atoms. For example, some saturated fatty acids found in foods are stearic acid, palmitic acid and lauric acid. Fatty acids containing one or more C-C double bonds are named unsaturated. These are for example oleic, linoleic and linolenic acids (Moghadasian and Shahidi, 2017).

While saturated fatty acids are more stabile, unsaturated fatty acids are suscpectible to oxidation due to the double bonds with what the oxygen in the environment reacts with. The initiators of lipid oxidation are light, temperature, enzymes in the food and metals (Shahidi and Zhong, 2009). During lipid oxidation, volatile oxidation products are produced which cause the development of off-tastes and off-odors in the product. For example, rancid products can be described as “grassy”, “fishy”, “papery”, “buttery”, “painty” etc. (Frankel, 2005). In addition to changing the organoleptical quality, oxidation also leads to loss of vitamins, alteration in color, degradation of proteins and in longer term, even the production of toxic substances (Kong and Singh, 2016). Lipid oxidation is primarily happening in foods with high content of unsaturated fatty acids, like nuts, fish, vegetable oils, potato chips, milk powder and some meats.

The oxidation processes can be controlled, delayed or avoided by different ways. For example, antioxidants are compounds that can be used to control the action of oxidation. For example, known antioxidants from food sources are given in table 3. As one major initator of lipid oxidation is the presence of oxygen, the right packaging solutions are important to protect oxidation-sensitive products from this process. These include active packaging solutions like modified atmosphere packaging (MAP), vacuum packaging, use of absorbers and suitable packaging materials with proper barriers.

Table 3. Antioxidants from food sources (Shahidi and Zhong, 2009)

Antioxidants	**Source**
Tocopherols	Seeds, grains, nuts, vegetable oils, etc.
Tocotrienols	Palm oil, rice bran oil
Ascorbic acid	Fruits, vegetables, etc.
Carotenoids	Carrots, tomato, fish/shellfish, marine algae, etc,
Phenolics	Fruits, vegetables, nuts, cereals, etc.
Peptides	Milk, egg, etc.
Enzymes	Plant and animal organisms

2.3.2 Degradation of bioactive compounds

Bioactive compounds in foods are substances that play important role in the prevention of several chronic diseases like cardiovascular diseases or cancer (Kris-Etherton et al., 2002). For example, these include polyphenols, carotenoids, vitamins, omega-3 fatty acids, organic acids and phytosterols (Kamiloglu et al., 2021). Phenolic compounds such as polyphenols, are present in all plants and many of them have antioxidant properties. However, their amounts in foods can vary depending on the type and quantity of plant foods in the diet. Apple and orange juices, legumes and red wine are particularly rich in polyphenols. Other examples of bioactive compounds found in foods are lycopene in tomatoes, soluble dietary fibres in oats, barley, fruits, vegetables, grains, etc., plant sterols in soybean and rise bran oil and resveratrol in grapes, red wine and peanuts (Kris-Etherton et al., 2002).

However, the stability of these compounds in foods is depending on many factors. For example, ascorbic acid is an important antioxidant used as an additive in foods, increasing the quality, technological properties and nutritional value of foods. However, its concentration decreases during storage depending on temperature, oxygen and light. As it is one important bioactive compound found in fruit juices for example, it affects the products quality significantly. In instance, the decrease of vitamin C content in quince nectar have been studied (Yilmaz and Karadeniz, 2013). It was shown that the total phenolic content and antioxidant activity of quince nectar decreased after storage at all temperatures but the rise in temperature decreased the content of ascorbic acid in the product even more. The degradation of ascorbic acid stored at different temperatures is shown on Figure 6.

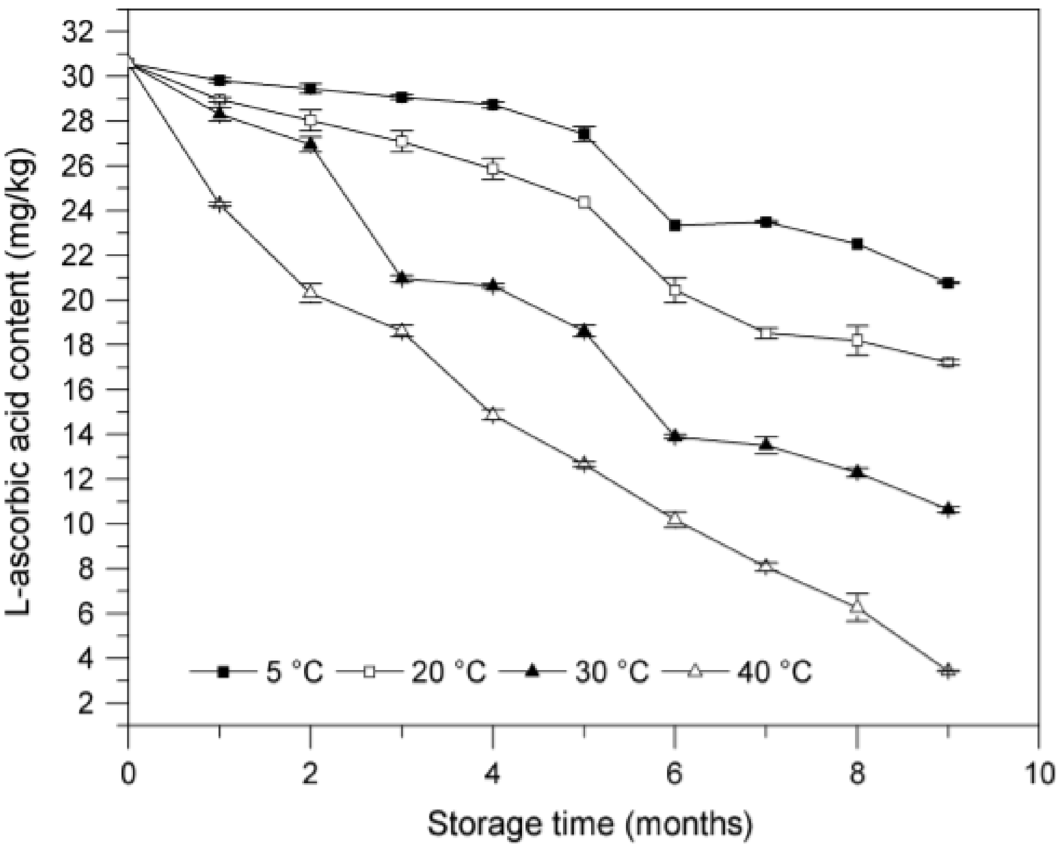


Figure 6. Ascorbic acid degradation of quince nectar stored at different temperature and time (Yilmaz and Karadeniz, 2013)

Next to that, the degradation of bioactive compounds in pomegranate during drying processes have been investigated. Pomegranates are high in phenolic acids, tannins, anthocyanins, vitamins and organic acids. Drying prolongs the shelf-life of pomegranate, however it is a complex process including heat and moisture transfer which could affect the quality of the product and reduce the amount of valuable bioactive compounds (Başlar, 2014).

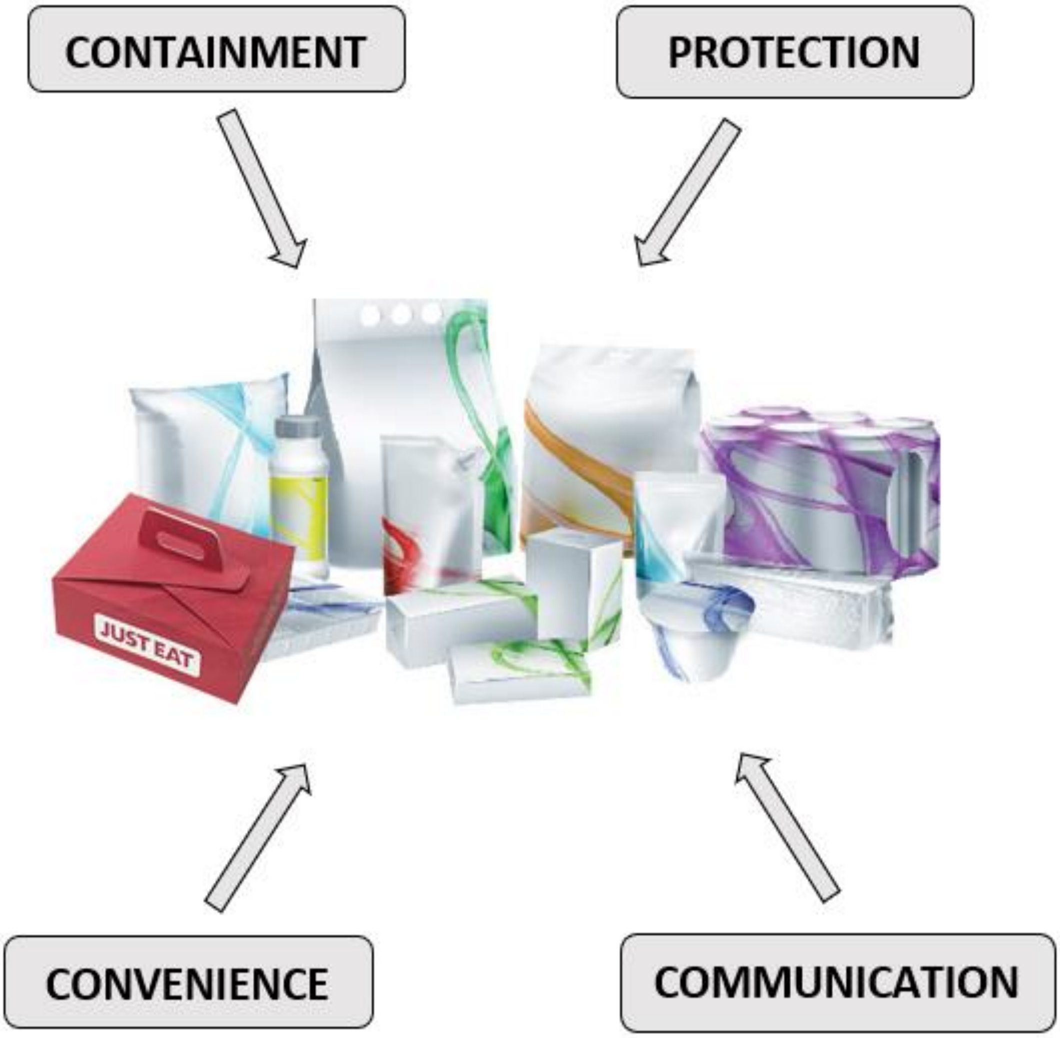
In the study, it was concluded that the bioactive compound degradation of pomegranate were significantly affected by drying temperature and time. The degradation rate of total phenolic content increased at higher temperatures between 55°C and 75°C, although lower temperatures and longer drying time also affected the content of bioactive compounds remarkably. Another conclusion was that the drying temperature levels did not significantly changed the color of the samples. This study suggested that high temperature but short time drying would be best solutions for preserving highest amounts of bioactive compounds in pomegranate (Başlar, 2014).

As a conclusion it can be said that the degradation of bioactive compounds in foods, such as phenols, vitamins, organic acids and others can take place during multiple stages, including pre-treatment, processing and storaging, depending on temperature, time, amount of oxygen and presence of light (Ali et al., 2018).

3. Packaging

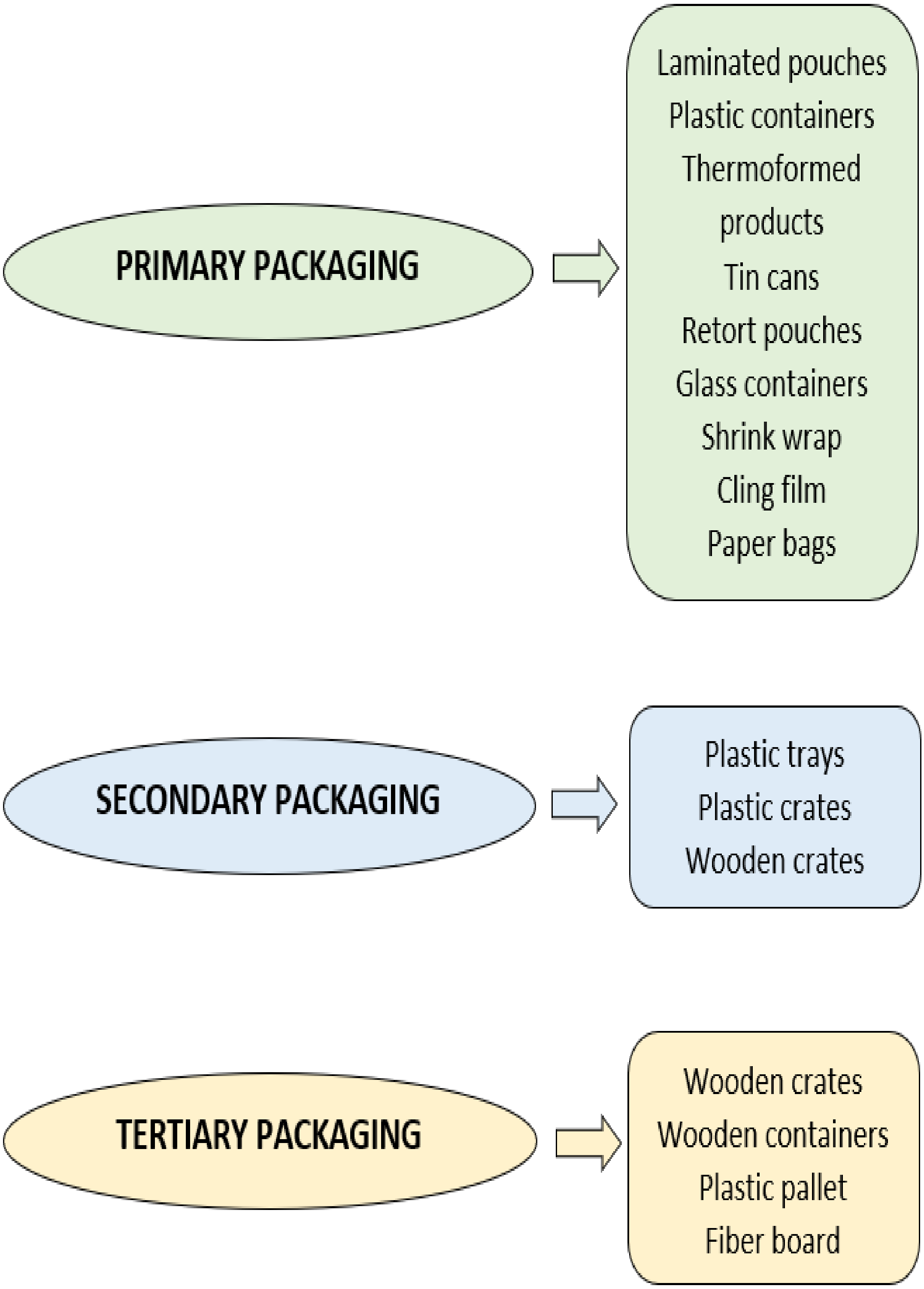
3.1 What is packaging?

Before defining packaging, it is important to emphasize the difference between „package", „packing" and „packaging". While package is the physical material that contains the product, packing is an act through which the product gets enclosed in the package or container. Packaging, on the other hand, is a process that provides protection to the foods customers buy from the moment they are processed, manufactured through storage and retailed to the final consumer. Furthermore, a packaging device or container is considered a package if it fulfills the functions of containment, protection, convenience, and communication (Robertson, 2016).



It is important to understand the necessity of these four functions that a proper package should have. Firstly, protection is the primary function of the package. This is necessary to protect its contents from environmental influences like water, water vapor, gas, odors, microorganisms, etc. Containment is considered as one of the most obvious functions a package should have, fulfilling the products needs to be contained before they can be moved from one place to another. In addition, the packages should be designed to be convenient. For example, a product that is not entirely consumed when the package is first opened, should be resealable and maintain the quality of the product until completely used. Furthermore, the packages should be designed to contain a portion size that is convenient to consume. Lastly, essential information should be on the package to be communicated to the consumers (Robertson, 2016).

Physically, different "levels" of packaging can be used in the package. First, primary package is in direct contact with the food product, and it is often the only package that the consumer buys from retail. This material provides the major protective barrier that the products need. A secondary package, for example a box, case, or other containers, contain a number of primary packages. This is the physical distribution carrier and is often designed to use in retail for the display of primary packages. Tertiary and quaternary package include a number of lower-level packages for transport and distribution (Robertson, 2016).


PRIMARY PACKAGING
Laminated pouches
Plastic containers
Thermoformed products
Tin cans
Retort pouches
Glass containers
Shrink wrap
Cling film
Paper bags
SECONDARY PACKAGING
Plastic trays
Plastic crates
Wooden crates
TERTIARY PACKAGING
Wooden crates
Wooden containers
Plastic pallet
Fiber board

3.2. Types of packaging materials

As it can be seen, there are multiple criterias a packaging material should fulfill when chosen in the product development process. One of the most important key properties of the packaging material is often the inclusion of barrier layers or coatings within a multilayer structure (package combining different materials, like polymers). Barriers are often used to manage oxygen, carbon dioxide or moisture ingress/egress and to protect the product from light, loss of flavorants, aromas, nutrients or oils (Morris, 2017). Another important factors when choosing a packaging material is their physical and mechanical strenght as the package can be ruptured during stacking, gas packaging, printing, forming, filling or transport. Regarding chemical safety, the migration potential of packaging materials is important. Migration is the transfer of substances from a packaging material into the food product, where factors like material, storage temperature and time play an influencing role (Singh et al., 2017). Next to chemical safety, packaging materials should also ensure hygiene and biological safety of food products. This means that barriers against contamination and microorganisms could be used (Barone et al., 2015).

With keeping mentioned key properties in mind, different types of packaging materials can be described. Generally, most widely used materials for packaging are plastics, glass, metal, paper and board. Common plastics used are polyolefins, which form an important class of thermoplastics. These include low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE) and polypropylene (PP). All of these materials have good sealability, but different barrier. LDPE is a tough, flexible, slightly translucent material that provides a good barrier to water vapor but a poor barrier to gases. The usage temperature range of LDPE is -50°C…+80°C and it is often used as bags, flexible lids or bottles. LLDPE has higher strength than LDPE and improved chemical and puncture resistance. This material is possible to use in the temperature range of -30°C…+100°C. Stretch wraps are usually LLDPE-based. HDPE is stiffer and harder than LDPE and provides superior oil and grease resistance. It is easy to process and form during production. HDPE has a temperature range of usage -40°C…+120°C. Commonly used HDPE materials include bottles, cardboard liners, tubs or bags. PP is a polymer with better barrier properties than polyethylene (LDPE, LLDPE, HDPE). It has the same range of usage temperature as HDPE, being also microwavable. Another known polymer-based plastic group is polyesters, in which the most widely used material is polyethylene terephthalate (PET). PET gives good oxygen and moisture barriers but less protection against light. This polyester is known as the stiffest and with the widest usage temperature in the range of -60°C…+200°C. PET, similarly to polyolefins, is also resistance to grease and oil. This material is usually used to produce bottles, jars, tubs or films (Singh et al., 2017; Robertson, 2017).

Glass materials, used in food packaging, are usually transparent, green or brown coloured. They all have absolute oxygen and moisture barriers when sealed correctly, but the coloured glasses are better to use since they give barrier against light (green glass has good and brown glass high barrier). Transparent glass has a low barrier against light. Glass materials itself doesn't have any sealability. The technical properties of glass bottles or jars include high temperature and pressure stability, chemical resistance and possibility to microwave (Han, 2005; Singh et al., 2017; Campbell-Platt, 2017).

Metal materials, including aluminum, tinplate or tin-free steel have absolute oxygen, moisture and light barriers but they are not sealable themselves. These materials need at least one additional layer of sealable material, like flexible plastics. On the other hand, metals have high temperature stability, being used for bottles, cans, tubs or caps (Han, 2005; Singh et al., 2017).

Paper and board are commonly used for boxes or liners. They have extremely low barriers against oxygen and moisture and no sealability, but high barrier against light. These materials are also known for mechanical stability (Han, 2005; Singh et al., 2017; Campbell-Platt, 2017).

Barrier giving layers or coatings are usually consisting of aluminum, polyvinyl chloride (PVC), ethylene vinyl acetate (EVA), ethylene vinyl alcohol (EVOH) or polyamides (PA). These materials possess high barriers against gases, moisture, fats and oils and odors and are usually used in the combination of materials (Robertson, 2017).

3.3. Recommendations of materials for different food products

As described previously, various food products have different needs regarding quality and safety. One way to ensure high quality food in the market, is packaging which meets the needs of shelf-life and enables the containment, communication and convenience along the supply chain.

Cereals are usually packaged in bags or boxes, made of plastic and/or paper/board. Cereal products, like breakfast cereals for example, are sensitive to moisture gain and therefore need a good moisture barrier to provide taste and freshness of the product. For this, HDPE polymers are typically used. When the package requires aroma or taste barrier, PA or EVOH polymers are often used (Morris, 2017).


Snack foods are often high in fat content and therefore require a package that provides an oxygen barrier. In addition, they also need moisture barrier to avoid moisture gain and light barriers. To avoid the package contacting with oil, grease resistance materials are also needed. Keeping in mind these requirements, fatty snack foods like potato chips for example can be packaged in barrier films containing foil, a metallized polymer film or a barrier polymer like EVOH or PVDC (Morris, 2017).

For bakery products, moisture barrier is normally the critical property. For this case, polymers like LDPE, LLDPE, HDPE or PP can be used. The bags are usually closed either with a strip of adhesive tape or a plastic clip to reduce moisture loss. For sealability and optical properties, EVA is often used. Applications which require aroma and taste barriers (like cake mixes for example) are packaged in films with PA layer. For bread bags, a combination of LLDPE and LDPE can be used, where the LLDPE allows to make the package thinner (downgauging) and the LDPE provides good optics and printability (Cauvain and Young, 2010; Morris, 2017).

Confectionery products include wide range of candies, biscuits, chocolates, gums, toffees, coatings, etc, with different barrier needs, including oxygen, moisture, and light. Chocolates can be packaged in aluminum and LDPE laminates as well as primary packaging along with paper or cardboard as secondary (Robertson, 2013). Next to that, one of the most common used material for chocolate packaging is polypropylene (Verde et al., 2020). Hard candies, gum and caramels are usually wrapped/packaged individually and bagged in an overwrap package, using PE or PP based solutions.

Meat, poultry and fish packaging requires a package that provides high oxygen, moisture, odor and grease barrier protection. There are different ways to package flesh foods like these. For example, shrink bag method involves placing the meat into heat shrinkable barrier bag, which typically consists of EVA, PVDC and/or PA. The bag is then heat shrunk by placing it in the water at 90°C. After shrinking, the bag holds closely to the meat and produces a tight vacuum pack. Another technique is the usage of thermoformed plastic bag, which is put into an enclosed chamber and evacuated. These bags usually consist of materials which include PET as the outside layer to provide strength, PA as the middle layer to provide good oxygen barrier and inner layers of LDPE or EVA copolymers which are good moisture barriers and can be easily heat sealed. Next to these, thermoforming method is used as deep trays are thermoformed in-line, meat is placed in the tray and the upper web of plastics is heat sealed under vacuum to form a lid. The materials used for thermoforming are laminates of PA, PET or PVC and heat-sealing layers are LDPE or EVA copolymer (Morris, 2017; Robertson, 2013).

Cheeses are categorised in the wide range of attributes and therefore have different needs regarding packaging. Cheeses can be defined with texture as very hard and hard, semisoft, and soft, fresh and processed cheeses. Very hard cheeses are ripened by bacteria and are characterized by a moisture content (on a fat-free basis) of <51%. These products are usually Parmesan, Romano, and Mozzarella. Hard cheeses are also ripened by bacteria and have moisture content of 49%-56%. Semihard cheeses possess a moisture content of 54%–63%. Cheeses in these classes include Cheddar, Edam, Gouda, Cheshire, Gloucester, Derby and Leicester, Emmental, Gruyere, Provolone, Mozzarella and Kasseri. Since some cheeses age over time during storage, they need applicable packaging materials for these processes. Rindless cheese may be defined as cheese that has been ripened under a plastic film that allows little or no evaporation into the atmosphere to occur. These materials are usually combination of PET, LDPE and PA (Robertson, 2013). When oxygen barrier is required to prevent mold growth, EVOH or PVDC is typically used (Morris, 2017).

For milk and milk products, different materials can be used. Milk powders are traditionally packaged in tinplate cans which, if correctly sealed, provide high oxygen, moisture, and light barriers. In recent years, aluminum foil-plastic laminates have replaced tinplate cans when packaging milk powders. A typical construction of this package includes an inner layer of LDPE (sealable), outer layer of PP or PET with aluminum foil in the middle. For powders that can have shorter shelf life, foil can be replaced by EVOH or PVDC. Liquid milk has traditionally been packaged in refillable glass bottles, but today single-serve paperboard cartons and plastic containers dominate the market. Regarding plastics, HDPE, PET, LDPE or LDPE/LLDPE are used (Robertson, 2013).

Frozen foods like fruits, vegetables, French fries, meat, poultry, and fish are packaged in a variety of packaging types. They must protect the product from moisture loss, light and oxygen. Traditionally, frozen foods were packaged in waxed cartonboard, often with a moisture-proof layer. These were replaced by folding cartons with PVDC coating. The majority of frozen foods nowadays are packaged in polymeric films based on blends of polyolefins, with the major component being LLDPE. To protect the product from light, it is also common for the film to contain a white pigment (Robertson, 2013).

Another food category is fresh-cut produce which key requirements for packaging include proper oxygen and carbon dioxide permeability and seal integrity. To extend the shelf life of the produce, films must provide oxygen permeability that is matched to the packed produce respiration rate. By controlling the permeation of gases through the package, the environment inside the package is controlled, respiration is slowed, and shelf-life is extended. The bags must have complete seal integrity in order to prevent the unplanned transfer of gases between the bags and the environment. Typically used bags may contain PP, LLDPE and EVA (Morris, 2017).

Continually, examples of some common packaging solutions for different food products are given in Table 4.

Table 4. Examples of packaging materials for food products (Morris, 2017; Robertson, 2013)

Food product	Examples of packaging material
Cereals	HDPE/EVA (bag-in-box)
	HDPE/EVOH/EVA (barrier bag-in-box)
	White lined chipboards
Salty/fatty snacks	OPP/met-OPP
	OPP/LDPE/met-OPP
	OPP-met/HDPE-EVA
	OPP/LDPE/OPP
	OPP/PVDC/OPP
Bakery wares	PP/EVA
	HDPE/EAA/PA/EAA
	LLDPE/PP/LLDPE
	PA/EVOH/PA/LLDPE
Confectionery	AL/LDPE
	BOPP
	PE
	PP
Meat	PA/LLDPE
	PA/EVOH/LLDPE
	LLDPE/LDPE/EVOH/PA/EVA
	OPET/EVOH/LLDPE
	EVA/PVDC/EVA
	OPET/PVDC/LLDPE
	OPA/LLDPE
Poultry and fish	LLDPE/PA/EVOH/PA/LLDPE
Cheese	Lower film PET/LDPE Upper film PET/LDPE or PET/PET/LDPE (sliced cheese with no gas production, e.g. Cheddar)
	OPA/LDPE

	(grated cheese, e.g. Emmental and cheeses without gas production)
	Cover film OPET/LDPE Trough film PET/HM/LDPE with migration barrier Tubular bag OPA/LDPE (sliced cheeses with high gas production)
Milk	LDPE
	LDPE/PA/LDPE
	Pigmented LDPE
	HDPE
	PET
	Paperboard carton
Milk powders	Tinplate can
	LDPE/AL/BOPP
	LDPE/AL/PET LDPE/EVOH/BOPP
	LDPE/EVOH/PET
Frozen foods	Waxed cartonboard with moisture barrier layer
	Folding cartons with PVDC
	Pigmented LLDPE
	White lined chipboard
Fresh-cut produce	PP and LDPE (in combination with EVA)

4. Packaging environments

One way to maintain or prolong the shelf-life of food products is the application of packaging environments. These include modified atmosphere packaging (MAP), vacuum packaging, active packaging solutions such as the use of absorbers and selection of suitable packaging materials with proper barriers (Robertson, 2013).

4.1. Vacuum storage

To prolong the shelf-life of products which main quality degradation processes are depending on the content of oxygen in the package, it is possible to apply vacuum packaging. The purpose of this is to remove oxygen by pulling the packaging material into close contact with the product (Embleni, 2013). In vacuum packaging, the residual oxygen in the package is less than 1%, depending on the texture of the packaged product. To ensure this type of oxygen levels in the package, it is important to apply hermetical sealing and avoid inadequate flushing (Degirmencioglu et al., 2011). Vacuum packaging works well for frozen poultry where the exclusion of air helps to reduce freezer burn and for fatty fish such as salmon. Other examples of vacuumed products are brick-shaped coffee and yeast packs, cheese, nuts, herbs and spices, meat (Embleni, 2013).



With removing air, the growth of mold and bacteria and the chemical processes induced by oxygen are inhibited. Therefore, the shelf-life of the products are extended. For example, in table 5, the storage times of some vacuum-packed products are given.

Table 5. Shelf-life of vacuum-packed versus non-vacuumed products (Source: Foodvacbags webpage)

Foods	Storage type	Shelf-life as un-vacuumed	Shelf-life as vacuum-packed
Beef, lamb, pork, poultry	Freezer	6 months	2-3 years
Fish	Freezer	3-6 months	2 years
Cheese	Refrigerator	1-2 weeks	4-8 months
Vegetables (green beans, corn, cauliflower, etc)	Freezer	8 months	2-3 years
Apples and pears	Refrigerator	2-4 years	1-3 years
Bread	Freezer	2-3 months	1-3 years
Cookies	Pantry/freezer	1 months/12-18 months	3 months/2 years
Nuts	Pantry	6 months	2 years
Ready-to-eat cereals	Pantry	1 year	1-2 years
Spices	Pantry	6 months	1 year

Another important advantage of vacuum storage is that the volume of the pack is minimal comparing to other packaging types. As the material is tightly contacted to the product, there is no empty space inside the package. However, when vacuuming hard texture products such as pasta, there is a risk of breaking the packaging material with force (Embleni, 2013).

4.2. Modified atmosphere

Modified atmosphere packaging (MAP) is a packaging mechanism which changes the gas composition surrounding the food product inside a package (Embleni, 2013). This method is also applied to maintain or prolong the shelf-life of certain products, influencing the chemical, microbiological and biochemical processes during storage. With modifying the atmosphere in the package, options to change the gas composition range from high concentrations of one gas to specific mixtures of gases. For example, nitrogen is used as filler gas to reduce the amount of other gases in the package. If oxygen has to be replaced, nitrogen (N_2) acts as an inert gas, reducing oxidative reactions in foods. In addition to this, carbon dioxide (CO_2) is another commonly used packaging gas, applied to prevent microbiological spoilage. Due to its high solubility in foods, it can form carbonic acid in reaction with fat and water, being an antimicrobic gas itself (Lucas, 2003; Fik et al., 2012; Fernandez et al., 2006). Oxygen is usually included at low levels, so it doesn't cause chemical and microbiological spoilage problems. However, it is important to use oxygen when packaging respiring products (like fruits and vegetables) for example. In this case, the presence of oxygen is more desirable than without oxygen which could cause fermentation and development of off-odors and off-tastes. Another way to use oxygen in MAP is applied for meat, where it maintains the red colour of the product (Embleni, 2013). The recommended gases and amounts to some food products are given in Figure 7.

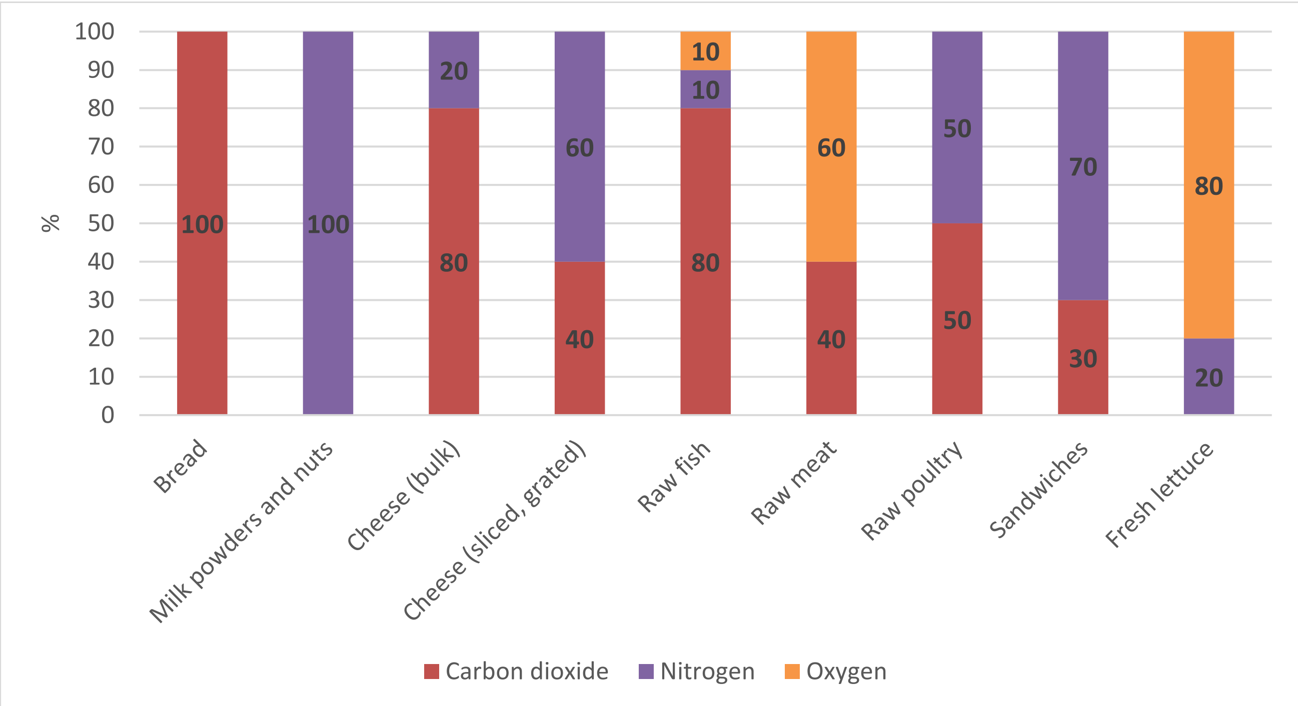


Figure 7. Examples of gases used for packaging various food products (Source: AGA recommendation brochure)

As seen on Figure.7, there are various gas compositions possible to use for MAP. Although, it must be emphasized that the gas composition for some of these products can be different based on the product itself. For example, for bulk cheese, AGA recommends using 80-100% of CO_2 and 0-20% of N_2. For raw fish, the gas composition may vary from 40-90% of CO_2, 10% of O_2 and 0-50% of N_2. Raw meat can be packaged in 60-80% of O_2 and 20-40% of CO_2. The gas composition for fresh lettuce can be 5% O_2, 5-20% CO_2 and 75-90% N_2 or the ratio of gases given on the figure.

As already stated, there are multiple positive arguments to use MAP in food packaging such as extending shelf-life, maintaining the appearance, odor, taste and texture of the product. However, there are some critical aspects of using MAP as well. Firstly, the right choice of gases and their composition for the type product is crucial. Another important key is the correct selection of barrier in the packaging to ensure the stability of chosen gas/gases. In addition to this, the tightness of the seal is vital to protect the atmosphere and maintain the preservation (Embleni, 2013).

5. Novel packaging technologies

Proper packaging is one of the most vital factors which keeps the food products safe and high-quality during storage. As already mentioned, food packaging needs to protect and contain the product, make it convenient to consume and have needed communication on the package. Traditional packaging includes the proper choice of packaging materials and environments. The composition of packaging materials must be applied based on food properties, keeping the quality of products with giving needed barriers, protecting the product from chemical or microbial contamination, dirt, insects, dust and having the mechanical properties to protect the product from physical injuries. Packaging environments on the other hand create the right surrounding for the food, keeping the products properties stabile during storage. In addition to these traditional packaging requirements, novel technologies are applied to enhance the shelf-life of food products even more, improving the security, safety, protection, convenience, and information delivery. These include the use of active and intelligent packaging. Next to that, the application of edible, biodegradable and/or biobased packaging materials are becoming more popular to reduce the economical burden of packaging production (Lee and Rahman, 2014; Han, 2014).

5.1. Active packaging

Active packaging is the type of packaging which changes the condition of the packed food to extend the shelf-life or to improve the safety or sensory properties, while maintaining the quality of packaged food (Ahvenainen, 2003). This includes the physical adding of sachets into the package or including applications as an integral part of the packaging material itself (Conte et al., 2013; Topuz and Uyar, 2020; Lee, 2016). Active packaging systems are scavenging systems in the form of absorbers and releasing systems in the form of emitters (Figure 8). The mechanism of absorbers is based on removing unwanted components from the package. This includes moisture, oxygen, ethylene, carbon dioxide or odor. Emitters on the other hand add compounds to the package, increasing the content of antimicrobial compounds, carbon dioxide, antioxidants, flavors, ethylene or ethanol (Yildirim et al., 2017; Lee et al., 2015).

In the context of active packaging, the packages interact with food and its surrounding environments which plays an important role in food preservation. It is said that the packaging may be defined as active when it performs some desired role in food preservation other than providing a barrier to outer conditions. Next to that, it can be defined as packaging that changes the condition of the packed food to extend the shelf-life or improve safety (Vinay Pramod Kumar et al., 2018).

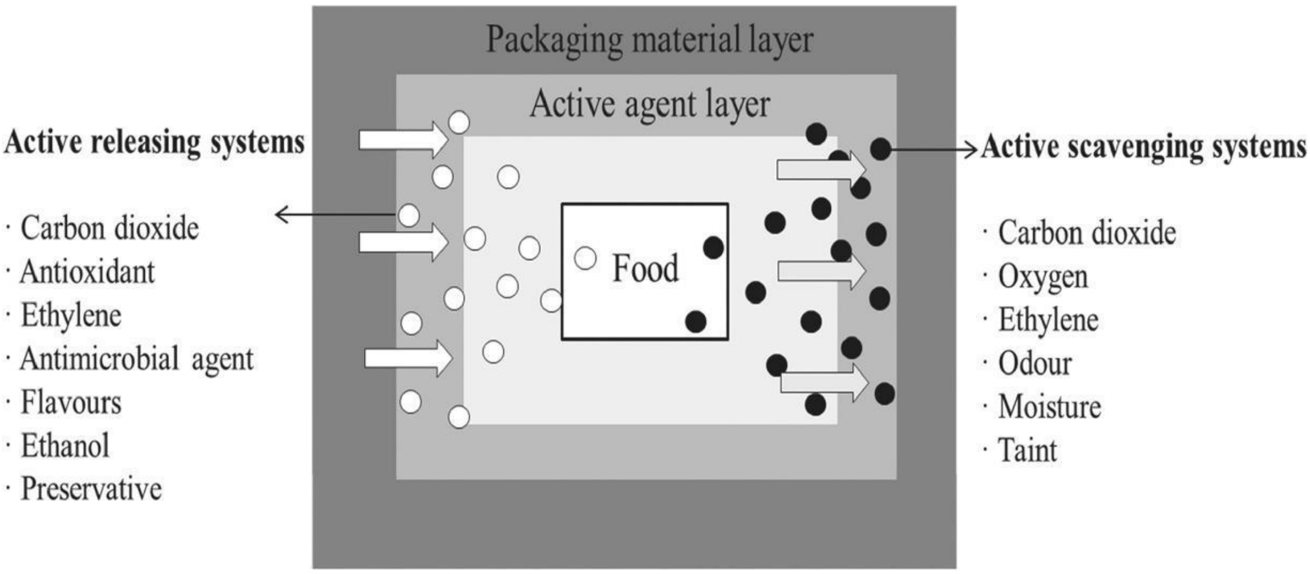


Figure 8. Active packaging solutions schematically (Lee et al., 2015)

One of the main solutions widely used is the application of oxygen absorbers. The aim of in this case is to remove residual oxygen present in the food package. Most of the oxygen-scavenging absorbers are iron-based where the function of the sachet is based on the oxidation of iron. Next to that, when wanting to create proper conditions for the inhibition of microbiological spoilage, the application of carbon dioxide emitters can be implemented. In this case, the release of carbon dioxide from an emitter system creates an antimicrobial effect in the package. The mechanism of this is based on a sachet that absorbs moisture from the product, triggering the release of CO_2 (Yildirim et al., 2017). Examples of active packaging solutions for food preservation are given in Table 6.

Table 6. Active packaging systems for food (Yildirim et al., 2017)

Type of active packaging	Food	Possible benefit
Oxygen absorber	Fried snacks, nuts, high fat content powders, dried meat	Prevention of rancidity
	Cooked meat products	Prevention of discolouration
	Grated cheese, bakery products	Prevention of mold growth
Moisture absorbers	Mushrooms, tomatoes, strawberries, corn, grains, seeds, fresh fish and meat	Absorbing excess moisture, decrease in moisture condensation, reduction of browning or discolouration
Ethylene absorbers	Fruits and vegetables	Reduction in ripening
Carbon dioxide emitters	Fresh fish and meat	Extension of microbiological shelf-life
Antioxidant releaser	Fresh high-fat fish and meat, powders, nuts, fried products	Prevention of rancidity
Antimicrobial packaging	Fresh meat, fish, dairy products, fruits, vegetables, grains, cereals, bakery, ready-to-eat meals	Inhibition of bacterial growth

Another type actively ensuring the quality of foods during storage is the incorporation of antimicrobial agents in the packaging systems. This can be achieved by adding antimicrobial agents in the packaging materials or using antimicrobial polymers. The aim of these materials is to control the growth of microorganisms in the food product during storage (Altaf et al., 2017). Based on which microbes are dominant in exact food products, specific type of antimicrobial agent can be used to be included in the packaging material. Some examples of antimicrobic compounds incorporated in packaging materials are given in Table 7.

Table 7. Systems of antimicrobial packaging (Altaf et al., 2017)

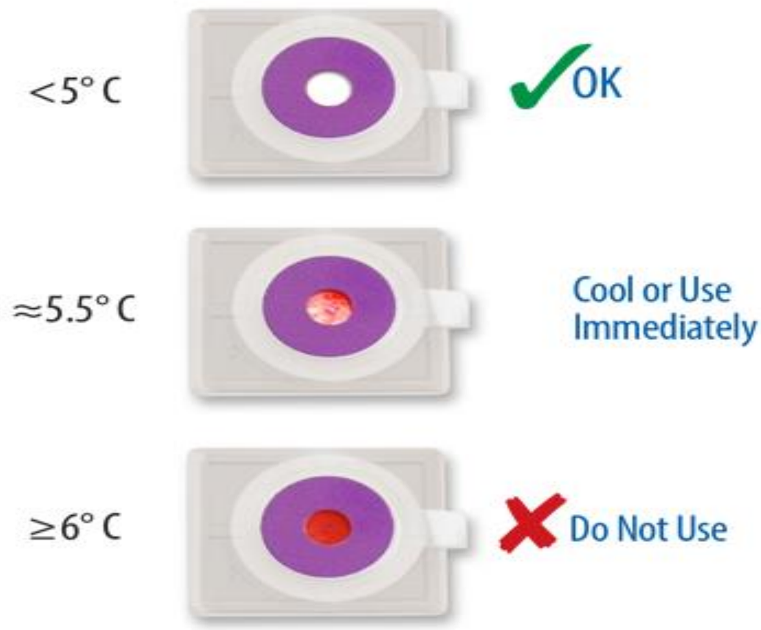
Antimicrobial compound	Packaging material	Microorganism
Benzoic acid	PE	Total bacteria
Parabens	LDPE	*S. cerevisiae, A. niger, Penicillium spp.*
Benzoic and sorbic acid	PE	*S. cerevisiae*
Acetic, propionic acid	Chitosan	*Penicillium spp.*
Eugenol, cinnamaldehyde	Chitosan	*Enterobacteriaceae, lactic acid bacteria*

5.2. Intelligent packaging

Intelligent packaging can be a part of active packaging but also as a separate unit itself with the ability to monitor the condition of the packaged food and environment in the package and giving this information to the users (Han, 2014). Therefore, intelligent packaging has been defined as labels or other systems that are incorporated into or printed onto a food packaging material which offers enhanced possibilities to monitor the products quality, trace the critical points and give more detailed information throughout the supply chain (Han et al., 2005).

The examples of intelligent packaging systems for food packaging include the use of indicators, barcodes and radiofrequency identification tags or sensors (Lee and Rahman, 2014).

Indicators give the information about the condition of the product and its environments, such as time and temperature, gas and freshness (microbial spoilage). It communicates the information through direct visual changes. For example, time-temperature indicators are used for monitoring the time and temperature history of chilled products throughout the food chain. As temperature is one of the most crucial factors affecting the quality and safety of foods, especially chilled or frozen products, it is important to observe its stability throughout the storage and supply chain. Time-temperature indicators should be simple devices which show easy visualization of the change in the system which rely on mechanical, chemical, electrochemical, enzymatic, or microbiological reactions. This results in the change of the color which has a visible response in the label (Lee and Rahman, 2014).



Gas indicators give the information about the integrity of the gas composition inside the package, helping to monitor the safety and quality of products. As the gas composition in the package headspace can easily change due to leakages, permeation, or respiration of fresh foods, it is important to observe its stability throughout the shelf-life. Gas indicators are devices placed onto package, changing its color by either a chemical or enzymatic reaction, usually giving information about the presence or absence of oxygen or carbon dioxide. For example, gas indicators that change their colors when detecting change in gas composition, turn from its original pink color to blue or purple when exposed to oxygen or carbon dioxide. When the level of gas reduces, the color changes back to original (figure 9) (Lee and Rahman, 2014).

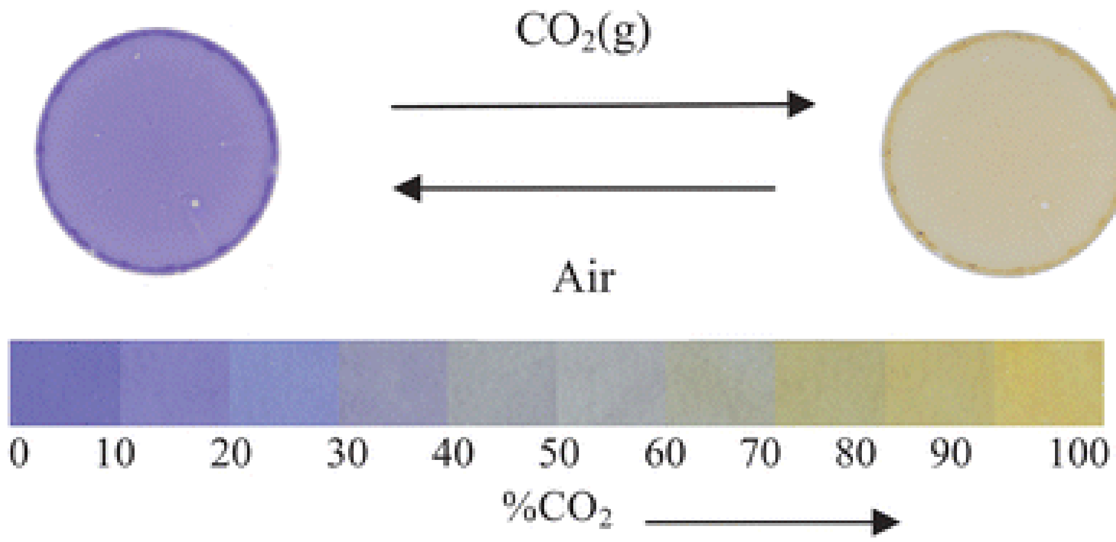


Figure 9. Carbon dioxide indicator with a color response chart (Mills and Skinner, 2010)

Freshness and spoilage indicators give information about the microbial growth in the package which degrade the quality of the product with producing metabolites such as glucose, organic acids like acetic or lactic acid, ethanol, volatile nitrogen compounds, carbon dioxide and sulfuric compounds. Monitoring these substances helps to evaluate the extent of microbial spoilage or ripening processes of fruits without with a non-invasive approach. For example, to observe the ripeness of fruits, colorimetrical labels are used to detect natural aroma compounds produced by the fruit (Lee and Rahman, 2014).

Barcodes are used for storing data on the package that can be read by an optical scanner. For example, this helps to track the location of the product throughout the supply chain. Most typically used barcodes consist of 12 digits with different sizes and numbers beneath them. This solution is widely used but also has the disadvantage of providing limited information (Lee and Rahman, 2014).

1 234567 890128 >

Radiofrequency identification (RFID) devices on the other hand are a type of intelligent packaging system that uses radiofrequency electromagnetic fields to transfer data from a microchipped tag with the aim of automating the identification and tracing the product (Figure 10). This approach allows to gather more information about the product in the label, giving more specified overview about the product (Lee and Rahman, 2014; Majid et al., 2018).

Figure 10. Visual drawing of radiofrequency identification system (Altaf et al., 2017)

In addition to previous intelligent packaging systems, sensors are also used to provide information about the product, monitor the changes during storage and track and locate the product throughout the chain. Sensors are considered as devices which give continuous signals. For example, biosensors give information about the physiological changes of the product or the presence of different biological or chemical materials in the packaging environment. In instance, microbes such as *Salmonella* and *E. coli* can be detected by a nanoporous silicon-based biosensor. Next to that, gas sensors give quantitative information about the gas composition of the package (Lee and Rahman, 2014; Majid et al., 2018).

5.3. Alternative novel packaging materials

Alternative packaging solutions such as bioplastics/biodegradable materials and edible films/coatings, may be considered as innovative application of food packaging since they are usually not included in conventional packaging systems.

While a large part of the food products is packaged in different kinds of plastic materials, it is necessary to offer an alternative with recyclable, reusable, or renewable scenarios. For example, bioplastics and/or biodegradable materials could be one way to go (Figure 9). Bioplastics are a type of packaging materials which consist of polymers produced from natural or renewable resources (Rudin and Choi, 2013). These include for example renewable biomass sources such as sugarcane, corn or other forms of cellulose or the use of microbes such as yeast (Ashter, 2016).

For example, one commonly used biobased and biodegradable polymer is polylactic acid which is primarily made from renewable resources such as corn by the fermentation of starch and condensation of lactic acid. In instance, it has been showed that when packaging meat in polylactic acid based packaging with needed modified atmosphere environment, no significant differences with conventional plastic and MAP were evaluated in the sensory attributes, meat color or total bacteria count over extended storage times (Hawthorne et al., 2020).

The aim of using bioplastic materials is to limit the use of fossil fuels and to enhance the protection of the environment. Bioplastics are always from natural or renewable resources, but their end-of-life scenarios could be different. For example, under the right conditions, they can be biodegradable or even compostable. While all compostable products are biodegradable, not all biodegradable products are compostable. The latter includes materials which are able to degrade to organic elements with time and give no toxic elements to the environment after degradation. Biodegradable materials could be referring to any materials which breaks down and degrades in the environment, breaking down to microplastics in any conditions including compost, landfill and soil (Oceanwatch Australia).

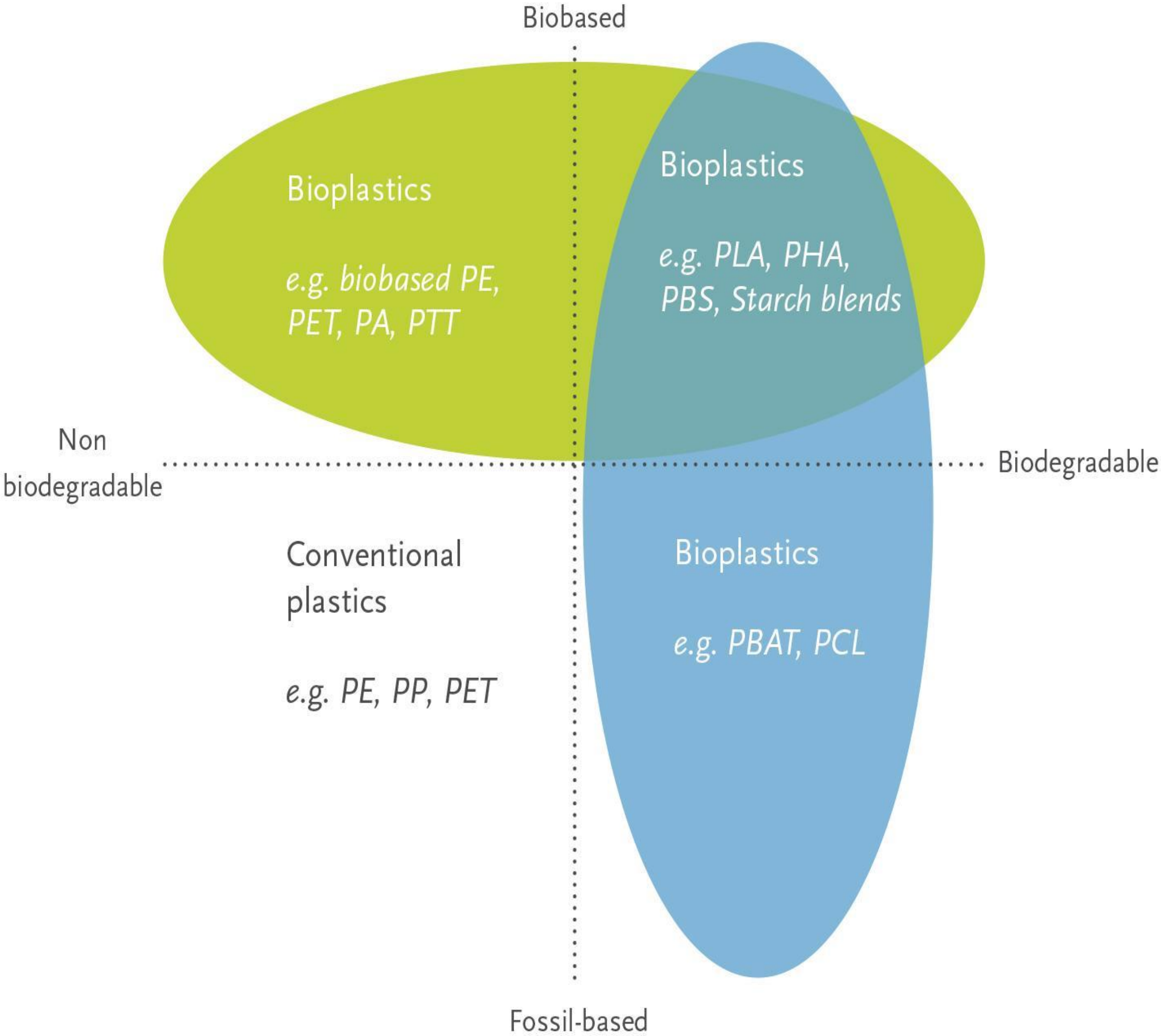


Figure 11. Map of biobased and conventional plastics (European Bioplastics webpage)

From Figure.9 it can be seen that conventionally known PE, PET and PA can also be produced from bio-based polymers, although being biobased, they can be both biodegradable and non-biodegradable.

Bioplastics such as polylactic acid (PLA), polyhydroxyalkanoate (PHA), polybutylene succinate (PBS) and starch blends are possible to biodegrade under right conditions.

Other novel food packaging materials are edible films and coatings which are materials produced from edible biopolymers such as proteins, carbohydrates and lipids. These materials can enhance the quality of foods with giving needed protection from oxidation, moisture absorption or desorption and microbial growth. Most common functions of edible films and coatings are to give barriers against oil, gas or moisture migration and to act as carriers of antioxidants, antimicrobial compounds, colors and flavors (Han, 2014). The primary steps of producing edible films and coatings are the same which includes the mixing, homogenizing the components and removing the dissolved gases from liquids. To produce edible films, the edible solutions are then casted on a tray, dried and detached. Coatings on the other hand are commonly used as dipping or spray solutions after which in both cases, drying is applied (figure 12) (Bizymis and Tzia, 2021).

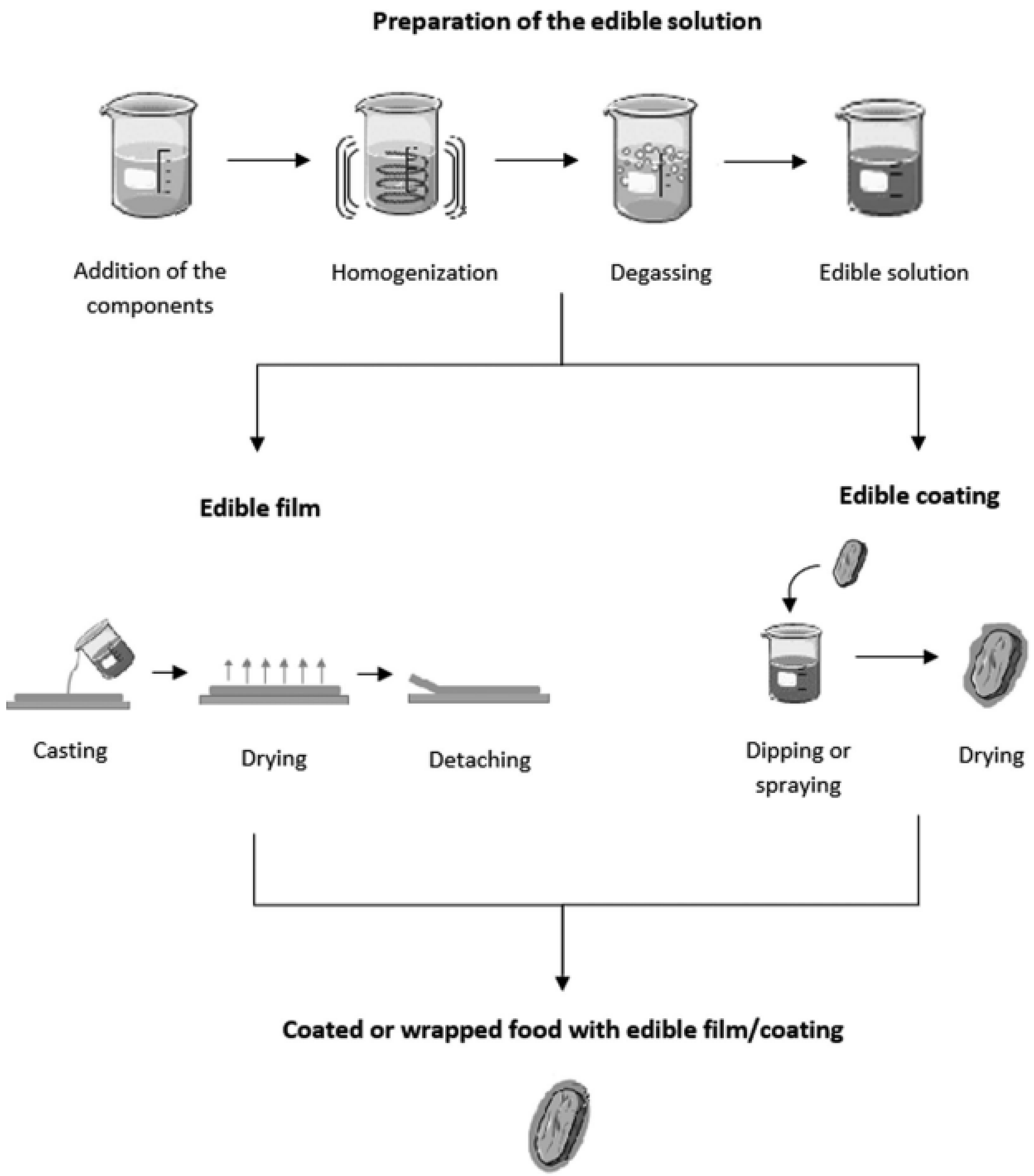


Figure 12. Production of edible films and coatings (Bizymis and Tzia, 2021)

Materials used as edible films or coatings can be diverse. For example, polysaccharides such as cellulose, chitosan, starch, pectin and alginate can be used, having different effects. Cellulose is a widely used material for this kind of purpose, being tasteless, odorless, transparent, and having high oxygen, carbon dioxide and lipid barrier properties. However, it has low resistance against water vapor transmission. Chitosan is a compound that is obtained from the outer skeletons of shellfish. It is transparent, hard but flexible and has good oxygen barrier and mechanical properties. Starch is also known to be transparent, odorless, tasteless, water soluble and has good oxygen and carbon dioxide barriers but it also has poor water vapor barrier properties. Proteins can also be used to produce edible films and coatings. These include for example collagen and gelatin which have good transparency, mechanical and barrier properties. Wheat gluten is also used, being transparent, mechanically strong, and insoluble in water. Whey protein can be used to create dense and strong films which have good oxygen and water vapor barrier properties. Finally, lipids such as waxes and paraffins give good gas and moisture barriers (Bizymis and Tzia, 2021).

6. Food storage guidelines

Proper food preservation is necessary to ensure the quality and safety of food products before consuming. As already introduced, there are multiple quality degradation mechanisms, which affect the shelf-life of different products. The deterioration of foods will result in loss of quality attributes, including flavor, texture, color, and other sensory properties. Next to that, deterioration processes affect the safety and nutritional quality of foods. Preservation methods should be chosen based on the properties of the products and they should be applied as early as possible in the food production pipeline. Another aim of proper food preservation is to reduce loss of food as it has been stated that 30% of available food goes to loss or waste (Gould, 2009; USDA Food loss and waste, 2021).

As different products need different storage conditions, the product categories are divided to shelf-stable foods being stored at ambient temperatures (+20°C, 75% relative humidity), frozen (-18°C or lower with relative humidity usually near 100%) and refrigerated (0°C…+5°C with a maximum of +8°C, relative humidity being ~90%) (Man, 2016).

6.1. Shelf stable foods and fresh produce

Foods that are stored safely at room temperature are called "shelf stable" (USDA Shelf-stable food safety). These products are usually dry ingredients, foods with low moisture, high in sugar or commercially or properly home-canned (Andress and Harrison, 2011). For example, such products are rice, pasta, flour, sugar, spices, oils, jerky, canned or bottled foods (USDA Shelf-stable food safety). The pantry or cupboard on which the products are storage should be clean, free of pests, dry, cool and dark (Andress and Harrison, 2011). Some examples of shelf-stable foods are given in Table 8.

Table 8. Shelf-stable foods (Andress and Harrison, 2011)

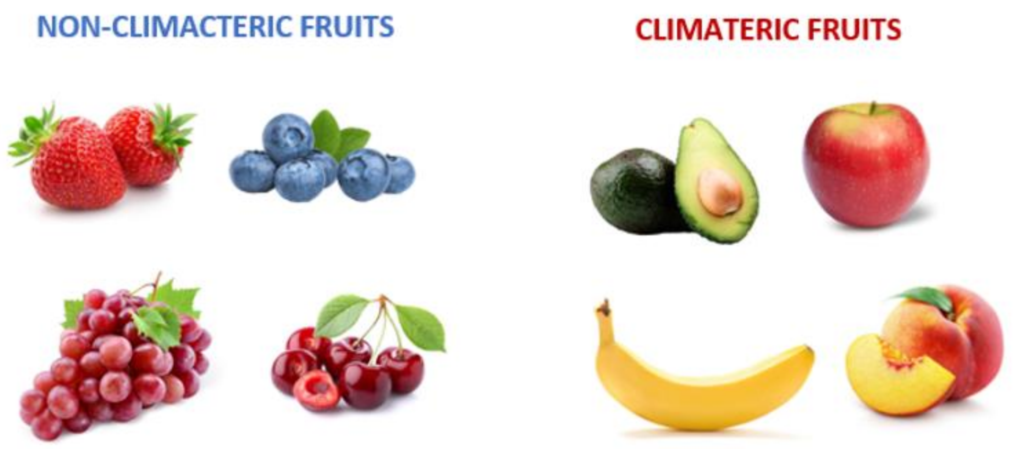
Food	Shelf-life in room temperature conditions	Food	Shelf-life in room temperature conditions
Bread	5-7 days	Canned fish and meat	12 months
Cookies	2-3 weeks	Dried fruits	6 months
Dry mixes for biscuits, muffins, brownies	12-18 months	Canned fruit	12 months
Chocolate	18-24 months	Honey	12 months
Crackers	8 months	Jellies, jams	12 months

Ready-to-eat cereals	12 months	Nuts	6 months
Ready-to-cook cereals	12 months	Sugar	24 months
Dry egg noodles	2 years	Syrups	12 months
White flour	12 months	Raisins	6 months
Pancake mixes	15 months	Breadcrumbs	6 months
Rice	2 years	Herbs	1-2 years
Tortillas	2-4 days	Oil	6 months
Parmesan cheese	10 months	Potato chips	6 months
Milk powder	12 months	Spices	2-3 years

Breads and tortillas should be stored in the original package at room temperature and used within a week. Dry products like cereals, rice, crackers, dried fruits, herbs and spices need to be stored in tightly closed containers to keep out moisture (Boyer and McKinney, 2013).

High-fat shelf-stable products like chocolate, nuts, potato chips, oil, milk powder, parmesan cheese, pancake and muffin mixes need to be stored in dark conditions or be packaged in opaque packaging materials. In addition, the protection against oxygen needs to be ensured by right choice of packaging material (Robertson, 2013). Canned foods are treated with high temperatures, therefore are non-perishable (USDA Shelf-stable food safety). High-sugar products like honey, jellies and syrups are other shelf-stable foods due to low water activity.

Fresh vegetables and fruits have different storage needs due to different properties. Some vegetables and fruits, like apples, bananas, peaches, tomatoes, etc., are climacteric foods, meaning they can ripen after harvest and produce ethylene in the ripening process. Some fresh produces are non-climacteric, which don’t ripen after harvesting, therefore not producing ethylene but are sensitive to ethylene. These foods are broccoli, cabbage, cauliflower, etc.



To delay the ripening processes with the production of ethylene, vegetables and fruits should be stored in ventilated rooms with relatively high humidity. Next to this, most fresh produce can be stored in room temperature, however, to extend their shelf-life, refrigerating is recommended. For example, removing air from the package, storing the vegetables at refrigerated temperatures, and maintaining high humidity extends the shelf-life of fresh vegetables. Next to this, fresh leafy vegetables like cabbage should be wrapped in moisture-proof bags to prevent wilting. When storing vegetables with tops like carrots, radishes, and beets, removing the tops will reduce loss of moisture. Tomatoes are vegetables which continue to ripen after harvesting and should be stored at room temperature. Fruits are generally also stored in humid and cool places to avoid loss of moisture and delay ripening (Boyer and McKinney, 2013).

Apples stored at room temperature will soften quickly within a few days, therefore it is recommended to keep them refrigerated. Pears and apricots on the other hand should be ripened at room temperature and then be stored as chilled. Citrus fruits like lemons and limes have longer shelf-life due to high acidity and high content of antioxidants. They can be stored in the refrigerator even for 2 weeks (Boyer and McKinney, 2013). The average shelf-life of some fruits and vegetables in ambient and chilled temperatures are given in Table 9.

Table 9. The shelf-life of fruits and vegetables (Andress and Harrison, 2011)

Food	Shelf-life at +2°C…+4°C	Shelf-life at +10°C…+21°C
Apples	3 weeks	1-2 days
Citrus fruits	1-2 weeks	10 days
Grapes	1 week	1 day
Melons	3-4 days	1-2 days
Beets	1-10 days	1 day
Eggplant	3-4 days	1 day
Garlic	1-2 weeks	1 month
Greens, spinach	1-2 days	No information
Mushrooms	2-3 days	No information
Onions	1-2 weeks	No information
Potatoes	1-2 weeks	1-2 months

6.2. Frozen and refrigerated foods

Chilled storage is a commonly used method for food preservation. Refrigeration temperatures are in range of 0°C…+7°C which slows the ripening processes of fresh fruits and vegetables and inhibits the growth of microorganisms in the products that are prone to microbial spoilage. Refrigerating preserves perishable foods for days or weeks, depending on the food. Chilling has a low impact of products sensory and nutritive attributes, although the conditions need to be ensured throughout the whole distribution chain: transportation, retail, and home storage (Sancho-Madriz, 2003).

Different types of products can be stored in refrigerator. For example, dairy products like milk, yoghurt, sour cream, and cheese need to be stored chilled. The shelf-life of fluid milk stored in the refrigerator can range from 8 to 20 days depending on the date of manufacture, heat-treatment, and storage conditions in retail. Cheeses can be stored in refrigerator for 1 month, fresh cream for 1 week, sour cream for 2-3 weeks and yoghurt for 1-2 weeks. Bread has a shelf-life of 2-3 weeks in the refrigerator. While fresh cuts of meat can be stored in the refrigerator up to 5 days, minced meat has shorter shelf-life, 1-2 days, due to manufacturing process and increased surface area of the product. Cured meats like bacon tend to become rancid when exposed to air, having shelf-life of 1 week. Hams can also be stored in a refrigerator for 1 week. Fresh poultry has a shelf-life of 1-2 days in chilled conditions and fresh fish can be stored in chilled conditions for 1-2 days (Andress and Harrison, 2011; Boyer and McKinney, 2013).

When storing foods in the refrigerator, raw foods like meats should be separate from foods that are cooked and foods that can be safely eaten without cooking to avoid contamination. Foods in the refrigerator need to be covered with air-tight wraps or put into air-tight containers (Andress and Harrison, 2011).

Freezing is another method used for prolonging the shelf-life of foods. Frozen conditions are temperatures of -18°C and lower which preserves foods for months or years if properly packaged. Freezing lowers the water activity in the product and stops microbial growth, however it does not kill bacteria or molds. It also has a low effect on nutritive quality of food, although impacting sensory attributes, especially texture. Different types of foods can be stored in frozen conditions to prolong their shelf-lives. For example, the shelf-life of bread in the freezer can be up to 3 months. Meat, poultry, and fish are other food groups possible to store as frozen. The shelf-life of fatty fishes like mackerel and salmon in the freezer is 2-3 months but leaner fishes like cod or flounder have a shelf-life of 4-8 months when stored under -18°C. Fresh chops of pork, lamb or veal can be stored in the freezer for 4-6 months and ground meats 3-4 months. The shelf-life of ham and bacon in the freezer is 1-2 months. The shelf-life of leaner poultry, like chicken, is 12 months (Andress and Harrison, 2011; Boyer and McKinney, 2013).

Conclusions

The quality and safety of food products during storage can be ensured by different practical actions which contribute to providing stability and enhancing the shelf-life.

Shelf-life can be defined whether as “best before” or “use by” which are dependent on the properties and storage needs of the product. To have proper understanding of what is the shelf-life of the product and how it is affected, multiple steps should be done before launching the product to the market. These include having an overview about the product characteristics, possible spoilage processes, selection of packaging solutions and execution of proper shelf-life test.

As various food products have different properties and needs regarding shelf-life, versatile processes can take place, involving microbiological, chemical or physical changes. As microbiological spoilage turns the food unsafe to eat, chemical and physical changes contribute to overall quality decrease.

After describing the factors playing important role during storage, the implementation of properly chosen packaging solutions is crucial. The packaging must first and foremost provide containment, protection, convenience, and communication to the food product. Different solutions can be used for this aim. For example, conventional packaging solutions include plastic, glass, metal, paper, and cardboard. In addition, barrier giving materials should be considered when the product has specific needs to maintain its quality and safety. To enhance the shelf-life of foods even more, vacuum and modified atmosphere packaging can be applied to achieve these goals.

Next to traditional packaging, novel technologies are becoming more common with wider fields of use. For example, using active or intelligent packaging to extend the shelf-life, improve the products properties or enhance its monitoring is becoming more easily approachable. Different types of mentioned technologies include using absorbers or emitters to prolong the products quality during storage or implementing indicators and sensors that give information about the condition of the product. Alternative packaging solutions such as bioplastics which can be biodegradable or even compostable are becoming more popular with the growing demand to find recyclable or reusable packaging solutions from renewable sources. Edible films and coatings are other possible uses to consider when wanting to enhance the quality of foods with giving needed barrier protection.

The final step after having a profound overview of the food product’s needs, characteristics, possible packaging solutions and ways to enhance the shelf-life, proper storage conditions must be applied. These are important to ensure the highest quality and safety of the product which have been thoroughly defined. Preservation methods need to be chosen based on the properties of the food. These include the possibilities of storing products whether in ambient temperatures, chilled or frozen conditions.

As conclusion, high-quality and safe food storage expects profound knowledge about the product properties, possible quality degradation and spoilage processes, choice of packaging solutions and storage conditions. This sums up to be a special mixture of different factors which impact the food that ends up on our table.

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