SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

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CONTENTS

CHAPTER 03

SmartFresh^{PRO} - Advanced Preservation of Fresh Produce at Home

ABSTRACT

ABSTRACT | English

Food is a very important part of our lives and the way we consume defines our lifestyle. The food we eat has a direct impact on our health, so following a healthy and balanced diet is crucial for us. Healthy diets suggest a high consumption of fruit and vegetables because due to their high content of micro and macronutrients, they provide greater benefits for our body.

Current trends push society towards a healthier and more responsible consumption. However, the increasing growth of the world population poses many problems about the future of food. It is estimated that by 2050 the world population will require 70% of extra food, and 3/5 of this request could be guaranteed by reducing food waste.

According to recent data from FAO*, 1/3 of all food we produce worldwide is wasted. Food waste is generated throughout each stage of the Food Supply Chain (FSC), and these data vary based on different factors. In developing countries, waste is mainly concentrated during the production stages, due to inefficiencies in the production processes caused by economic problems. On the other hand, in developed countries, most of these wastes are produced during consumption, which accounts for about 20% of fruit and vegetable wastes only during this stage.

We as consumers waste huge amounts of fruit and vegetables every year. There are many causes that influence these losses, but at the domestic level, the one with the greatest impact is that these foods are often not stored properly. According to studies, fresh foods such as fruit and vegetables are normally stored using the ‘cold chain’ throughout different stages of the FSC. This system produces the appropriate storage conditions for fresh food, through the control of temperature, humidity, air composition, and bacterial activity, among others. However, at our homes these storage conditions are poorly respected, which leads to reduce the shelf-life of these products, increasing the total amount of food waste. The home refrigerator needs to be improved, and the purpose of this project is to solve this huge challenge.

** Food and Agriculture Organization of the United Nations*

ABSTRACT | Italiano

Il cibo forma una parte molto importante della nostra vita e il modo in cui consumiamo definisce il nostro stile di vita. Il cibo che mangiamo ha un impatto diretto sulla salute, quindi seguire una dieta sana ed equilibrata è fondamentale per noi. Le diete sane suggeriscono un elevato consumo di frutta e verdura perché, grazie al loro alto contenuto di micro e macronutrienti, offrono maggiori benefici al nostro corpo.

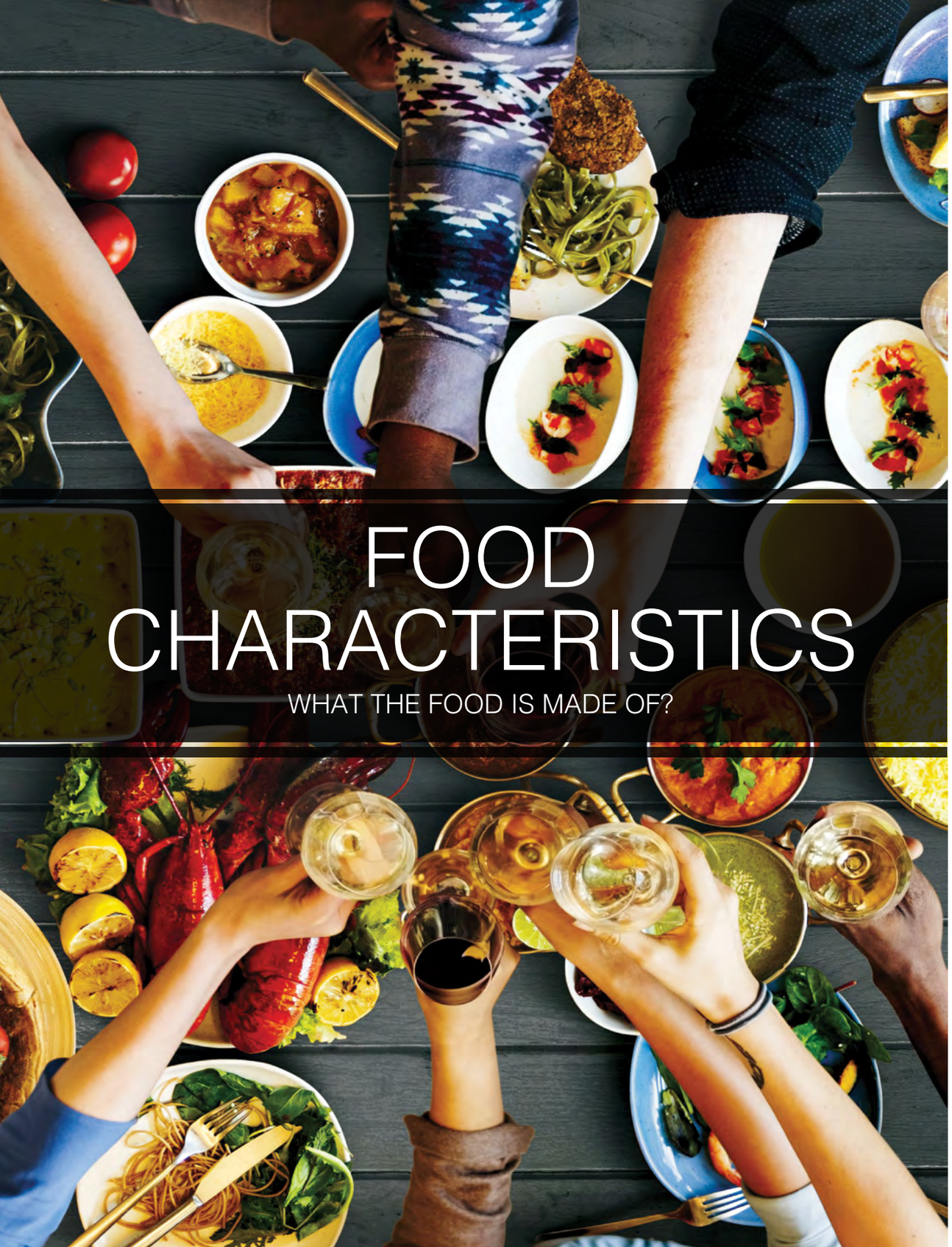
Le tendenze attuali spingono la società verso un consumo più sano e responsabile. Tuttavia, la crescente crescita della popolazione mondiale pone molti problemi sul futuro del cibo. Si stima che entro il 2050 la popolazione mondiale richiederà il 70% di cibo extra e che 3/5 di questa richiesta potrebbero essere garantiti riducendo gli sprechi alimentari.

Secondo i recenti dati della FAO*, 1/3 del cibo che produciamo in tutto il mondo viene sprecato. I rifiuti alimentari vengono generati in diversi fasi della catena alimentare (FSC) e questi dati variano in base a diversi fattori. Nei paesi in via di sviluppo, i rifiuti sono concentrati principalmente durante le fasi di produzione, a causa delle inefficienze nei processi produttivi causate da problemi economici. D’altra parte, nei paesi sviluppati, la maggior parte di questi rifiuti viene prodotta durante il consumo, che rappresenta circa il 20% dei rifiuti di frutta e verdura solo durante questa fase.

Come consumatori noi sprechiamo enormi quantità di frutta e verdura ogni anno. Esistono molte cause che influenzano queste perdite, ma a livello domestico, quella con il maggiore impatto è che questi alimenti spesso non vengono conservati correttamente. Secondo gli studi, gli alimenti freschi come frutta e verdura di solito sono conservati facendo uso della “catena del freddo” durante le diverse fasi dell’FSC. Questo sistema produce le condizioni di conservazione appropriate per alimenti freschi, attraverso il controllo di temperatura, umidità, composizione dell’aria e attività batterica, tra gli altri. Tuttavia, nelle nostre case queste condizioni di conservazione sono scarsamente rispettate, il che porta a ridurre la ‘shelf-life’ di questi prodotti, aumentando la quantità totale di rifiuti alimentari. Il frigorifero domestico deve essere migliorato e lo scopo di questo progetto è quello di risolvere questa grande sfida.

CHAPTER 01

Food and Society



FOOD CHARACTERISTICS

WHAT THE FOOD IS MADE OF?

1.1 FOOD CHARACTERISTICS

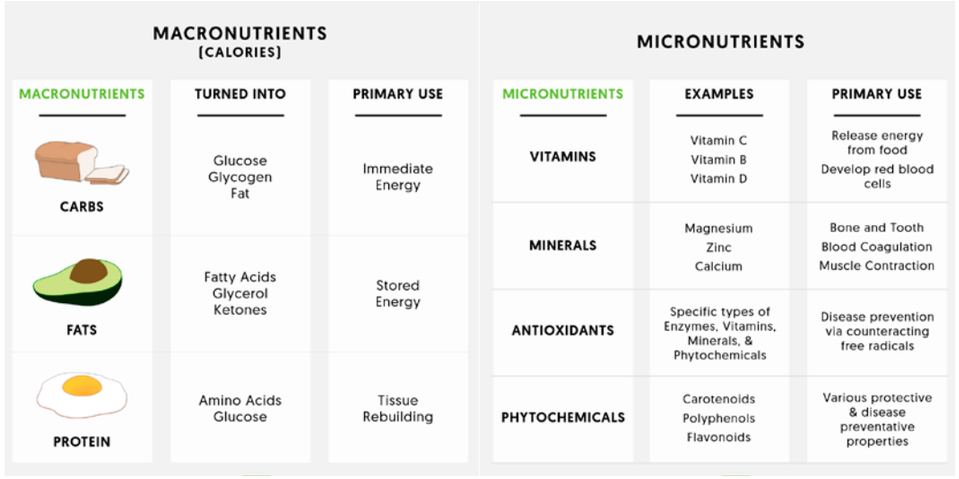
1.1.1 What Is The Food Made Of?

The world is full of different cuisines and thousand of different meals. Yet when we reduce them to their essence, there are just a handful of nutrients that our bodies process to enable it to function. These nutrients can generally be broken into two categories: *macro* and *micronutrients* (see Fig.1).

Macronutrients are composed by proteins, carbohydrates and fats and their main role is to make up a majority of our diet (the amount of calories we consume) and provide energy for us to move and to function. *Micronutrients*, on the other hand, don't give us calories or energy like macronutrients do. Instead, they are composed by vitamins, minerals and antioxidants that we ingest in small amounts to help our body to grow efficiently and healthy.

Our body, as any other mechanism, requires energy to move or work correctly. The most common way to obtain required energy is by consuming food that later will be broken down in smaller components by our digestive system, until they can be absorbed and assimilated into the body. The food that are consumed must guarantee hygienic safety but also an adequate nutritional intake and a good organoleptic quality. Additionally, the nutritional content of the food determines the composition of our body, like cells, blood, organs, skin and hair. The food we consume is used as the source to replace different cells of our body everyday. In fact, scientists have demonstrated that the diet can even affect the composition of our genes, as our organisms construct their DNA using building blocks they get from food[1].

1 *Researchers (Dr. Steven Kelly and Emily Seward) at University of Oxford Demonstrate that Diets of Organisms Can Affect Their DNA. (http://www.sci-news.com/biology/diets-organisms-affect-dna-04374.html)*



MACRONUTRIENTS (CALORIES)

MACRONUTRIENTS	TURNED INTO	PRIMARY USE
CARBS	Glucose Glycogen Fat	Immediate Energy
FATS	Fatty Acids Glycerol Ketones	Stored Energy
PROTEIN	Amino Acids Glucose	Tissue Rebuilding

MICRONUTRIENTS

MICRONUTRIENTS	EXAMPLES	PRIMARY USE
VITAMINS	Vitamin C Vitamin B Vitamin D	Release energy from food Develop red blood cells
MINERALS	Magnesium Zinc Calcium	Bone and Tooth Blood Coagulation Muscle Contraction
ANTIOXIDANTS	Specific types of Enzymes, Vitamins, Minerals, & Phytochemicals	Disease prevention via counteracting free radicals
PHYTOCHEMICALS	Carotenoids Polyphenols Flavonoids	Various protective & disease preventative properties

Fig.1 Food Macronutrients and Micronutrients, their composition and function in our body. Info by My Nutrition Advisor.

What, when, how, and why people eat and drink is linked not only with biological needs and the availability of various food, but also with the customs, aspirations, and expectations of their societies. Food and diet are directly linked to the culture, being one of the most reliable symbols of national identity. Our diet comes to incorporate all aspects of who we are: our religious taboos, class structure, geography, economy, even government. The emphasis given to different food we consume today, as well as their quality and quantity, have varied throughout history and within cultures. Nevertheless, the major influence on the daily diet has been the availability of food.

The way we perceive food is complex, and it also have impacts on what we consume. Human evolution, food and taste are intimately linked, and as it was said before, the food we eat determine the composition of our body, as it relies on the nutrients we get from the food. What the humans have been consuming throughout the history, has allowed the evolution to what we are now. Since the discovery of fire, cooking changed the taste of what we eat and it has produced a whole revolution in flavor. As a result, it has evolved a lot since those times, and people have developed a taste for much richer food than they had in the past. Pulitzer Prize-winning author said, "we owe our existence and our humanity to taste—and, in many ways our future depends on it, too" (John McQuaid, 2015)[2].

The way the humans consume is not only linked to the society or food availability, but it also depends of our personal food preferences and eating behaviors, guided mainly by our taste. Our body experiences the flavor of the food through the senses such as taste, smell, sight and touch[3]. Then, all the data is taken

2 *John McQuaid, journalist and author of Tasty: The Art and Science of What We Eat.*

3 *Organoleptic properties of food are the aspects of food that we experience through the senses.*

and analyzed in the part of the brain that implies these senses. The sum of these signals, plus our emotions and past experiences, result in perception of flavors, and determine whether we like or dislike specific food. What we perceive through our senses can be summarized as a sensory reaction to different stimuli coming from food:

Appearance - is commonly observed by our sight and is the response to visual stimuli and include texture, color, surface reflectance, size and shape.

Touch - are the properties of the food which can be felt by receptors in the skin and mucous membranes.

Smell - is the ability to identify by millions receptors in our nose, different aromatic compounds and in different concentrations.

Taste - is the sensory experience of the taste buds that is primarily identified in our mouths, and comprised of 5 different types: sweet, sour, bitter, salty and umami. A food is usually a blend of tastes, each in different concentrations.

Sound - is the acoustic effect produced when the food is subjected to a variety of mechanical forces.

In one interview, Linda Bartoshuk of the University of Florida explained, "when we chew, swallow, and exhale, volatile molecules from the food are forced up behind our palate and into our nasal cavity from the back," like smoke going up a chimney. In the nasal cavity they bind with odor receptors—and it's those receptors, of which humans have somewhere between 350 and 400 types, that are the main source of what we perceive as flavor. That's different from taste, which is the sensation derived from our taste buds, and it's also different from ordinary smelling, because the brain distinguishes between odors we sniff through our nostrils (orthonasal olfaction) and odors that reach our nasal cavity from behind as we eat (retronasal olfaction)—even though the same receptors detect both. "The brain pays attention to whether you're sniffing or chewing and swallowing," Bartoshuk continued, "and it doesn't treat those signals the same. Odor information from retronasal olfaction goes to a different part of the brain—the one that also receives information from the tongue. The brain combines retronasal olfaction and taste, creating what we call flavor."

As we experience the flavor through our senses, the result we perceive may be altered by external stimuli. There are many studies that explain how our perception of food can be altered by different factors. Some of them prove that the appearance of the food can make people "see" flavors before they actually taste anything, a phenomenon that can influence their flavor experiences[4]. Other studies demonstrate that the smell can override a person's taste buds. In this popular experiment, two groups of volunteers were asked to have a sip of plain water after smelling different food. One group smelled sweet things like caramel and strawberries, while the other smelled non-sweet food like bread, meat, or fish. For the sweet-smelling group, the plain water tasted sweet. But the water wasn't sweet at all for the other group. In different circumstances, other senses and parts of the brain can overcome visual stimuli. The memory may also influence the flavor of the food if the person have had a pleasant past experience. Additionally, people have a strong desire for new experiences and that input from the brain and nose may override the eyes in these situations.

4 *Terry E. Acree (2013). National Meeting of the American Chemical Society.*

1.1.2 The Different Food Groups

When we try to group the food together by their similar nutritional properties or biological classification, we obtain these five main food groups:

- Fruits
- Vegetables
- Grains
- Protein Food
- Dairy

These food groups make up the guide to healthy eating. Eating varied and well-balanced diet means eating a recommended amounts of food from each food groups daily, as these food groups provide with different types and amounts of key nutrients (Fig.2). By the other hand, the daily intake of calories and essential nutrients that our body needs to work correctly, has been established by recommended dietary allowances (RDA).

Grains, sometimes categorized as cereals, can be processed (refined) or unprocessed (whole grain), and is often a large category in nutrition guides. They are a rich source of carbohydrates/starch (energy), protein, fibre and a wide range of vitamins and minerals including the B, iron, vitamin E, zinc, magnesium and phosphorus. Grain food are mostly made from wheat, oats, rice, rye, barley, millet, quinoa and corn. The different grains can be cooked and eaten whole, ground into flour to make a variety of cereal food like bread, pasta and noodles, or made into ready-to-eat breakfast cereals. It is important to point out that refined grains have been milled, a process that removes the bran and germ to give grains a finer texture and improve their shelf life. This process also removes dietary fiber, iron, and many B vitamins, reason why refined grains are not recommended to consume in large scale.

The lack of fiber in processed grains make them a high-glycemic[5] food that slowdowns metabolism and is associated with obesity and many diseases[6]. Also potatoes often are included to this group as they are high in starch too.

Vegetables, including legumes and beans, are another large category in nutrition guides. They are nutrient dense, low in kilojoules, and are a good source of minerals and vitamins (such as magnesium, vitamin C and folate), dietary fibre and a range of phytochemicals including carotenoids. Vegetables come from many different parts of the plant, and they are divided into the following categories:

- root vegetables (potatoes and carrots)
- bulb vegetables (onion family)
- leaf vegetables (spinach and lettuce)
- stem veg. (bamboo shoots and asparagus)
- inflorescence veg. (artichokes and broccoli)
- other vegetables (cabbage or cauliflower).

Fruits, sometimes categorized with vegetables, is another food group. They are low in energy (kilojoules) and high in fibre and water, what helps our bodies to feel fuller, reducing the risk of overeating. Characterized by carbohydrates, mostly in the form of sugar, they are also important source of vitamins, minerals and phytochemicals. Vitamins such as vitamin C and E and different phytochemicals may reduce the risk of cardiovascular conditions. Potassium and magnesium found in fruit have also been linked to lower blood pressure. Different colored fruits, especially orange, red and yellow fruit, contain carotenes (Vitamin A) which are also thought to assist in immune function. While fruit is one food group, there are subgroups to consider within it. You will need to get a mixture from the different types of fruits, as they all offer various health benefits, these categories are:

- pome fruits (such as apples and pears)
- citrus fruits (oranges, lemons and mandarins)
- stone fruits (peaches, cherries and plums)
- tropical fruits (bananas, mangoes, papayas)
- berries (strawberries and blueberries)
- other fruits (grapes and passion fruit).
- botanical fruits (tomatoes and eggplants)

Some botanical fruits, such as tomatoes, pumpkins, and eggplants, are mostly eaten as vegetables. Current dietary guidelines recommend eating a variety of fruits and vegetables. However, based on nutrient composition, some particular fruits and vegetables may be more or less beneficial for maintaining or achieving a healthy weight. Studies support that greater consumption of fruits and vegetables with a higher fiber content and lower glycemic load helps on prevention of obesity, a primary risk factor for type 2 diabetes, cardiovascular diseases, cancers, and many other health conditions.

Protein Food, is a food made of all kinds of lean meat and poultry, fish, eggs, tofu, nuts, seeds, legumes and beans. This food group also provides a wide variety of other nutrients such as: iodine, iron, zinc, vitamins, especially B12,

5 *Carbohydrates from Sources with a Higher Glycemic Index during Adolescence. US National Library of Medicine National Institutes of Health (https://www.ncbi.nlm.nih.gov/pubmed/28604592)*

6 *Is There a Place for Dietary Fiber Supplements in Weight Management? US National Library of Medicine National Institutes of Health (https://www.ncbi.nlm.nih.gov/pubmed/22611521)*

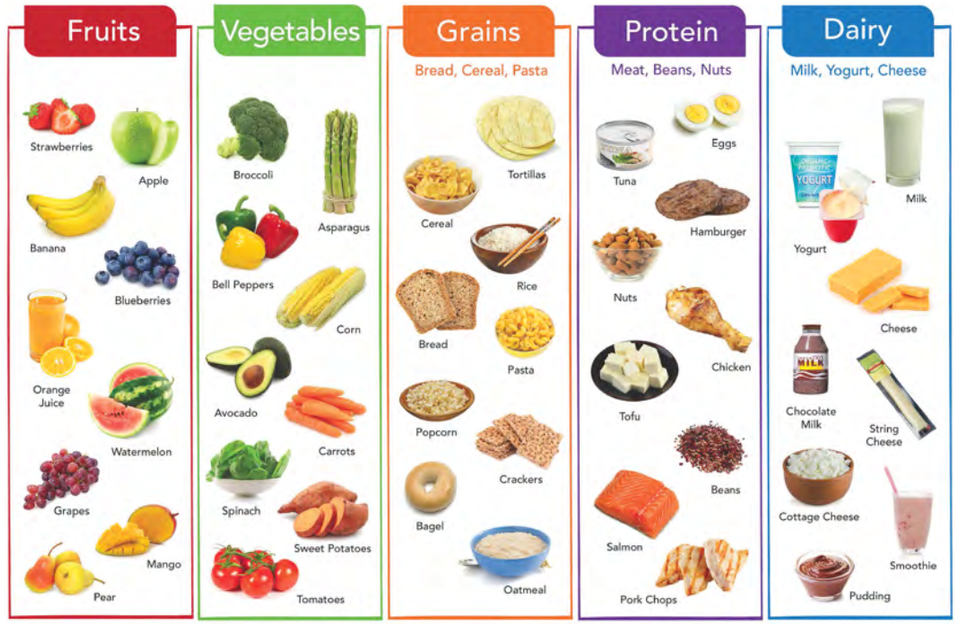


Fig.2 The 5 main food groups by Australian National Health and Medical Research Council.

and essential fatty acids. Legumes provide many of the same nutrients as lean meats, poultry, fish and eggs and because of this they have been placed in this food group as well as the vegetable food group. They are essential in vegetarian and vegan eating patterns to get enough of the key nutrients found in this food group.

Dairy, also called milk products, is the food group that includes all kinds of milk products as milk, yogurt and cheese, and/or alternative products. Normally, food made from milk that retain their calcium content are considered as part of this group, instead, those that have little to no calcium, such as cream cheese, cream, and butter, don't belong to it. Another kind of dairy group is the calcium-fortified soymilk (soy beverage). Milk, cheese and yogurt provide calcium in a readily absorbable and convenient form. They also have various health benefits and are a good source of many nutrients, including calcium, protein, iodine, vitamin A, vitamin D, riboflavin, vitamin B12 and zinc. Some people prefer to follow a dairy food-free or milk free diet because of allergies, or intolerances to lactose (the natural sugar in milk). Avoiding dairy food and not making suitable alternative choices such as the ones recommended in this food group can affect your long term health.

FOOD CLASSIFICATION

FOOD SOURCE AND FOOD STATE

Fig.3 Main Sources and States of the Food that composes our diets.

1.1.3 Food Classification: Food Source and Food State

All the food that our society consumes today are commonly divided into *plant-based* and *animal-based* food sources. However, a third and a quite small food source is *fungi*, which includes various edible fungi, especially mushrooms, boletus and others (see Fig.3).

A ***plant-based*** food are very important in our diet as they form the most part of food is produced worldwide. Even the animals that are used as food are raised by feeding them with grains derived from plants. Many plant-based food are directly obtained from plant and these are whole grains, nuts, seeds, legumes, fruits and vegetables. In fact, the majority of food consumed by human beings are seed-based food. These edible seeds include cereals (corn, wheat, rice), legumes (beans, peas, lentils), and nuts. Oilseeds, such as sunflower, canola or sesame, are often pressed to produce rich oils. Fruits make up a significant part of the diets of most cultures, and they are often eaten raw, although some varieties can be cooked. Vegetables are also eaten as food, and they usually come from many different parts of the plant, including the leaves, roots, tubers, flowers, stems, seeds and shoots.

An ***animal-based*** food are used as food either directly or indirectly by the products they produce. Meat, milk, and eggs are some examples of direct products taken from an animal. However, indirect animal products are usually obtained by processing direct ones, such as cheese that can be obtained from milk. Some cultures and people do not consume meat or animal food products for cultural, dietary, health, ethical, or ideological reasons. Among the most relevant cases are Vegans and Vegetarians.

The food that we normally eat can be found in 3 different states, such as raw, cooked and processed. Raw food usually refers to food that has not been treated and is kept in its original form. Once the food passes through different processes, its quality varies distinctly, and it is better to analyze these states more carefully.

Raw food - is food that has not been cooked or processed. Raw food diets are nutritious, tasty, full of nutrients, and low calorie density. They allow to preserve all food nutrients and enzymes, keeping the food in its most natural form. Advocates claim that raw food are more nutritious than cooked or processed food, as during these processes many enzymes and some vitamins are destroyed[7].

In general, raw food diets are made up of at least 70% raw food, based on consumption of food including a selection of fruits, vegetables, nuts, seeds, eggs, fish, meat, and diary products. The diet may also include some simply processed food (some sprouted seeds, cheese), and fermented food (yogurts, kefir), but generally not food that have been pasteurized, homogenized or produced with the use of synthetic pesticides, fertilizers, and food additives. Due to personal or social reasons, many raw 'foodists' consume only a vegetarian or vegan diet, eating mostly raw plant food and eliminating animal products from it. However, a small number of population today also consume raw dairy products, some fish and even raw meat. Some evidence suggests that switching to a raw diet from a standard Western diet (which includes a low fruit/vegetable intake combined with a high intake of sugar, chemicals, and refined carbohydrates) results in health improvements. Raw food is costly, metabolically speaking, to eat and digest. We need to chew a lot, and the body needs to do more work to break down what we consume. We tend to obtain less energy from raw food, what can be beneficial for today's obese society, however, it is not so desirable for someone with a lean body and no weight to lose, and can be dangerous and decrease chances of survival.

While there are some clear benefits of eating raw fruits and vegetables, there are also some potential problems with a raw-food diet. One of the main concerns people have with the raw food diet is the risk of nutritional deficiencies, such as vitamin B12, vitamin D, iron, zinc, and omega-3 fatty acids. In addition, many raw dishes are high in sugar and carbohydrates. Another concern is that with a lower energy intake, key processes in the body (such as hormone synthesis) may be suppressed. The consumption of raw food diet has also been associated with low bone mass. A study published in the *Journal of Nutrition* suggests that following a strict raw food diet may be also associated with deficiency in vitamin B12 and elevated risk factors for heart disease[8]. Another study published the relationship between following a long-term raw food diet and body weight. They found that body mass index (BMI) of people that followed this diet was below the normal weight range in 14.7 percent of men and 25 percent of women. Furthermore, approximately 30 percent of women under 45 years of age had partial to complete amenorrhea (the absence of menstrual periods)[9].

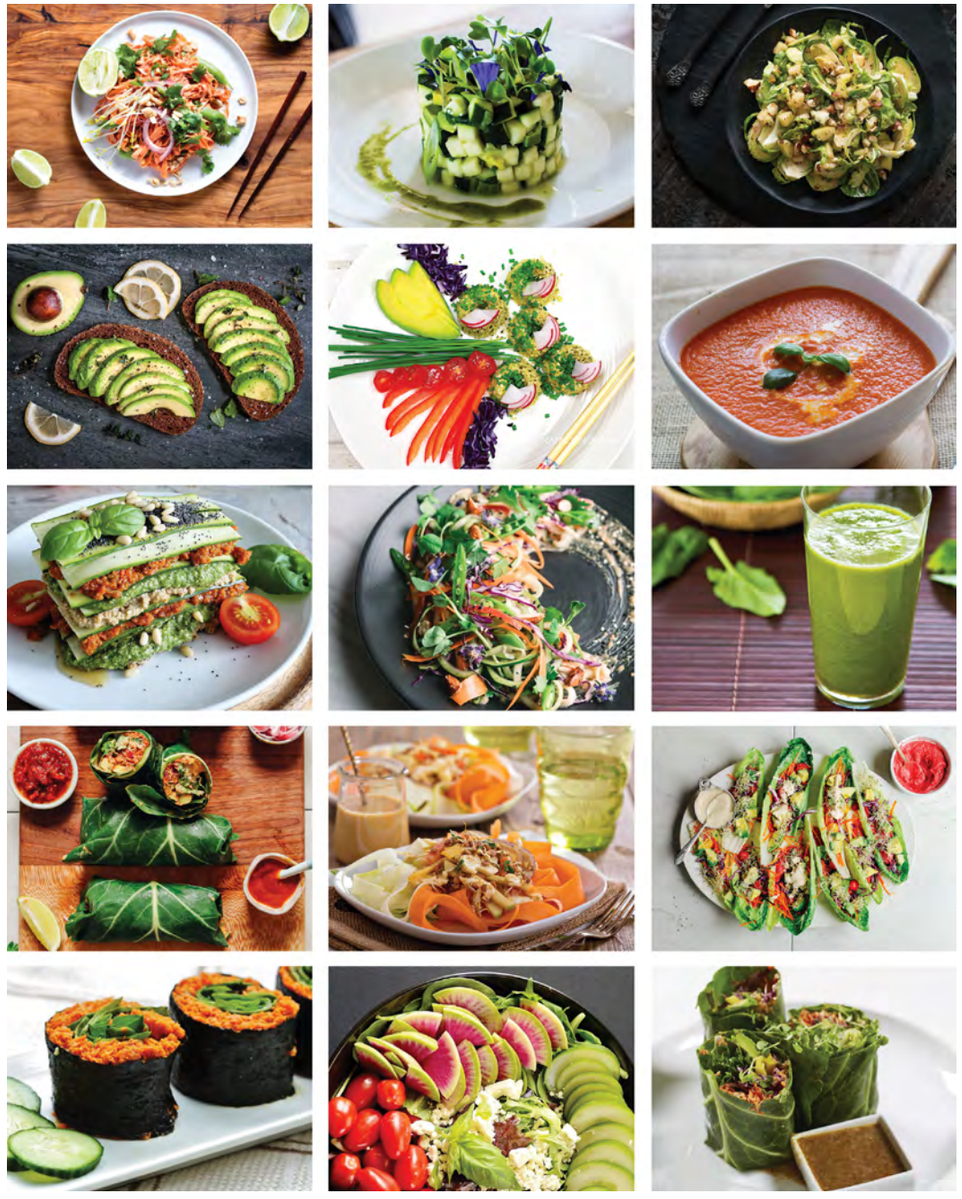


Fig.4 Some raw food diet meals.

7 *Transient model of thermal deactivation of enzymes. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3172083/)*

8 *Long-Term Consumption of a Raw Food Diet. The Journal of Nutrition, Volume 135, Issue 10, 1 October 2005, Pages 2372–2378. (https://academic.oup.com/jn/article/135/10/2372/4669843)*

9 *Consequences of a long-term raw food diet on body weight and menstruation: results of a questionnaire survey. Annals of Nutrition & Metabolism. (https://www.ncbi.nlm.nih.gov/pubmed/10436305)*

Cooked food - is considered a food that has been prepared for its consumption, using any of the cooking methods, such as roasting, baking, frying or cooking, among others. Cooking is also part of food processing, but these concepts are commonly differentiated since cooking is more focused on making the food ready for its direct consumption, while food processing also looks to extend its shelf-life. Cooking takes place mainly by applying heat to food, thus breaking down cell walls and creating chemical changes that improve its taste and aroma. This makes it much more enjoyable to eat and also easier for the body to digest and absorb the nutrients. The digestibility of a food is important because the body can only receive a food's health benefits if it is able to absorb the nutrients contained in it.

When you consume food, digestive enzymes in your body help break it down into molecules that can be absorbed. Raw food also contains enzymes that aid digestion, but they all are heat sensitive and deactivate easily when exposed to high temperatures over 47°C. This is one of the primary arguments in favor of raw-food diets, however some scientists confirm that human body is able to produce its own enzymes necessary to digest food, what can not lead to an enzyme deficiency[10]. Cooking has also created a great impact on the meat consumption, since the human body is not able to digest and absorb high amounts of raw flesh efficiently. However, raw food may be richer in certain nutrients than cooked food, as some nutrients are easily deactivated or leached out of food during the cooking process. In fact, boiling vegetables may reduce the content of water-soluble vitamins C and B, by as much as 50–60%[11]. Some minerals and vitamin A are also lost during cooking, although fat-soluble vitamins D, E and K remain mostly unaffected. Other cooking methods like steaming, roasting and stir-frying are some of the more effective to preserve the nutrient content of food[12,13].

Cooking your vegetables may make certain antioxidants more available to your body than they are in raw food. Antioxidants are important because they protect the body from harmful molecules called 'free radicals', and a diet rich in antioxidants is associated with a lower risk of chronic disease. Studies have found that cooking some vegetables such as carrots, broccoli, zucchini and tomatoes, among others, increases the availability of antioxidants like beta-carotene, lycopene and lutein, associated with reduced risk of heart disease and prostate cancer. As most bacteria cannot survive at temperatures over 60°C, cooking process also effectively kills dangerous bacteria and microorganisms that may cause food-borne illness[14]. Raw meat, fish, eggs and dairy often contain bacteria and it is not recommended to consume them raw or undercooked. However, fruits and vegetables are generally safe to consume raw, as long as they have not been contaminated.

10 *Conservation of Digestive Enzymes. (https://www.physiology.org/doi/full/10.1152/physrev.00022.2001)*

11 *Effect Of Heating On Vitamin C Content Of Some Selected Vegetables. (http://www.ijstr.org/final-print/nov2013/Effect-Of-Heating-On-Vitamin-C-Content-Of-Some-Selected-Vegetables.pdf)*

12 *Effects of different cooking methods on health-promoting compounds of broccoli. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2722699/)*

13 *Effects of Different Cooking Methods on the Antioxidant Properties of Red Pepper. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3866734/)*

14 *Food safety and foodborne disease in 21st century homes. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2094945/)*

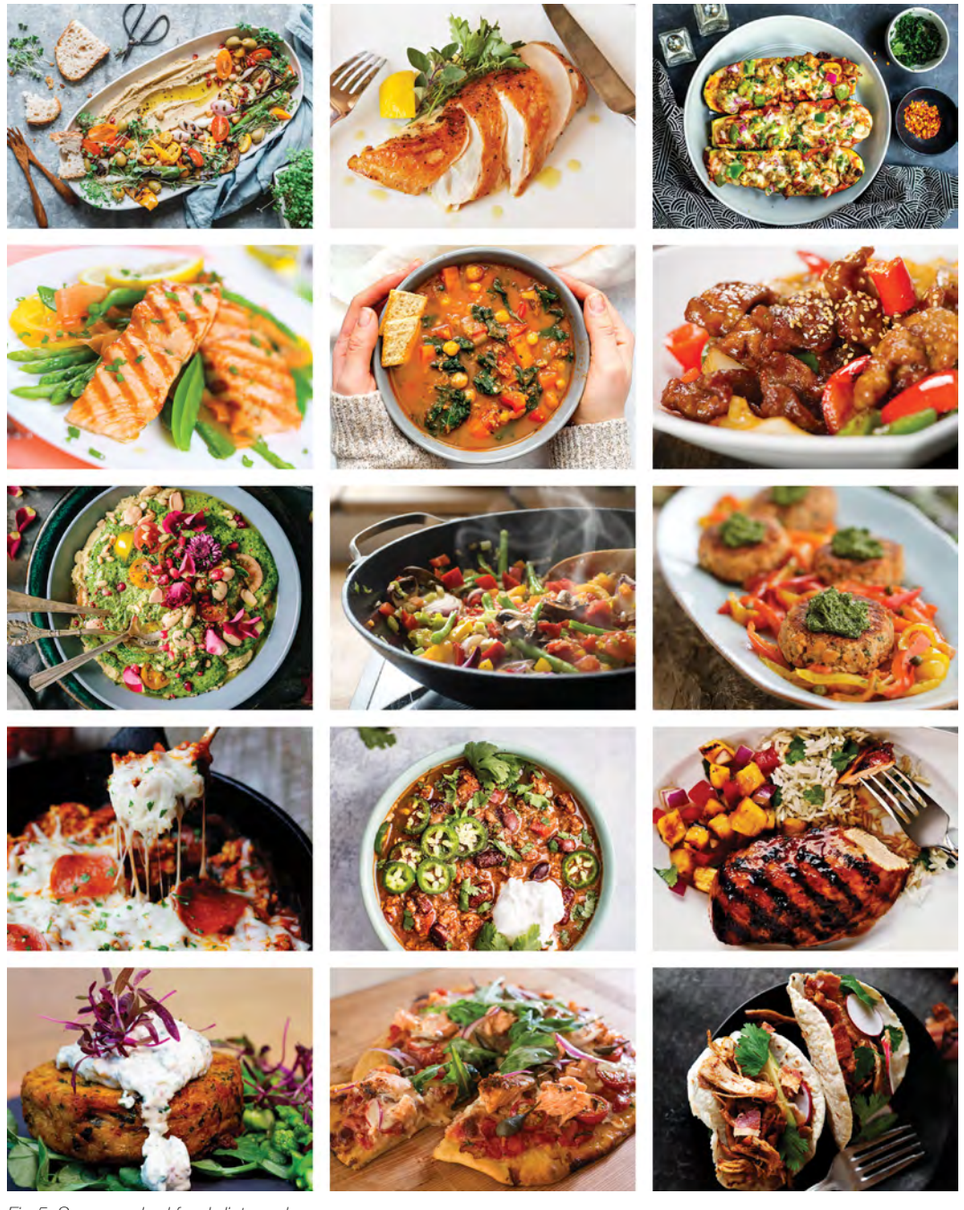


Fig.5 Some cooked food diet meals.

Processed Food - has a much broader meaning that cooked or prepared food. While food cooking is mainly focused on preparing the food, through different cooking processes, for its direct consumption, food processing pays more attention to the extending of its shelf life, apart from the food preparation.

All processed food can be divided into two main categories. Primary processing, in which food are stabilized after harvest and sometimes converted into a more convenient form for storage (drying crops, milling cereals, extracting oils from oilseeds). And secondary processing, in which fresh food or the products of primary processing are made into a wide range of processed food.

Processing does more than change the eating quality of raw food. All food are biological materials that begin to decay as soon as they are harvested or slaughtered. Without processing, as much as 50 to 60 percent of fresh food can be lost between harvest and consumption. This may be due to inadequate storage facilities, which allow micro-organisms or pests to spoil the stored food. Processing involves applying scientific and technological principles to preserve food by slowing down or stopping the natural processes of decay, hence, to prevent its spoilage and increase food safety. Furthermore, this offers an opportunity for people to diversify their regular fresh food consumption together with off-season processed products (such as canned food), creating more balanced and tasty diet throughout the year.

Most food are processed in some way before we eat them, but not all processed food are necessarily bad. Cooking food is also considered food processing, and most food needs to go through some sort of processing to be edible and digestible for our body. All processed food (see Fig. 6), usually fall somewhere on a spectrum from minimally processed (like washed or chopped salad mix or frozen fruits and vegetables) to what some nutrition experts refer to as highly or ultra processed (like ready-to-eat meals and snack food).

Many processed food such as frozen fruits and vegetables, canned beans and fish, cheese, or vacuum packed meats, do not always have to be seen as harmful. When processed without adding many of unhealthy ingredients, these food can actually be considered healthy. The main concern is with processing that reduces a food's nutritional wealth, using, additionally, high amounts of sweeteners, sodium, unhealthy fats and preservatives. This means that the nutritional value of these products changes from healthy to unhealthy, creating products considered worldwide as highly processed, or ultra-processed. The list of these products is very large, including many sodas and sweetened drinks, packaged baked goods and snacks, frozen or shelf-stable ready meals, industrialized desserts and fast food, often containing high levels of sugar, fat, and salt, but lacking in vitamins and fibre. Different studies have linked the regular consumption of ultra-processed food to higher risks of obesity, high blood pressure, cholesterol levels and different cancers (breast, prostate and bowel)[15]. However, despite the controversy, they are thought to account for up to 50% of total daily energy intake in several developed countries.

15 *Cancer: 'Ultra-processed' food may increase risk. Medical News Today. (https://www.medicalnewstoday.com/articles/320932.php)*

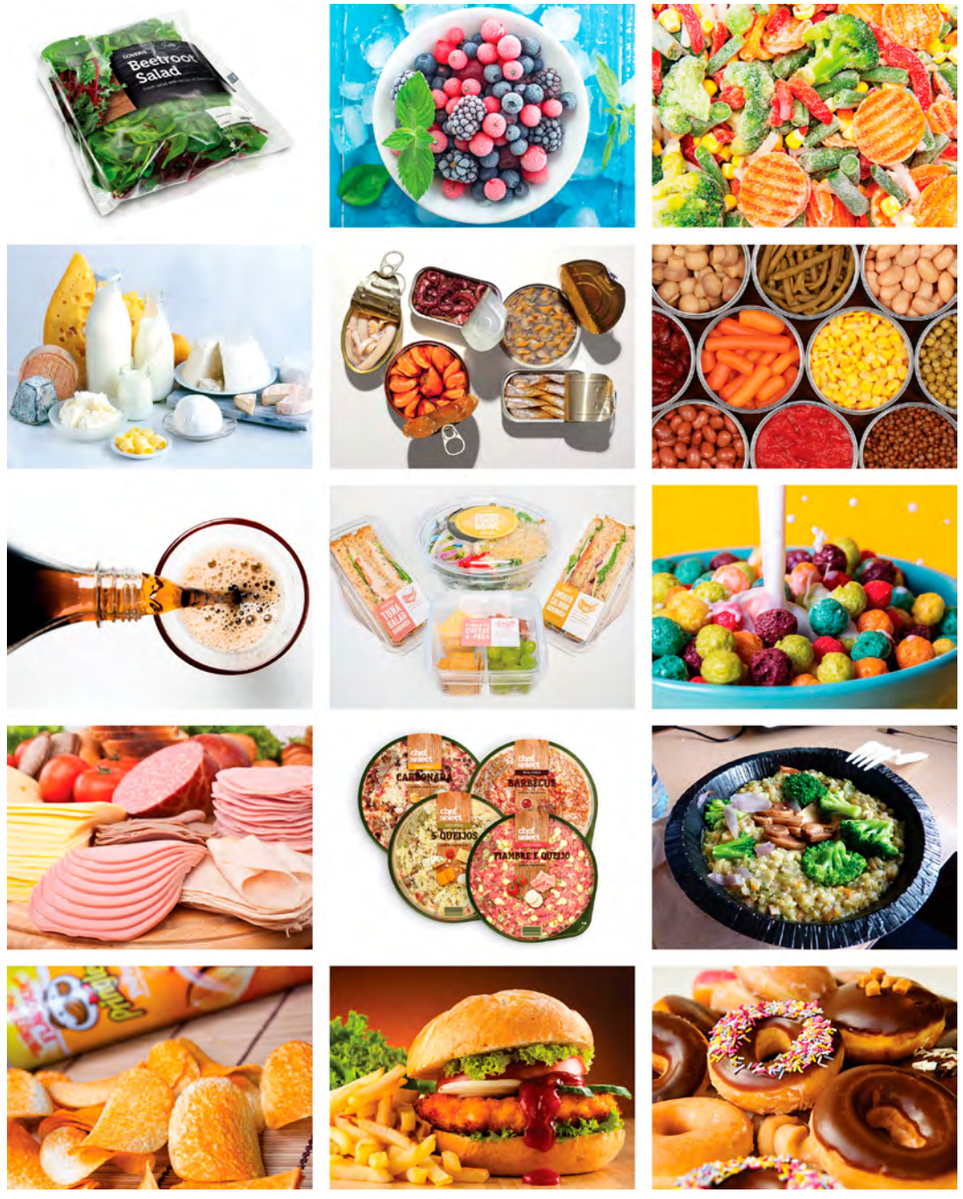
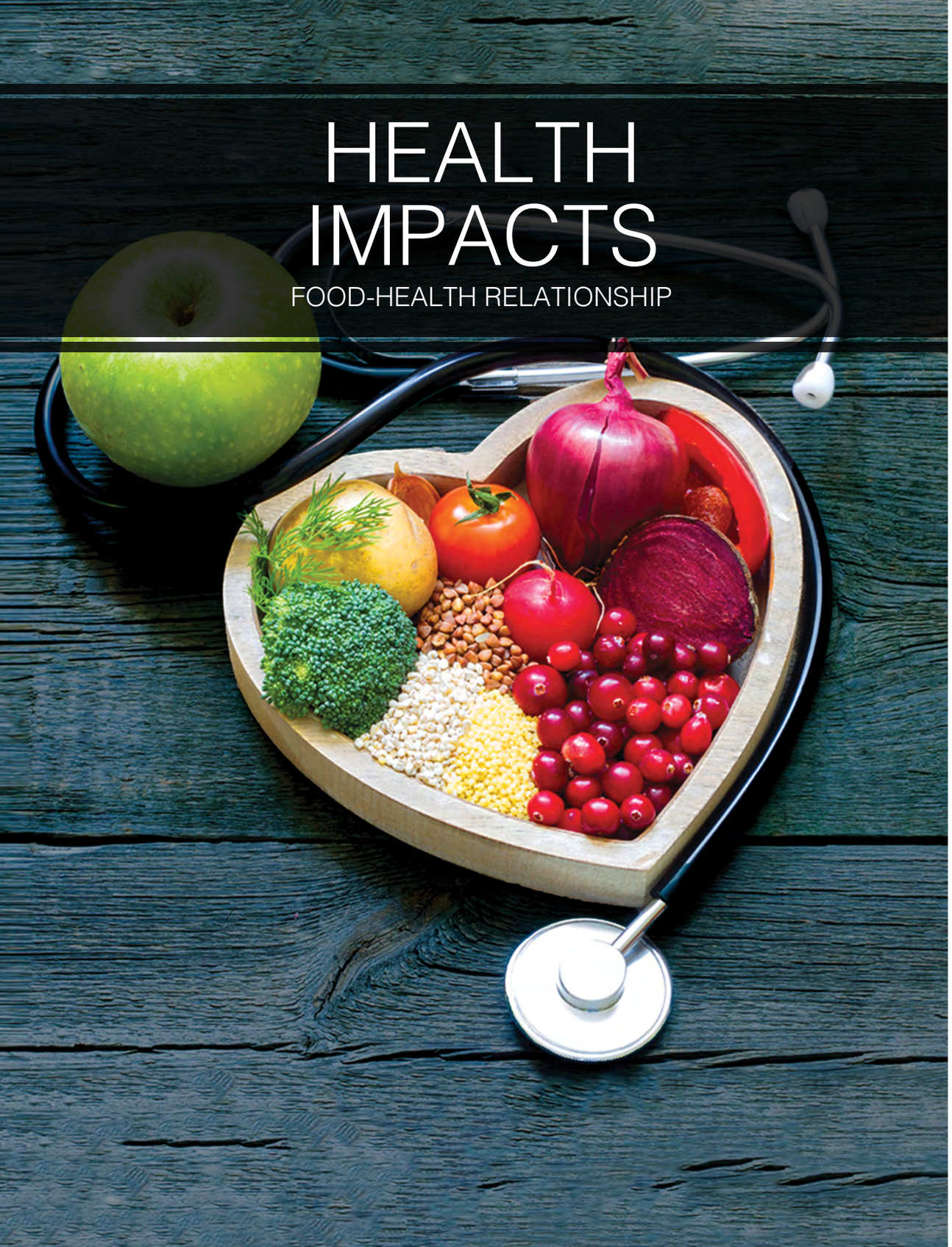


Fig.6 Some processed food diet meals, from 'lightly-processed' to 'ultra-processed'.



HEALTH IMPACTS

FOOD-HEALTH RELATIONSHIP

1.2 HEALTH IMPACTS

1.2.1 Food-Health Relationship

Food as “Preventing Medicine”

Dating back to the 5th century BC, in ancient Greece, Hippocrates was the first person who revolutionized the practice of medicine by shifting its approach from religious to the “rational”. Considered to be the “Father of Medicine”, he became an important figure in the history of medicine as he was among the earliest to assert that diseases were caused by natural processes rather than the gods. Hippocrates believed that a complete knowledge of the nature of the body was necessary to understand how it works, and that the food is crucial for our health. His famous statement “let food be thy medicine and medicine be thy food” is still one of the greatest medical prescriptions ever offered to human populations.

In the contemporary society, the meaning of this statement has changed significantly, as food is not exactly medicine, and in many cases can’t replace it. Many studies have confirmed this theory showing that a healthy diet influences human health and can decrease the risk of certain diseases, or cancer[16]; what is not well-accepted, mainly because there is little or no good evidence, is that the food can replace the medicine, pretending to cure diabetes, or impact on the progression and course of cancer. Food is far more that just its energy output as not all the calories are created equal and what we get from it mainly depends of its sources. Modern society is considering food as “preventing medicine”, since what people eat has a direct impact on their health.

16 *World Health Organization. Diet, nutrition and the prevention of chronic diseases (https://www.who.int/dietphysicalactivity/publications/trs916/summary/en/)*

LET FOOD BE THY
MEDICINE
AND MEDICINE BE THY
FOOD

HIPPOCRATES

Fig.7 Healthy eating and exercise and rest are the key to a healthy life.

Factors that Influence Our Health

Our health and well-being are very important aspects of our lives but there are many factors that influence the integral health of people. Among the most common factors that impact our health are: ***environmental factors, lifestyle, genetics*** and ***medical care.***[17]

The first group that includes different environmental factors, influences your health by 20%. On the one hand, there are physical environmental factors, which depend on different aspects of the environment in which we live (such as water or air pollution), and they physically affect our health. On the other hand, there are environmental social and economic factors, which consist of the relationship that exists between us and the society in which we live, but also how the economic aspect can compromise our health. The most prominent factors here is poverty, unemployment or social integration, which can negatively compromise our mental health, causing different mental disorders such as anxiety and stress.

The second group of factors depends of your living lifestyle and it can influence your health by 50%. These factors depend totally on you since it is your choice which lifestyle (healthy or not) you prefer to enjoy. Balanced nutrition, enough exercise and sleeping well

17 *8 Aspectos Que Inluyen En La Salud Integral (https://www.lifeder.com/factores-que-influyen-en-la-salud/).*

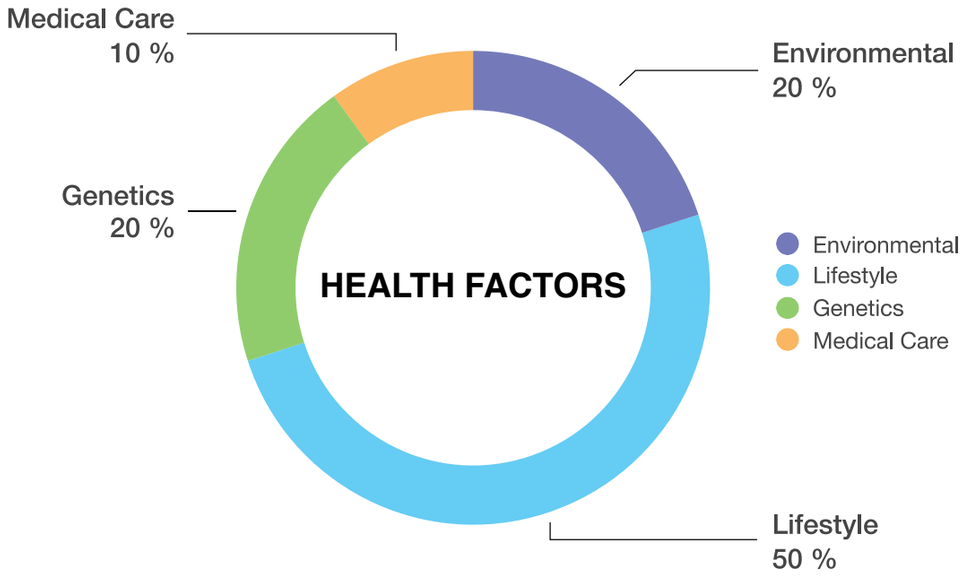


Fig.8 The most important factors that influences or health.

are the key to a healthy lifestyle (Fig.7). They will make your body work properly and stay healthy, while controlling your weight and thus preventing some heart diseases. In addition, it is recommended to avoid addictions such as tobacco, alcohol or drugs, since they negatively influence our health, worsening our quality of life.

Genetics is the third group of factors that usually influences our health by about 20%. These are biological aspects that are inherent to each organism in particular, and they mostly do not depend on us, as they are really hard to be changed.

The medical attention is the last group of factors to mention, and it depends only on 10% of your health. The quality of the service, its availability or accessibility and its cost, are the common aspects that define the medical attention you receive (Fig. 8).

In conclusion, half of the factors that influence our health depends directly on us, on our habits and behaviors that mainly define our lifestyle. Our lifestyle is essential for the correct developing and body performance, and it can promote better health and even allow to live longer. Researchers have been demonstrating for many years the importance of good

Fig.9 The 80/20 Fitness rule consists of 80% diet and 20% exercise.

sleeping and its benefits.[18] Other studies show the harmful effects of ***tobacco***, ***alcohol*** and ***drug*** use, and explain they are the biggest threat to human health around the world.[19] What refers to the ***exercise***, after many years of research it has been shown that its benefits are multiple, and evidence shows that there are plenty of compelling reasons to start moving at any age.[20] However, one of the crucial factors in being healthy is proper ***nutrition***.[21] Regular exercise is important but according to research[22], nutrition has the largest impact on our fitness. Nutrition and exercise are both important parts to losing fat and gaining strength, but nutritional habits will have a far greater impact on your body composition and physique goals than any other fitness component. You actually will not be able to out-exercise a bad diet, and the combination of both provides a complete healthy package to your body. It is not surprising, therefore, that 80/20 rule has such importance in the fitness world, which consists of applying 80% of nutrition to 20% of exercise (Fig.9). Focusing on healthy food intake is a primary fitness goal, and getting healthy eating habits to become a lifestyle, will make us healthier and happier, and will also help to reduce body fat and risk of illness.

A Guide to Healthy Eating

For a healthy and balanced diet, different food organization around the world recommend to drink plenty of water and enjoy a wide variety of nutritious food from different food groups everyday (see Fig. 2). As a result, this will allow our body to obtain all the nutrients necessary for its proper functioning and development. However, it is also important to get your portions right. Around a third part of your daily intake should be made up with vegetables and another third with whole grains (see Fig.10). The last part can be split into three smaller groups, as shown on the same picture. In addition, our diet should also contain small amounts of healthy fats, as they are essential part of our diet, especially for hormone regulation. Being higher in energy (kilojoules) than any other nutrient, fat consumption should be limited.

Among different types of fats (unsaturated, saturated and trans fats), consumption of higher amounts of saturated or trans fats has been linked with an increased risk of heart diseases and high blood cholesterol levels. That is why to make your diet healthier, it is important to eat unsaturated fats in small amounts, as they will reduce the risk of heart disease and lower your cholesterol levels.

A healthy lifestyle is crucial to live better and longer, but food is just one of many factors that influences our health. Emerging nutrition science research, as well as data collected from people in their 90s and beyond, shows that what, when, and how we eat has a profound influence on how long we live. There are a wide range of nutritious and delicious food that can help to “add years” to your life due to its anti-aging benefits. These researches support

18 *Benefits of Sleep. Harvard Medical School. (http://healthysleep.med.harvard.edu/healthy/matters/benefits-of-sleep)*

19 *Tobacco, alcohol and illegal drugs ‘are a global health threat’. Department of Health & Social Care. UK. (https://www.nhs.uk/news/medical-practice/tobacco-alcohol-and-illegal-drugs-are-global-health-threat/#)*

20 *7 Surprising Benefits of Exercise. Time Journal. (http://time.com/4474874/exercise-fitness-workouts/)*

21 *Nutrition: What is it and why is it important? (https://www.medicalnewstoday.com/articles/160774.php)*

22 *Is Nutrition More Important Than Exercise? (https://www.verywellfit.com/nutrition-vs-exercise-80-nutrition-wins-3121406)*

WHAT A BALANCED AND HEALTHY DIET LOOKS LIKE

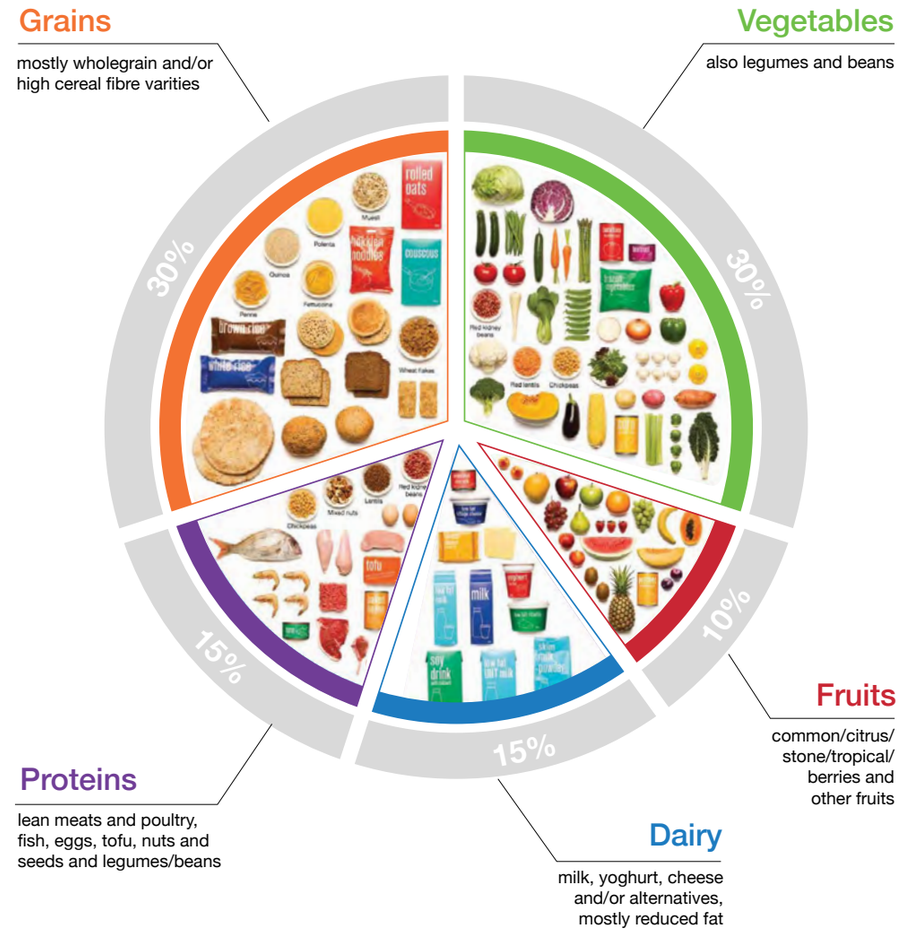


Fig.10 The Australian Guide to Healthy Eating. Australian National Health and Medical Research Council.

that increasing a consumption of whole grains, cruciferous vegetables, tomatoes, berries, probiotic-rich food (usually a fermented food such as some yogurts, kefir and pickles), coffee and green tea can help to reduce the risk of a big range of diseases and even cancer. Some of them also help to prevent a cell damage, reduce stress and increase a body immunity. Researches also show that centenarians (people 100 years or older) eat less meat and more fatty fish (at least two to three servings of fish a week), which are high in heart-healthy Omega-3 fatty acids. The consumption of mostly plants and beans is a great choice as they are high in fiber, low in fat, and packed with nutrients. Staying hydrated is very important too, that is why drink plenty of water is recommended to lower the risk of blood clots and boost the energy.

Mediterranean Diet

Since in my research I have tried to deal with the consumption of fresh and healthy food and its preservation, I could not proceed without mentioning the diet of the area we are living in. Mediterranean diet is well-known as one of the world's healthiest diets and its consumption is also associated with less environmental impact. Traditionally, it is comprised of high levels of olive oil as the main source of fats, high consumption of plant-based food such as fresh fruit and vegetables, wholegrain cereals, nuts, moderate consumption of fish and dairy products, a little meat, and moderate consumption of alcohol, especially wine, usually during meals (Fig.11).

The Mediterranean diet involves a set of skills, knowledge, rituals, culture, symbols and traditions concerning crops, harvesting, fishing, animal husbandry, conservation, processing, cooking, and particularly the sharing and consumption of food. As a result, since 2013, UNESCO has inscribed the Mediterranean diet on the Representative List of the Intangible Cultural Heritage of Humanity[23].

Mediterranean diet presents different health benefits[24], and many studies have been associating it with improved health and reduced risk of chronic age-related diseases such as heart disease[25], stroke, type 2 diabetes and dementia[26]. Other studies confirm its positive impacts on improving the cognitive function[27] and reducing the risk of developing of Alzheimer. However, the Mediterranean diet is more than just eating the food of this particular area, it is a combination of healthy eating habits and behaviors over a long period of time. Different studies indicate that the evidence for health benefit appears stronger when it is applied a food synergy pattern[28], based on the significant interrelations between constituents in food, instead of individual food components.

Fig.11 The Mediterranean Diet, considered one of the healthiest diets in the world.

23 *UNESCO Intangible Cultural Heritage. (https://ich.unesco.org/en/RL/mediterranean-diet-00884)*

24 *Benefits of the Mediterranean Diet. (https://www.sciencedirect.com/science/article/pii/S0033062015000286)*

25 *Primary Prevention of Cardiovascular Disease with a Mediterranean Diet. (https://www.nejm.org/doi/full/10.1056/NEJMoa1200303)*

26 *Proof that the Mediterranean diet is good for your brain. (https://theconversation.com/proof-that-the-mediterranean-diet-is-good-for-your-brain-18530)*

27 *Mediterranean diet, cognitive function, and dementia. (https://www.ncbi.nlm.nih.gov/pubmed/23680940)*

28 *David R Jacobs, Myron D Gross, Linda C Tapsell; Food synergy: an operational concept for understanding nutrition, The American Journal of Clinical Nutrition, Volume 89, Issue 5, 1 May 2009, Pages 1543S–1548S, https://doi.org/10.3945/ajcn.2009.26736B*

HOW FOOD IMPACTS
ON OUR BRAIN AND MOOD

1.2.2 How Food Impacts On Our Brain and Mood

Our brain is a very complex organ and it is responsible for countless processes that occur in our body. It takes care of our thoughts, movements, breathing, heartbeat and senses, working 24/7, even when we sleep. This means it requires a constant supply of energy to work adequately, and as this energy comes from food we eat, what is in that food, makes all the difference. The human brain only makes up about 2% of our body weight, but it uses up to 20% of our energy resources. As an expensive car, our brain works better when it gets only premium fuel. Eating high-quality food rich in vitamins, minerals, and antioxidants, nourish the brain and protect it from damage. Unfortunately, "low-quality" fuel (such as what we get from processed or refined food) can damage our brain. Many studies have found that diets high in refined sugars are harmful to the brain. They are worsening the regulation of insulin in our body, and even increase the symptoms of mood disorders.

The food is more important factor in our lives that you might think. Over the past ten years, the "gut-brain connection" has been explored on hundreds of different studies, with much greater focus. According to gastroenterology scientist Giulia Enders[29], good mental and physical health begins in the gut, and the gut-brain axis is key to our overall well-being. Our gut-brain connection is not as simple as we sometimes think. We tend to think our brain makes commands and then sends them down to our organs, and they all have to listen. But really, only 10% of the nerves that connect brain and gut, deliver information from the brain to the gut. Instead, 90% of this information is being delivered in opposite direction (Fig.12).

As the brain, our gut is a very complex organ too. It is forty times larger than the area of the skin, and the biggest part of our immune cells (2/3 part) is being trained there. There are 100 trillion bacteria of different species living there, and, in addition, about 20 different hormones are produced by our gut. The gut, actually, is the most important advisor for the brain. It is the largest sensory organ, hosting multitude of neurons and collecting information of the quality of our nutrients, our immune cells, and the hormones in our blood.

What we eat, directly affects the structure and function of our brain, and, ultimately, it also has a direct impact on our mood. Serotonin is a neurotransmitter that helps to regulate sleep, appetite, pain and moods, and it is almost entirely produced in our gastrointestinal tract. As it is lined with hundred million neurons, it is possible to deduce that the inner workings of the digestive system don't just help to digest food, but also guide our emotions. Furthermore, the function of these neurons, as the production of serotonin, is highly influenced by the "good" bacteria that can be found in the

29 *Enders, G. (2015). The Brain and the Gut. Gut: the inside story of our body's most under-rated organ. Scribe United Kingdom.*

intestinal microbiome. These bacteria play an essential role in our health and improve the way we absorb nutrients from the food, activating neural pathways directly between the gut and the brain[30].

Different studies indicate that altered gut microbiota and digestive issues have a significant role in the development of many mental-health disorders and can adversely affect the behavior of those people[31]. In modern society, depression is by far one of the most common mental disorders, and specific studies have now looked at the possibility of applying probiotic bacteria to help alleviate symptoms of depression[32] and other anxiety-related conditions[33].

Of course, if our microbiome can affect our mood and brain health so significantly, then it follows that our diet can also significantly affect our mental health too. The type of diet we choose to follow can directly influence the type of flora – "good" or "bad" – that flourish in our intestines. Dr. Perlmutter, an esteemed neurologist who is the president of the Perlmutter Brain Foundation, believes that eating a diet rich in fermented food that feed the right types of gut bacteria is the key to good brain health, and offers a comprehensive diet plan in his book, "Brain Maker". Another experiment carried out by professor Tim Spector from King's College London, is an interesting proof of how the diet can influence our gut bacteria. To promote his own book, he put the junk food theory to the test using his 23 year old son, also called Tim. Prior to the experiment, young Tim's gut microflora contained over 3,500 different species of bacteria, but after only ten days, these populations had plummeted down to just 1,300 species.

A recent study conducted at Ohio State University, was focused on the role of the gut bacteria in the development of future health issues such as obesity, asthma, allergies and bowel disease. As a consequence, the researchers noted that the presence of certain types of bacteria, the diversity of species and the size of the bacterial populations, noticeably affected the behavior of the children and they also influenced their adult health[34].

What is interesting at this point, is that for many years, the medical field did not fully acknowledge the connection between mood and food. But today, fortunately, the nutritional psychiatry is finding there are many consequences and correlations between not only what you eat, how you feel, and how you ultimately behave, but also the kinds of bacteria that live in your gut.

30 *Harvard Medical School. Nutritional psychiatry: Your brain on food. 2018 (https://www.health.harvard.edu/blog/nutritional-psychiatry-your-brain-on-food-201511168626)*

31 *Krajmalnik-Brown et al, (2015) , 'Gut bacteria in children with autism spectrum disorders: challenges and promise of studying how a complex community influences a complex disease', Microbial Ecology in Health and Disease, Vol 26 (2015).*

32 *Akkasheh et al, (2015) 'Clinical and metabolic response to probiotic administration in patients with major depressive disorder: A randomized, double-blind, placebo-controlled trial', Nutrition, September 25, 2015.*

33 *A psychobiotic that modulates brain activity, the stress response and neurocognitive performance in healthy volunteers. Microbiome Institute. (https://www.ucc.ie/en/media/academic/psychiatry/Allen_NeurolIreland_2015_BifLongum.pdf).*

34 *Ohio State University Center for Clinical and Translational Science. "Toddler temperament could be influenced by different types of gut bacteria." ScienceDaily. ScienceDaily, 27 May 2015.*

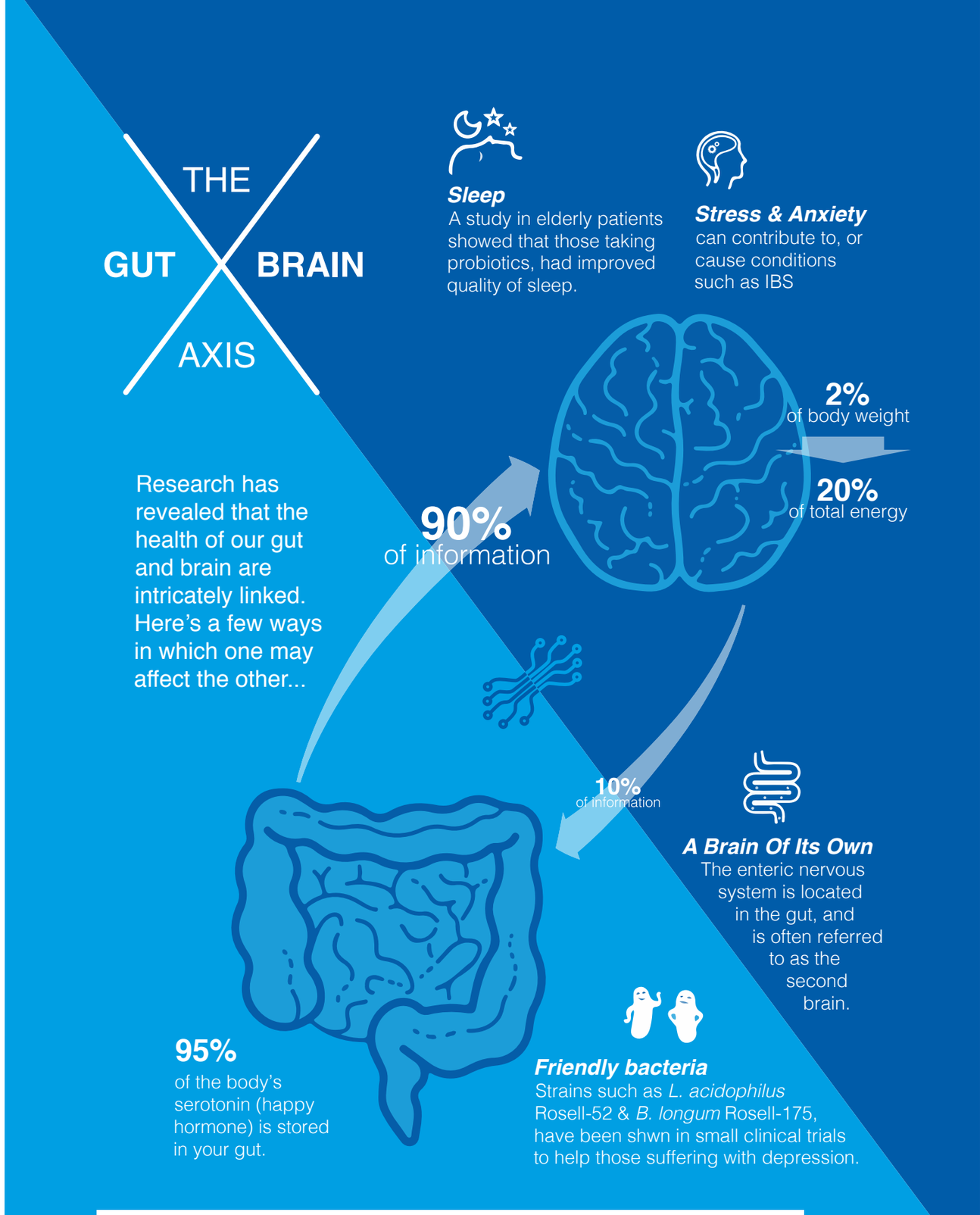
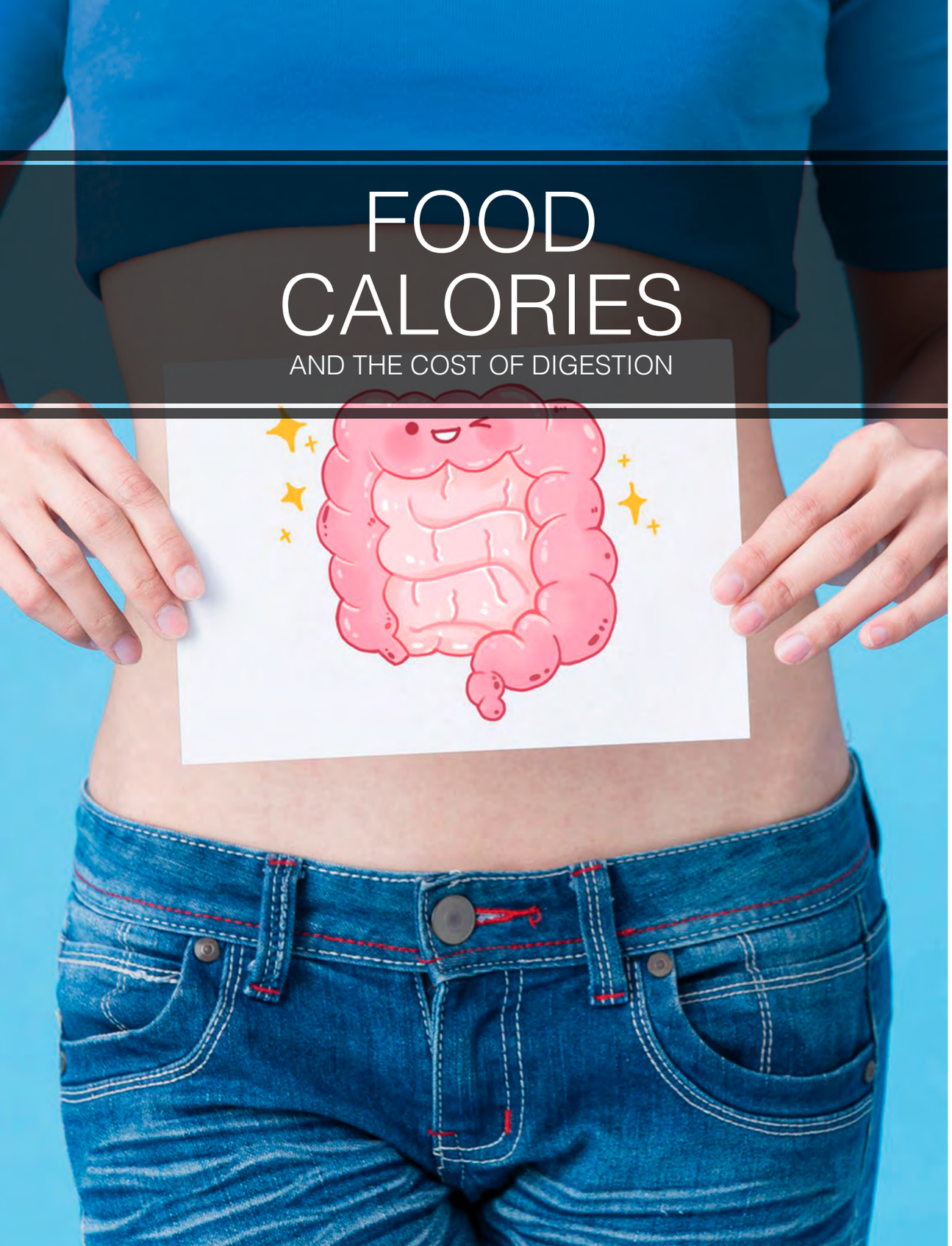


Fig. 12 The Gut-Brain Axis by Probiotics Learning Lab Revealing How The Health Of Our Brain And Gut Are Linked.



FOOD CALORIES

AND THE COST OF DIGESTION

1.2.3 Food Calories and the Cost of Digestion

Food nutrition labels seem to give all the necessary information to understand the composition of a food and the amount of calories it contains. However, the calories that are displayed there are not the calories that our body actually gets, as it depends on how highly the food is processed.

The current food industry uses the ***Atwater system***[35] to determine the amount of energy available in food. Developed more than 100 years ago, this system estimates how easily our body digests the proteins, carbohydrates and fats in a food, which is, in turn, used to calculate the number of calories. However, different studies in recent years suggest that the Atwater formula may not be entirely accurate, since the calories that this system suggests for different food often differs significantly from reality[36,37].

It has been known for a long time that the accessibility of calories from carbohydrates can vary, as not all carbohydrates are equal. It was also discovered that fibre and resistant starches provides fewer calories than other types of carbohydrates, as they are less readily digested. But how does cooking or

35 *Atwater System. Wikipedia. (https://en.wikipedia.org/wiki/Atwater_system)*

36 *Measured energy value of pistachios in the human diet. British Journal of Nutrition (2012). (https://www.cambridge.org/core/services/aop-cambridge-core/content/view/301A8C1A28E73425E799E32B008D76CE/S0007114511002649a.pdf/measured_energy_value_of_pistachios_in_the_human_diet.pdf)*

37 *Discrepancy between the Atwater factor predicted and empirically measured energy values of almonds in human diets. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3396444/pdf/ajcn962296.pdf)*

Fig.13 Raw versus cooked spinach. They look different but also the calories they provide for the body are different.

processing food really affect the calories it contains? There are substantial differences in energy between raw, cooked and processed food. Taking carbohydrates, for example, they provide more than half of the world's calories, and are mainly digested in the small intestine. If you eat a starchy food raw, up to half the starch grains pass through the small intestine entirely undigested. Your body gets two-thirds or less of the total calories available in the food[38]. The rest might be used by bacteria in your colon, or might even be passed out whole. The same goes for meat since our body is not able to digest it properly. However, when we cook it, the heat allows proteins to unwind from their tightly bound structures, increasing the surface area of meat exposed to gastric acids and enzymes, what finally increases a proportion of proteins digested in the gut. Some anthropologists believe that cooking was one of the great transitions in the history of human life, as since our ancestors started cooking, they could get more energy from it, hence develop bigger brain and larger body.

A study published in the Proceedings of the National Academy of Sciences, by a group of Harvard researchers in 2011, has explained how these factors are linked[39]. The result of the study suggest that breaking down the cell walls of starchy food by pounding, not only makes the starchy food easier to chew and digest, but also increases the amount of calories available compared to raw, unprocessed starches. However, the greatest effect was obtained from cooking, since this heat-induced process has lead to relatively complete gelatinisation of starch and efficient denaturing of proteins, facilitating their digestion. In this case the body gets more energy from cooked food since it is

38 *The energetic significance of cooking. Journal of Human Evolution. Volume 57, Issue 4, October 2009, pages 379-391. (https://www.sciencedirect.com/science/article/pii/S0047248409001262?via%3Dihub)*

39 *Energetic consequences of thermal and non-thermal food processing. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3228431/pdf/pnas.201112128.pdf)*

Fig.14 How food processing influences the calories the food is packed with. Pictures provided by app Calorific.

more bioavailable and also because the body requires less energy to break down the food chains into their building blocks (monomers) during digestion, making the total amount of calories available to the body much higher if compared to consuming it raw. Additionally, cooking reduces food-induced thermogenesis and metabolic cost of immune defense. Consuming your food raw will tend to lose weight, meanwhile the consumption of the same food cooked will make you get more calories and tend to gain weight. That means that same food may give you different calories in term of how processed it is (see Fig. 13).

On the other hand, there is another very common problem in our society, and is that we often do not pay attention to the calories that different food contain. Processing food in any way will generally provide them with higher calories due to added sugars or fats, or just because its thermogenesis will be reduced, as in the case of cooked food. And although these food can be consumed in small portions, their caloric content is usually quite high if compared to fresh food such as fruit and vegetables (see Fig.14). Unfortunately, processed food also tend to have poorer nutritional quality, as their contents of micronutrients are usually low, and part of them, are often added artificially. For this reason, to follow a healthier diet, many organizations worldwide recommend paying more attention to food labels of the products we want to buy and check its nutritional value. It is important to control the calories it contains, limiting some unhealthy fats and trying to get enough micronutrients such as minerals, vitamins and fiber (see Fig.15).

However, we must take into account that current calorie-counting system is inaccurate, and some information provided on these labels may not be completely reliable. The main issue here is that this system ignores some factors linked to the food such as changes in digestibility, cost of digestion, and cost of the immune system, all of which are influenced by food processing. Unfortunately, these energy differentials are not currently being reflected, either in the scientific literature or in the nutrition

Fig.15 Sample of nutrition fact label for Macaroni and Cheese.

labels that are being presented to consumers. For decades there have been several attempts to reform this system, although they have all failed, since the main problem is the shortage of information. Researchers find it hard to predict precisely how many extra calories will be gained when our food gets processed, as it would require to analyze the amount of the digested food of the total intake after digestion. However, even this would be unfeasible because when we eat the food, it get mixed with the one consumed previously, what makes this process even more complex. Hence, every country has opted to take no account of the food-processing on their food labels, overestimating the calories available in unprocessed food.

The average user can find the process of analyzing the nutritional value of each food he/she intends to buy as a difficult task. In the first place, this process requires some time to identify the food that each consumer is interested in. Secondly, it is not always

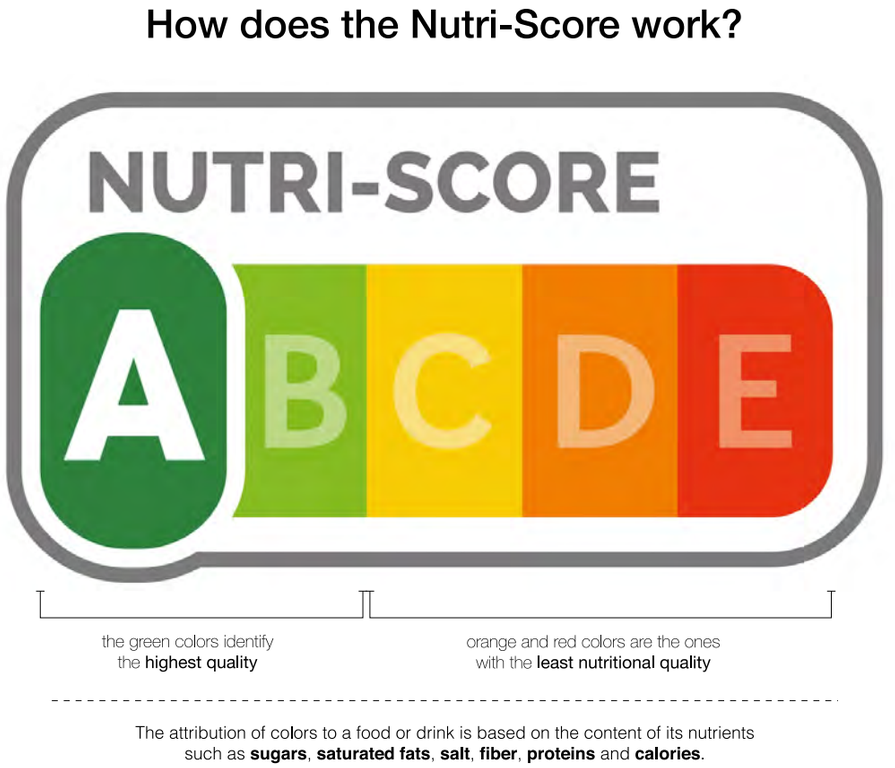
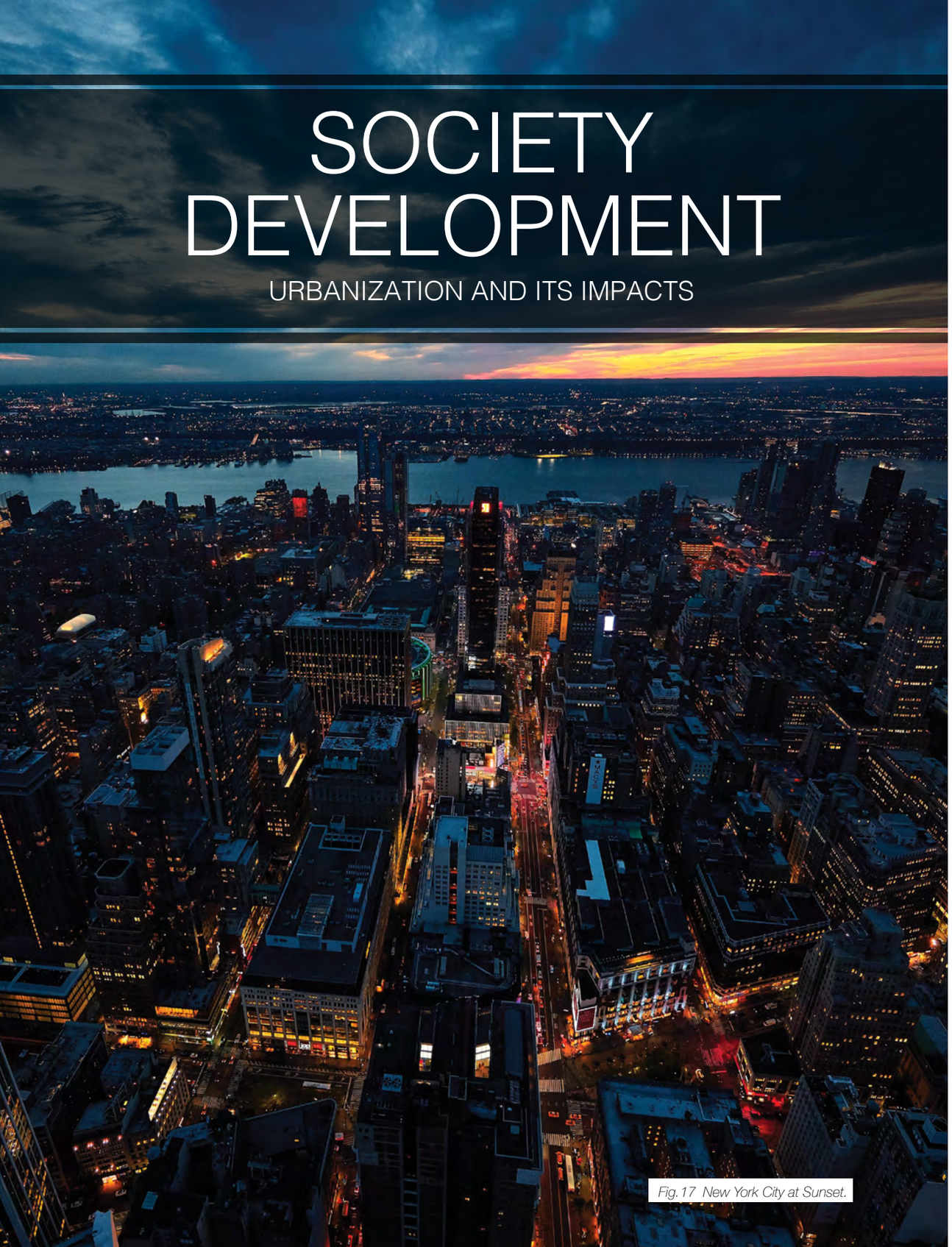


Fig.16 Nutri-Score Nutrition Labeling and how it works.

clear whether the amounts of each nutrient advertised on the food labels are within the healthy ranges, which often tends to confuse people more than to help. Nonetheless, as the solution to this problem, countries such as France and Belgium have recently implemented new front-of-pack nutritional labeling called "Nutri-Score"[40], which aims to orient consumers towards healthier food choices, offering better transparency over food consumption (Fig.16). Basing this food-quality identification system on five different colors and letters, it gives the consumers a simple and intuitive method towards healthier consumption behaviors. Researches show that it will have a positive impact on the purchase, reducing the consumption of ultra-processed food and incentive manufacturers to reformulate their products towards healthier compositions.

40 *Nutri Score. The front of pack nutrition labelling scheme recommended in France. (https://ec.europa.eu/food/sites/food/files/animals/docs/comm_ahac_20180423_pres4.pdf)*



SOCIETY DEVELOPMENT

URBANIZATION AND ITS IMPACTS

Fig.17 New York City at Sunset.

1.3 SOCIETY DEVELOPMENT

1.3.1 Urbanization and its Impacts

One of the aspects of the contemporary society is the urbanization. This gradual shift in residence of the human population from rural to urban areas has increased significantly over the past 60 years, being this shift more evident in more developed countries. Today, 55% of the world's population lives in urban areas, the proportion that is expected to increase to 68% by 2050[41] (also see Fig.22).

Cities have always been focal points for economic activity, employment and innovation. Historically, most cities developed because of some advantage as its location, access to markets or raw materials. Today, cities play a central role in creating national wealth, enhancing social and economic development. Their high population density provide an opportunity for governments to deliver basic services such as water and sanitation more cost-effectively and to more people. However, cities are also concerned with a huge responsibility in almost any area, as their impacts may be quick and devastating. On average, urban residents enjoy better access to education and health care, as well as other basic public services as electricity and water, than people in rural areas. Urbanization is often linked to industrial revolution as this last allowed the birth of large industries, better job opportunities, and availability of means of transport. Urbanization often determine the progress of technology development and the economic growth of the country.

41 *World Urbanization Prospects: 2018 Revision, published by the Population Division of the United Nations Department of Economic and Social Affairs (UN DESA)*

Fig.18 New York by 1903. The Flatiron Building.

Fig.19 Contemporary employment in developed countries offers bigger equality among sex, race or sexual orientation.

Different projections show that the world is heading towards the development of "mega-cities" (urban areas with over 10 million people), however, the fastest-growing urban agglomerations are mainly smaller and the most part of them are located in Asia and Africa. Given the size of their populations, the greatest urban growth is expected to occur in India, China and Nigeria (see Fig.22). Taken together, these three countries are projected to account for 37% of the total growth of the total urban population between 2018 and 2050[42].

As the world continues to urbanize, sustainable development of the cities depends on the successful management of the urban growth. This factor is especially important in developing countries, where the growth is projected to be the fastest. Many countries will face challenges in meeting the needs of their growing urban populations, including housing, transportation, employment and basic services as education and health care, but also the food production.

Socio-Cultural Impact

Urbanization is as much a social process as it is an economic and territorial process. It transforms societal organizations, demographic structures and the nature of work. It also modifies domestic roles and relations within the family, and redefines concepts of individual and social responsibility. The shift from rural to urban alters rates of population growth, declining birth and death rates. This initially means rapid urban population increase, but the decrease in fertility rates due to this shift, makes decrease the rate of growth of urban population. As a result, families become smaller, not only because parents have fewer children on average, but also because they are more expensive to rear. Children are clearly less useful in urban settlements as units of labor that are very typical of rural settings. In fact, fertility levels in developed countries have dropped so low that

42 *United Nations Population Division. World Urbanization Prospects: 2014 Revision*

Fig.20 Pictures showing different examples of environmental impact around the world, affecting mostly developing countries. These are air and water pollution, waste-disposal problems and an environmental degradation.

cities are seldom capable of reproducing their own populations. They usually grow through immigration from other cities or from rural areas, or even from surrounding countries. Those cities, in turn, have been transformed, in social and ethno-cultural terms, as a result of this displacement.[43]

Environmental Impact

In terms of sustainability, large and dense urban areas are more cleaner and energy efficient, when compared to rural areas. Urban density significantly differs from those in rural areas, what allows to design better infrastructures, manage more effectively different public services and resources, while reducing the urban footprint. Urban living encourages walking and cycling, taking public transport and it makes key places as supermarkets, work or schools, more accessible due to a shorter distance.

Dense urban areas imply bigger resource consumption, and their emissions and impacts are bigger too. As a result, cities have become the principal venue for attempting to archive the goals and targets of sustainable development. However, if not controlled adequately, uncontrolled urbanization may lead to different environmental issues such as air and water pollution, waste-disposal problems and environmental degradation, being all of them very common in developing countries.

43 *Larry S. Bourne. Urbanization - The Social Impacts of Urbanization.*

Fig.21 Population inequality is one of the effects of urbanization. Cape Town, South Africa. Photo by Johnny Miller

Socio-Economic Impact

Urbanization and economic growth are inevitably linked, and its impacts can be both, positive and negative. Cities have always been a strong attraction for the people of surrounding rural areas, as their size and density confer them considerable economic advantages. These denser and larger areas are seed-beds of innovation, technological advances, productivity improvement and prosperity. This usually is translated in better job opportunities, improved services and infrastructures, what makes citizens aspire and pursue a better-quality life.

However, governments are often unable to meet the increasing population of the cities and their needs, which usually are defined as negative effects of living in cities, or their disadvantages. The most common problems here are their high costs of living, expensive food and services but also economic inequalities (see Fig.21). Additionally, when compared to the life in the rural area, a living space in these areas is reduced, the traffic is noisy and generally people in big cities are more stressed, living a hectic life.

However, it is now widely established that urbanization is both a social and an economic process. It transforms social organizations, the role of the family, the demographic structures, the nature of work, and the way we choose to live and with whom. Furthermore, it changes the roles and domestic relationships within the family, and redefines the concepts of individual and social responsibility. The challenge facing the world today is to minimize the negative effects of this process, while creating new benefits for society living in these areas.

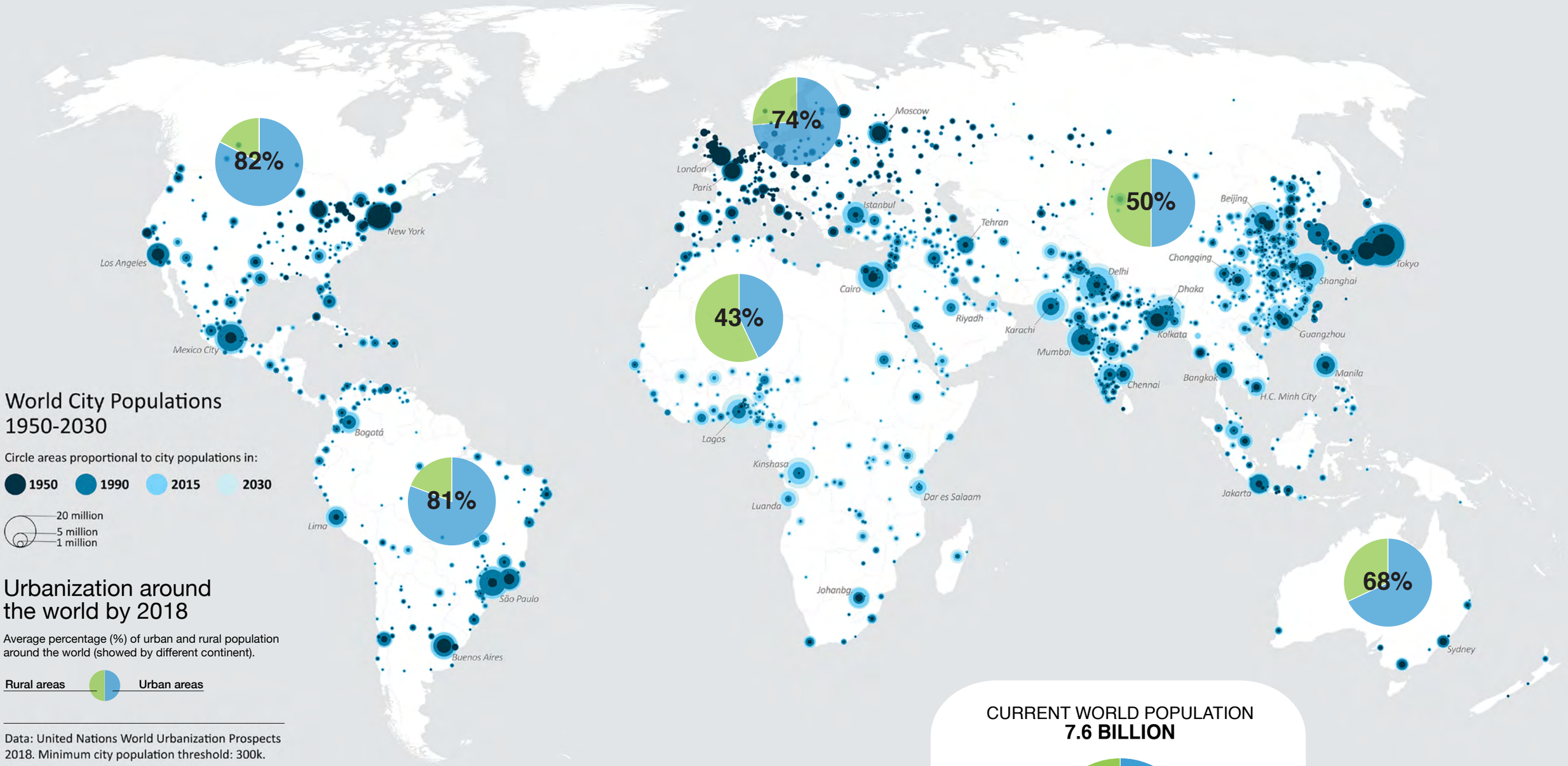
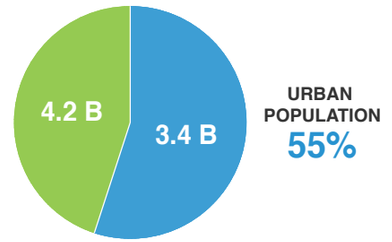
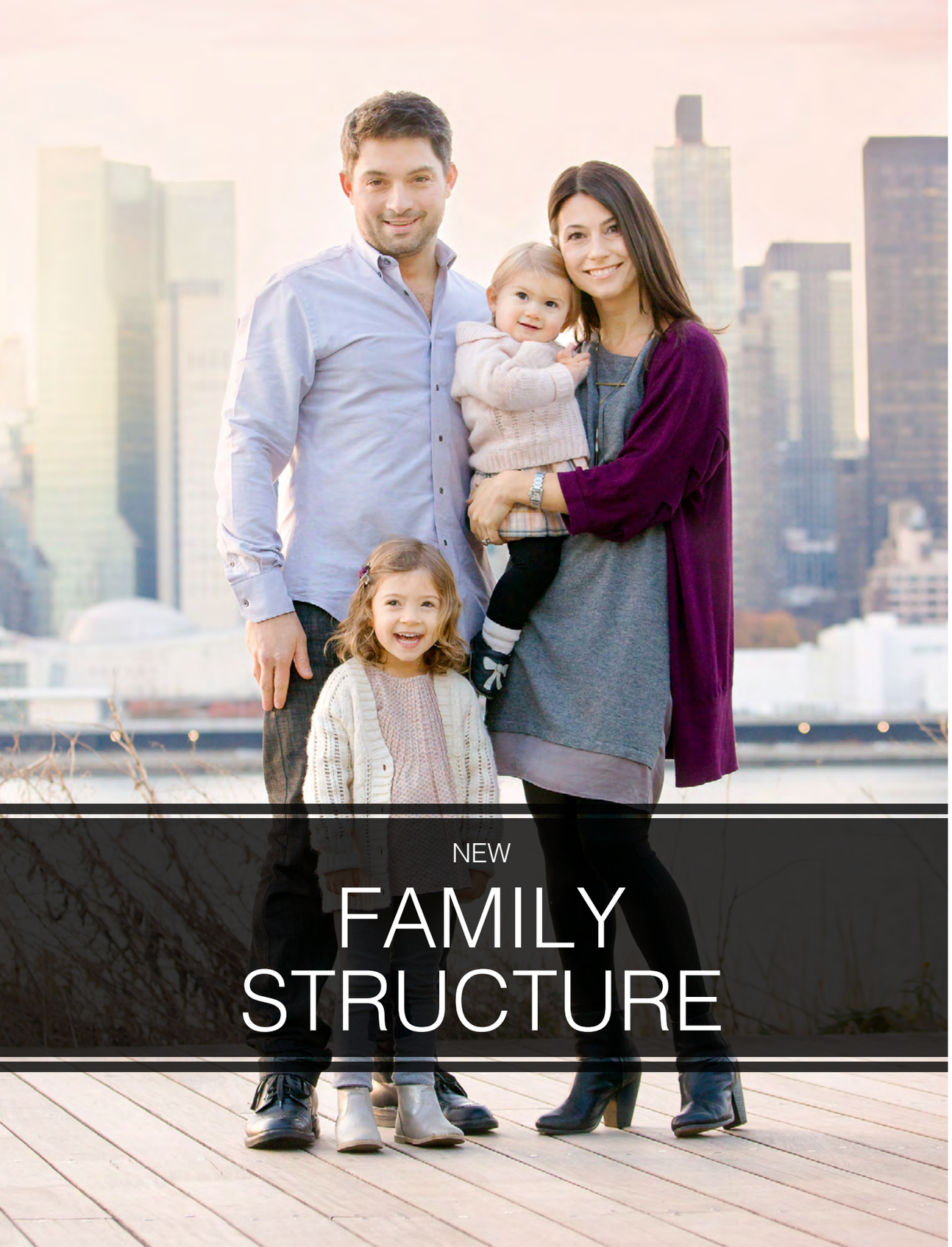


Fig.22 United Nations World Urbanization Prospects 2018. Mixed data: Urbanization around the world by 2018 and Estimated and projected populations in cities, 1950–2030.

CURRENT WORLD POPULATION
7.6 BILLION





1.3.2 New Family Structure

In the last few decades, the development of urban society, notably in the Western countries, has created several changes in the family structure and also has increased the diversity of the household formation. Rising of non-traditional families, those without two parents and/or children, have become quite common in big cities. Furthermore, this evolution has also increased new forms of urban household living units, starting from marriage, traditional arrangement, or any other association of individuals within the housing system, whether they are related by marriage, blood, or are unrelated.

Urbanization has played a very important role in all these changes, since it has also allowed to create a great change in employment and working life. This led to the fact that, over the last half century the proportion of labor population has increased, especially among women. Historically, in pre-urban societies, they used to perform “domestic” and unpaid work, but through the process of urbanization much of that work became marginalized. As a result, this entailed women involvement in the formal and paid labor market, shifting their role and economic position within the family. All these changes have modified domestic roles and relations within the family, and redefined concepts of individual and social responsibility.

Family structure has changed over the past decades. There is an increasing number of singles, couples without children and single-parent families, while large families have been shrinking (Fig.23). One of the factors that have influenced these changes has been the persistently low fertility rates mainly in big cities. On the other hand, lower marriage rates and

Fig.23 Households with children in the EU. Data by Eurostat. 2017

higher divorce rates, has led to the increasing number of children growing up in single-parent or reconstituted families, meanwhile, there is also an increasing number of families without children.

In 2017, the average household size in the EU-28 was 2.3 members.[44] Looking at the number of persons by household, almost two thirds of all households in the EU-28 were composed of one or two persons. Over the last decade, the relative importance of the larger households fell, reaching less than a third part of the total distribution (Fig.25). For various reasons and by a set of different factors, the reduced size of the family becomes a tendency in big cities.

The most common household type in the EU-28 in 2017 was a single person living alone (33.6%). Among households with more than one adult, the most common household type consisted of 'couple without children', accounting for 24.9%. And the next most common household type was composed of 'couple with children', accounting for 20.0% of all private households. The choice to live with classmates or workmates is also widespread, especially among people aged 18-30. And the proportion of men which stay alone is almost double that of women, in this case. However, there are more women than men that decide to stay with their parents or grandparents.

In recent decades, the number of commuters has also increased. Most of these people do it for work reasons, although the number of cases of people moving for study reasons has increased. Often, the main problem is that there is much more job offers in large cities, however the high price of housing in these areas pushes people to seek accommodation on the outskirts of the city or even in nearby cities. In the end, all these changes in family structure together with many other factors have certainly changed family lifestyles and consumption patterns.

44 *Eurostat. 2017. Household composition statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics*

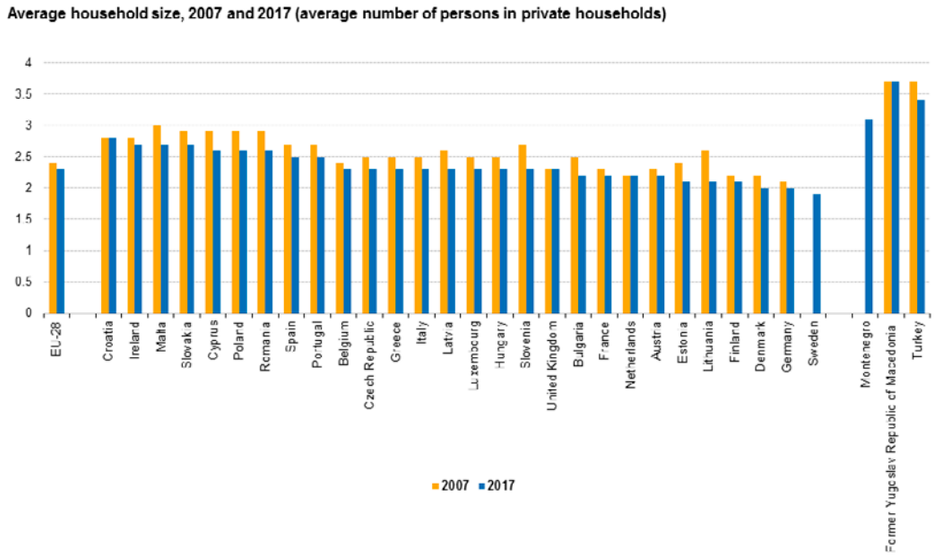


Fig.24 Average household size in Europe (EU-28), between 2007 and 2017. Data by Eurostat.

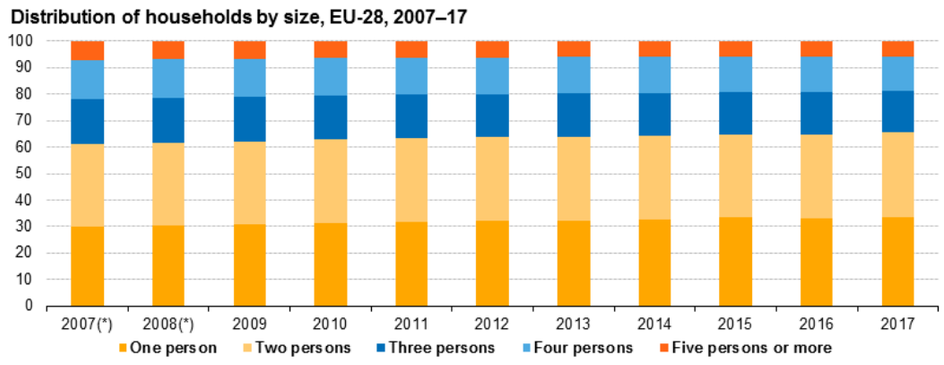
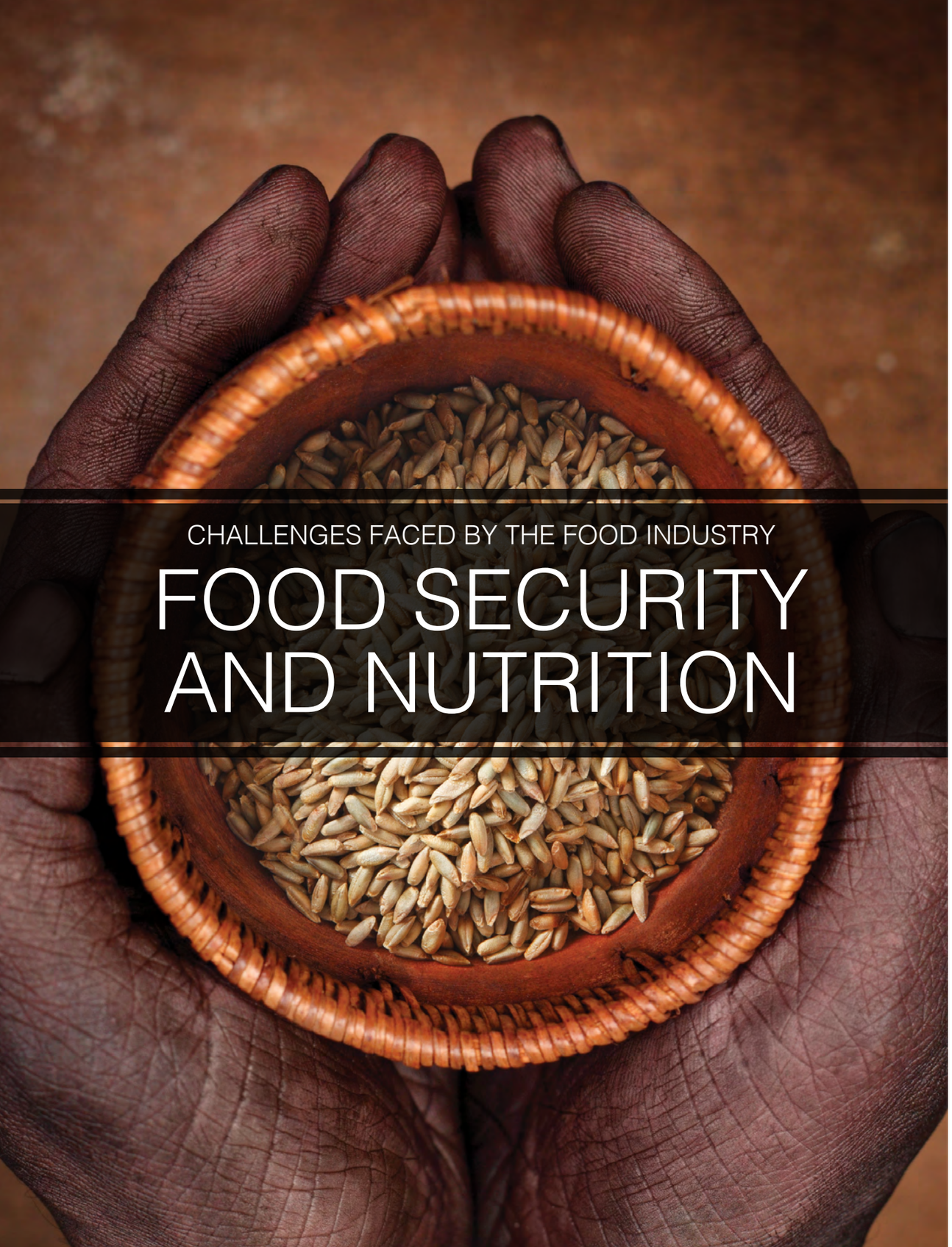


Fig.25 Distribution of household in Europe (EU-28) by size, between 2007 and 2017. Data by Eurostat.



CHALLENGES FACED BY THE FOOD INDUSTRY

FOOD SECURITY AND NUTRITION

1.4 CHALLENGES FACED BY THE FOOD INDUSTRY

1.4.1 Food Security and Nutrition

Food security is a condition related to the supply of food and also an access to it, and it is one of the main battles of the modern world.[45] Food security is the "availability at all times of adequate, nourishing, diverse, balanced and moderate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices" (FAO, 1996). Among the main pillars to guarantee food security, are:

- Availability, sufficient quantities of food available on a consistent basis;
- Access, physical and economical access to appropriate food for a nutritious diet;
- Use, appropriate use based on appropriate means and knowledge of basic nutrition and care;
- Stability, access and utilization.

Food security is a complex sustainable development issue, linked to health through malnutrition, but also to economic and environmental development. It has a significant consequences for individuals as well for society, including malnutrition, obesity, disease, child wasting, stunting, micronutrients deficiencies and poverty (Fig.26).

Currently, there are many problems related to food, and the problem of food insecurity affects both developed and developing countries. And while in the more developed countries the inhabitants die of overweight and obesity, in the developing countries there is still a high percentage of people that live in hunger or fear of starvation. The hunger in the world is on the rise. The number of people that did not get

45 *The state of food security and nutrition in the world, 2018. Food and Agriculture Organization of the United Nations. (http://www.fao.org/state-of-food-security-nutrition/en/)*

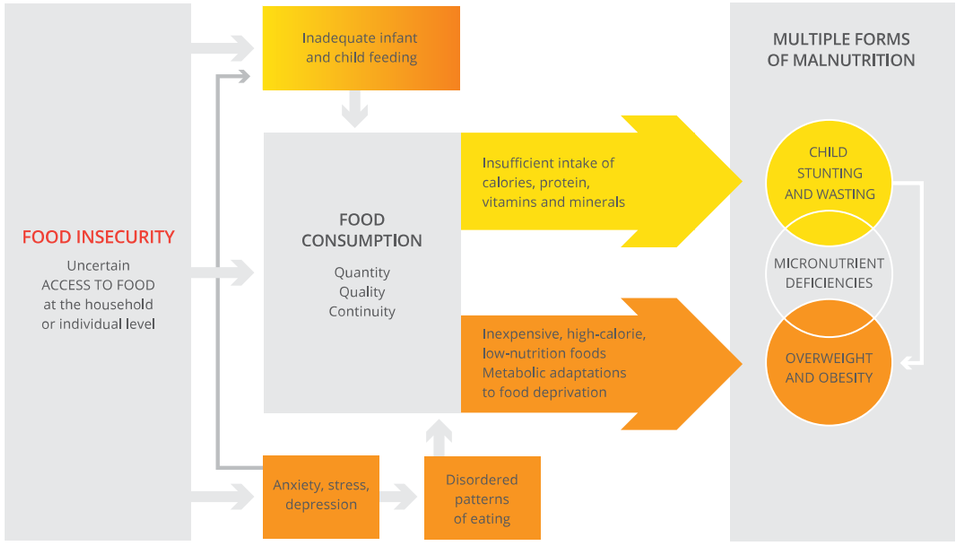


Fig.26 Pathways from inadequate food access to multiple forms of malnutrition. Source: FAO. 2018

enough food to eat in 2017, has increased to 821 million around the world. Statistics show that the highest rates of cases of chronically undernourished people occur in developing countries, where 15% of the population suffers its effects. Large regions of countries of South America and most regions of Africa are the mainly affected areas that suffer these effects.[46] The most common risk factors that influence this situation, include shipping disruptions, fuel shortages, economic instability and wars. However, some of the most devastating effects of food insecurity in the last decade are the extreme climate-related disasters such as extreme temperature, droughts, floods and storms (see also Fig.27).

Evidence shows that the recent increase in hunger is associated with extreme climate events, especially where there is a high exposure to extreme climate effects and high vulnerability related to agriculture and livelihood systems. The main issue is that they are negatively impacting livelihoods and all dimensions of food security (availability, access, utilization and stability), as well as contributing to the other causes of malnutrition related to child care and feeding. The risk of food insecurity is greater nowadays because livelihoods and livelihood assets, especially of the poor, are more vulnerable and exposed to extreme climate conditions.[47]

46 *FAO: Hunger increases in Latin America. (http://www.fao.org/americas/noticias/ver/en/c/1152157/)*

47 *Food security and lifehood. Identification of people most at risk of food insecurity. (https://www.paho.org/disasters/index.php?option=com_docman&view=download&alias=536-pandinflu-leadershipduring-tool-9&category_slug=tools&Itemid=1179&lang=en)*

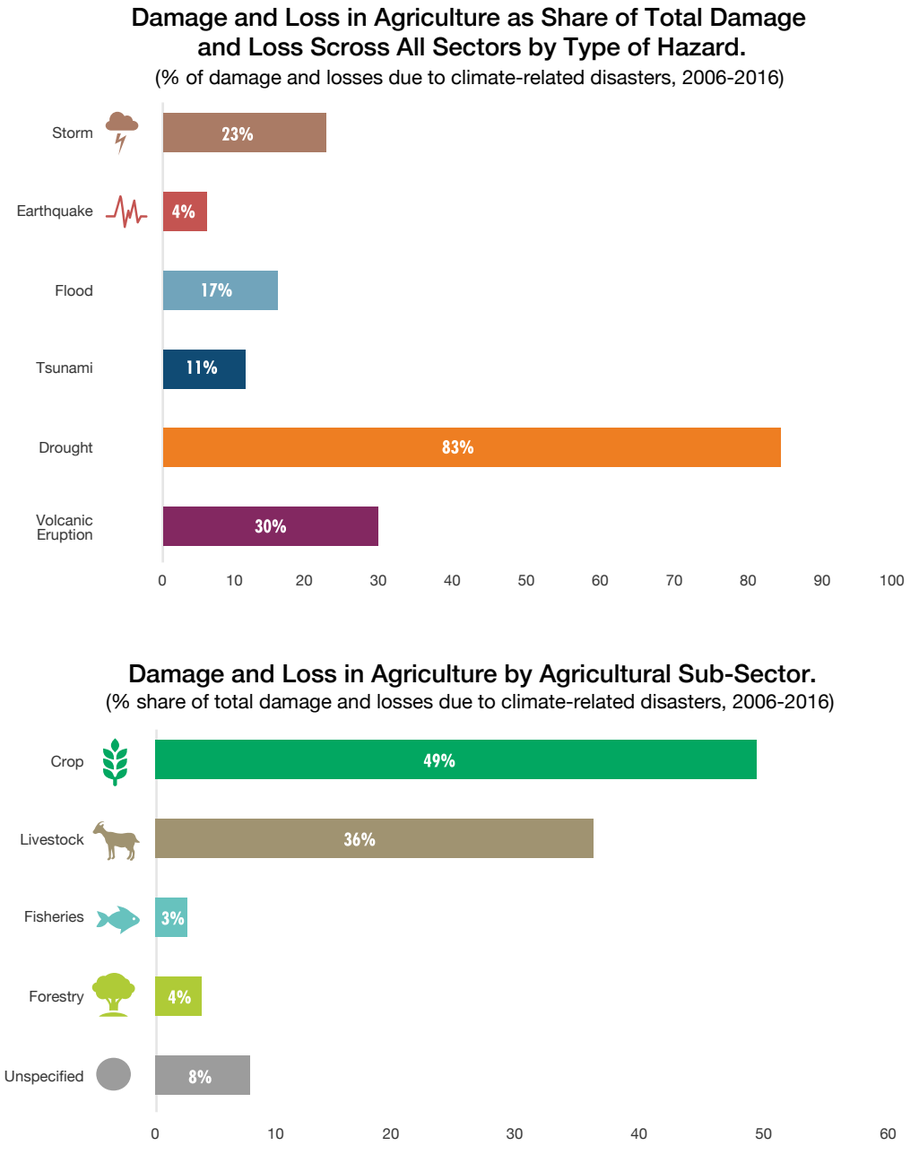


Fig.27 Damages and losses in agriculture due to climate-related disasters. Source: FAO. 2018

1.4.2 Feeding the World in the Future

Upcoming Food-Related Threats

The current world population is growing at a huge rate, and as it has been already mentioned before, we are currently 7,7 billion people in the world.[48] According to the United Nations projections, world population will reach 9,8 billion in the year 2050. However, there is a steady decline in the population growth rate, and, as a result, world population will account 11.2 billion by year 2100.

Some analysts have questioned the sustainability of the continuous growth of the world population, highlighting the growing pressures on the environment, global food supplies and energy resources. As a result, solutions for feeding the extra billions in the future are being studied and documented by different organization around the world.[49,50]

Often, food is something that a priori does not seem to pose a big problem for the environment, or be an evident threat to our planet. However, when this issue is carefully examined, it becomes clear that food production has so large impact on the environmental, that its pollution exceeds that of all cars, trucks, trains,

48 *The current world population data obtained from (http://www.worldometers.info/watch/world-population/)*

49 *How do we feed the planet in 2050? The Guardian. (https://www.theguardian.com/preparing-for-9-billion/2017/sep/13/population-feed-planet-2050-cold-chain-environment)*

50 *Where will we find enough food for 9 billion people? National Geographic. (https://www.nationalgeographic.com/foodfeatures/feeding-9-billion/)*

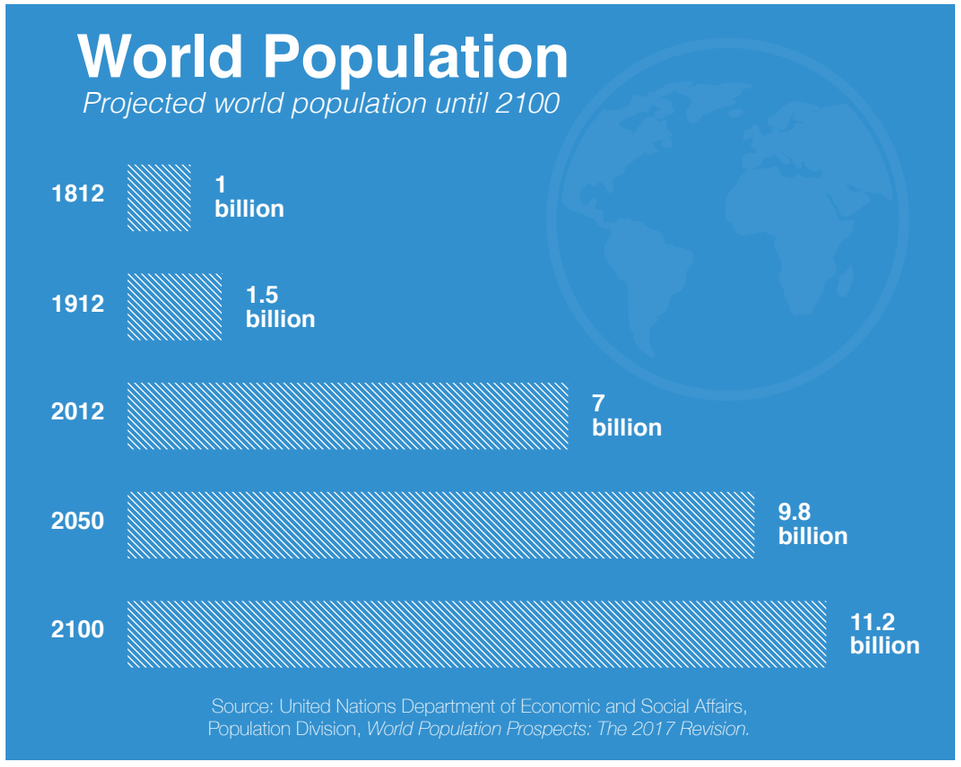


Fig.28 World population projections from 1812 to 2100. Source: United Nations, World Population Prospects 2017.

ships and airplanes together. Food production, both agriculture growing and livestock raising, releases large amounts of gases into the atmosphere that generate a large impact on global warming. Food production also requires large quantities of drinking water, which in fact greatly exceeds the amount of water consumed by people. The use of fertilizers and pesticides pollutes water and land, and as a result this reduces the reserves of drinking water even more. Agriculture and livestock are responsible for reducing biodiversity on the planet, as large areas of land are usually destroyed for crops cultivation and farms, being also the main factor of the wildlife extinction.

Our population grows at a very fast pace and in about 30 years we will have to feed 2 million more people, which will be a great challenge for our society. While producing so much food means that the impact on the environment will be even greater, another great challenge is being able to increase the current food production to supply nearly 10 billion people with enough food by the year 2050.

If that was not enough, one of the important dilemmas of food production is to decide which production methods and consumption patterns we should follow in the future, since despite being omnivores, our society is beginning to get into a dead end. The cultivation of the crops today serves to provide food both to human beings and to feed livestock, which will eventually be consumed as meat. However, meat production is not efficient, since it requires too much grain and water to produce meat. Instead, it would be much more profitable to use that grain to feed people directly. If the consumption demand of meat, eggs and dairy products continues to grow in the future, it would be practically impossible to satisfy that demand, since this would require doubling the production of the crops by 2050, with respect to the amount that is already produced today.

Different theories are trying to improve current productive methods and solve these problems in the future. A certain part of society supports the idea of the use of modern mechanization, fertilizers and technologies to improve production methods through genetic modification. However, many advocate the use of conventional methods, based on organic agriculture which will avoid at all costs the use of fertilizers and pesticides. Both cases could be valid, meanwhile we must ask ourselves the following question: How can the world double the food production while reducing the environmental impact of its production?

Measures to Meet the Objectives

To achieve the proposed objectives, there is a set of solutions and initiatives that we should take into account.

First, we should *freeze agriculture's footprint*, since global deforestation, that aims to expand the areas for crop cultivation or livestock production, does not really solve the problem Agriculture already covers 38.6% of land that is free of ice, and if we continue to increase that area, we will only create far greater problems than the already existing ones.

Second, we should *focus on producing more food* on the land that is already destined for that purpose, while reducing the use of fertilizers that are causing so much damage to our ecosystem. Many studies show that the use of new technologies, precision systems, and organic farming methods could increase the production of food in these places several times.

Third, we must *use resources more efficiently* and reduce the use of fertilizers and pesticides. Advances in organic and conventional cultivation could provide better results in food production, reduce the use of water and chemicals, and improve the quality of soil, among others.

Fourth, we should *change our diets*, since there is no way to sustainably raise enough animals to feed the world's current demand on meat. Today, only 55% of all the crops produced worldwide end up feeding people directly. The remaining 45% are used mainly to feed livestock (about 36%), and for other purposes, including producing biofuels and other

Deforestation Must Be a Top Priority

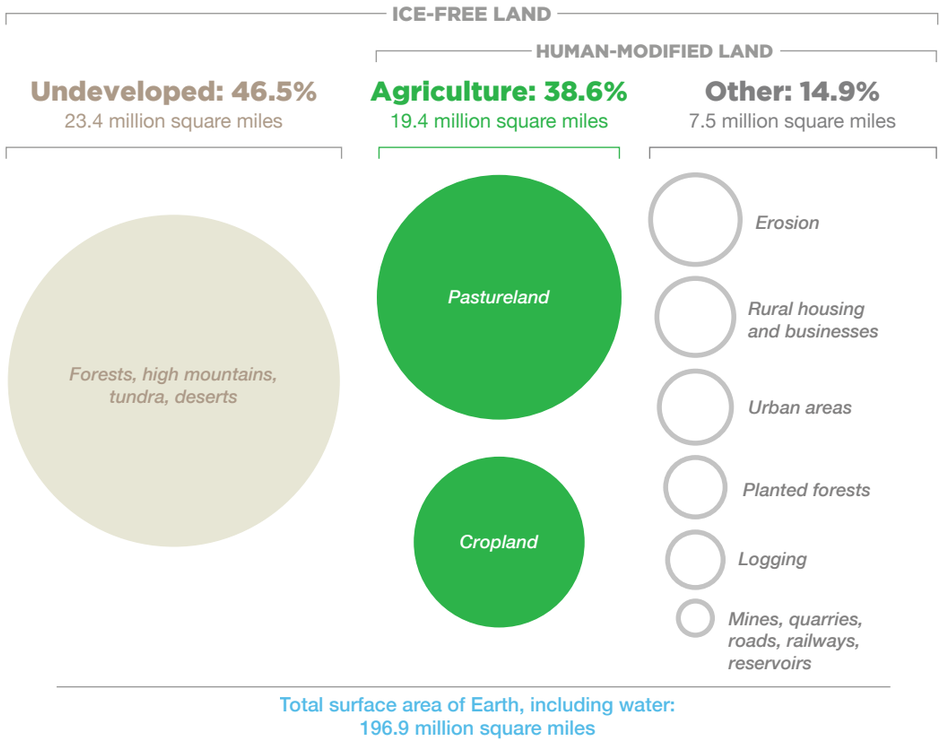


Fig.29 The use of land around the world and why we should stop deforestation. Source: National Geographic.

industrial products. The production of products derived from animals such as meat, dairy and eggs is inefficient, mainly because most of these calories are lost. For every 100 calories of grain we feed animals, we get only about 40 new calories of milk, 22 calories of eggs, 12 of chicken, 10 of pork, or 3 of beef. If we do not reduce our consumption of meat in the coming decades, we would be forced to double the production of the crops by 2050. This makes the task of providing food for future generations a really difficult challenge to achieve. The most obvious solution is by finding more efficient ways to grow meat and shifting to less meat-intensive diets, or at least switch from grain-fed beef to meats like chicken, pork, or pasture-raised beef. However, people in developing countries are unlikely to eat less meat in the near future, given their newfound prosperity. As a result, we should focus on implementing

A World Demanding More

By 2050 the world's population will likely increase by more than 35 percent.

To feed that population, crop production will need to double.

Why? Production will have to far outpace population growth as the developing world grows prosperous enough to eat more meat.

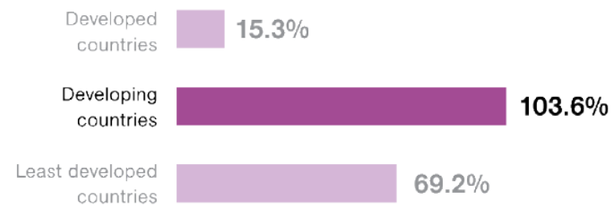


Fig.30 A world demand on food by different countries. Source: National Geographic.

these measures mainly in developed countries, by reducing meat consumption and shifting to crop consumption. In this context, the consumption of fruit and vegetables would suppose a prevalent part of the diet, being this one of the main reasons of my research.

Fifth, and which is another main reason of my research, we should *reduce food waste*. One third of all food produced worldwide is lost or wasted before it can be consumed. In the most developed countries, most of that waste occurs in homes, restaurants, or supermarkets. In less developed countries, food is often lost between the farmer and the market, mostly due to storage and transportation problems. Reduce food waste is a very important measure that would provide more food to the world population, and reduce the impact on the environment it produces.

THE CURRENT SITUATION OF

FOOD WASTE

1.4.3 The Current Situation of Food Waste

Defining Food Loss and Food Waste

One-third of food produced for human consumption is lost or wasted globally, which according to the Food and Agriculture Organization of the United Nations, is about 1.3 billion tonnes a year. Food losses represent a waste of resources used in production such as land, water, energy and inputs. Producing food that will not be consumed leads to unnecessary CO_2 emissions in addition to loss of economic value of the food produced. Food can be lost or wasted throughout different stages of the food supply chain, from initial agricultural production all the way to final household consumption (Fig.31). At this point, let's see what are the differences between food loss and food waste.

Food loss normally refers to any food that is lost at any phase of the supply chain (FSC) between the producer and the market. These losses can occur both during the pre-harvest operation, and during harvesting, handling, storage, packing or transportation processes. Some of the underlying causes of food loss include the inadequacy of infrastructure, markets or even the lack of legal frameworks. *Food waste*, on the other hand, refers to the discarding or alternative (non-food) use of food that is safe and nutritious for human consumption.

Fig.31 A simplified view of the Food Supply Chain

What Food Are Normally Wasted?
Since 1974, food waste in the world has increased by 50%, what means that today we throw away much more food than few decades ago. According to data provided by FAO in 2015, the amounts of food loss and food waste around the world depends on many factors, including food type, location (country) and on the stage of the Food Supply Chain in which it is found (see Fig. 32).

Every day, huge amounts of food are thrown around the world, and the reasons are several. What is clear is that the most affected type of food are usually "perishable food", those that require specific preservation conditions, since they are collected until they are consumed. Therefore, the most wasted food products throughout the entire food supply chain are fruit and vegetables along with roots and tubers. Their global food losses and waste per year are about 45%, while for cereals and fish is 30%, and only 20% for oilseeds, meat and dairy products (see again Fig.32 for more detailed information).

Where These Food Are Generally Wasted?
Food loss and food waste occurs in different stages of the food supply chain, which is composed by all those processes that bring a food product "from the field to the consumer's table". The causes of food loss and food waste in different stages of the FSC can be both controllable and not controllable by man.[51]

Agricultural production is the first stage of the food supply chain and it involves sowing, cultivation and harvesting the agricultural production. Here some of the causes of food waste can be produced by meteorological reasons or pest infestations, that will not always be controllable by man. Instead, what man could avoid are losses produced due to mechanical damage and/or spillage during harvest operation (e.g. grain threshing or fruit picking).

Post-harvest handling and storage is the second stage, which can include losses due to spillage and degradation during handling, storage and transportation between farm and distribution.

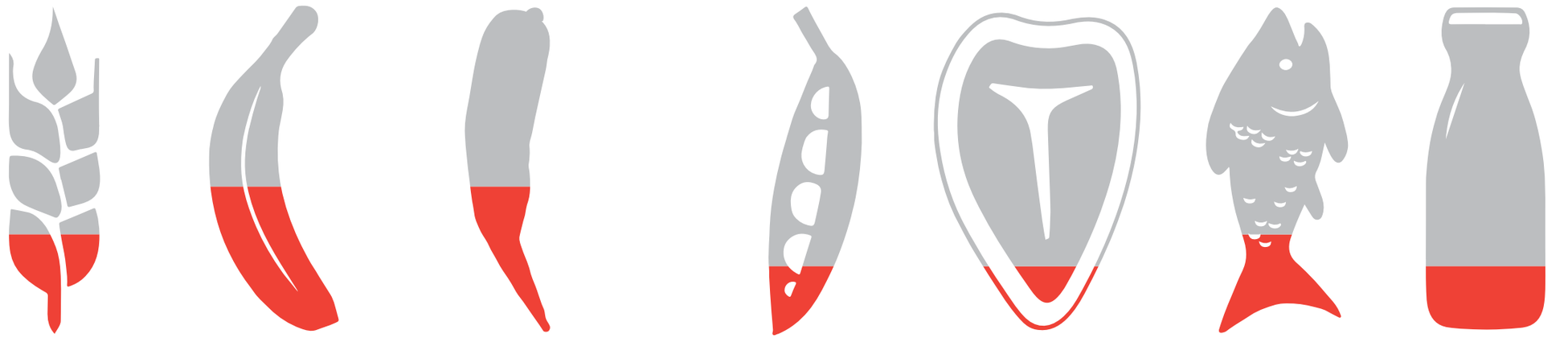
Processing is the third stage, and it can usually include losses due to spillage and degradation during industrial or domestic processing (e.g. juice production, canning and bread baking). Losses may occur during washing, peeling, slicing and boiling or during process or temperature interruptions.

Distribution is the fourth stage. Often, causes like limits in distribution systems, problems in order forecasting and inventory management, deterioration of products and packaging. On the other hand, marketing and sales standards that normally refer to aesthetic and shape of the food products, also may have an impact on food waste.

Consumption is the last (fifth) stage, related mainly to the consumption at household level. Here the main causes of food waste are due to incorrect management of personal purchases. In fact, most of the food thrown away as a result of the excessive amounts of food prepared, lack of attention to expiry dates, and incorrect food storage.

51 *Lo spreco alimentare: cause, impatti e proposte. Barilla Center. 2012. (https://www.barillacfn.com/m/publications/spreco-alimentare-cause-impatti-proposte.pdf)*

Food Loss and Food Waste by Different Food Type, Region, and FSC Stages.



30% CEREALS

45% FRUITS & VEGETABLES

45% ROOTS & TUBERS

20% OILSEEDS & PULSES

20% MEAT

30% FISH & SEAFOOD

20% DAIRY

FOOD LOSSES

In industiralized countries, consumers throw away 286 million tonnes of cereal products.

763 billion boxes of pasta

FOOD LOSSES

Fruits and vegetables have the highest wastage rates: almost half of all their production is wasted.

3.7 trillion apples.

FOOD LOSSES

In North America & Oceania alone, 5.814.000 tonnes of roots & tubers are wasted at the consumption stage alone.

This equates to just over 1 billion bags of potatoes.

FOOD LOSSES

Every year, 22% of the global production of oilseeds and pulses is lost or wasted.

This is the same as the olive oil needed to fill 11.000 Olympic swimming pools.

FOOD LOSSES

Of the 263 million tonnes of meat produced globally, over 20% is lost or wasted.

This is equivalent to 75 million cows.

FOOD LOSSES

8% of fish caught globally is thrown back into the sea. In most cases they are dead, dying or badly damaged.

This is equal to almost 3 billion Atlantic salmons.

FOOD LOSSES

In Europe alone, 29 million tonnes of dairy products are lost or wasted every year.

This is the same as 574 billion eggs.

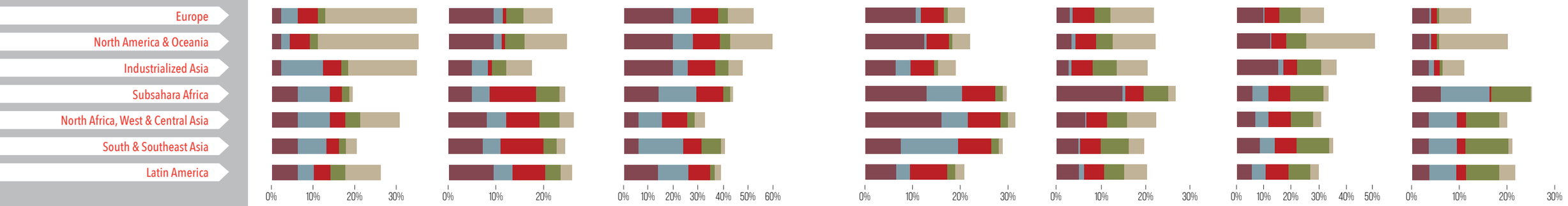


Fig.32 Food loss and waste around the world by food type, region and different FSC stages. Source: FAO, 2015.

The food resources being lost and wasted in Europe would be enough to feed all the hungry people in the world two times over (European Commission 2015).

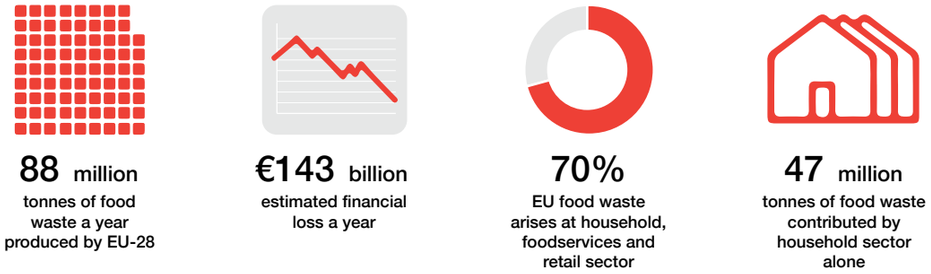


Fig.33 Data about the situation of food waste in Europe. Source: European Commission, 2015.

Food Waste Situation In Europe

The situation of food waste is overwhelming, and it affects every country in the world. Across the globe, nearly 30% of food is wasted throughout the food supply chain. However, according to the latest data provided by European Commission in 2015, 70% of the EU food waste arises in household, food service and retail sectors (Fig.33).

The amount of food that is wasted per person per year is very high, and according to the data provided by Barilla Center for Food & Nutrition Foundation, the general situation of waste per capita (kg / year) in the most relevant European countries looks like this:[52]

- 579 kg/year in Netherlands;
- 238 kg/year in Great Britain;
- 176 kg/year in Spain;
- 149 kg/year in Italy.
- 144 kg/year in France;
- 44 kg/year in Greece.

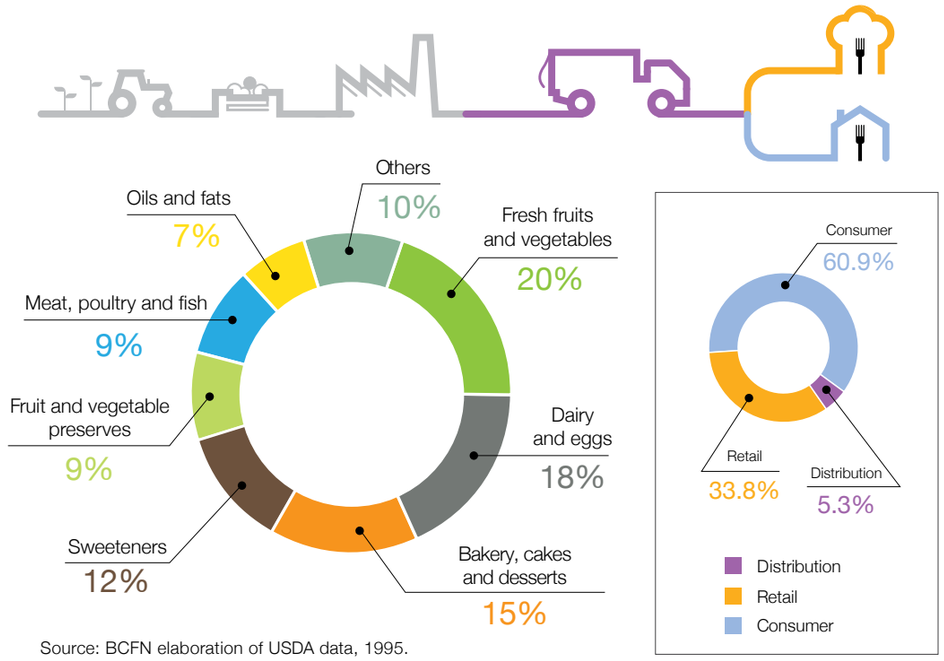
Food loss and waste in industrialized countries are as high as in developing countries, but their distribution is different. In developing countries, over 40% of food losses happen after harvest and during processing. Much of post-harvest products are lost here due to lack of adequate storage facilities, good roads, and refrigeration. However, in industrialized countries, over 40% occurs at retail and consumer level. This usually happens when retailers order, serve, or display too much food products and when consumers ignore leftovers in the back of the refrigerator or toss perishables before they've expired.

Today, saving trashed food has become a matter of international urgency. In Europe, many countries have adopted measures and some of them have even created laws that prohibit throwing away food that is still edible, in order to reduce the amount of food loss and food waste that we generate.[53]

52 *Food Waste: causes, impacts and proposals. 2012 (http://residus.gencat.cat/web/.content/home/ambits_dactuacio/prevencio/malbaratament_alimentari/experiencies/barilla_food_waste.pdf)*

53 *How is food waste regulated in Europe? (https://www.euronews.com/2019/02/06/how-is-food-waste-regulated-in-europe)*

Origin and Composition of Food Waste in the United States during the Distribution and Final Consumption Stages



Source: BCFN elaboration of USDA data, 1995.

Fig.34 Data about the origin of food waste and its composition during distribution, retail and consumption in the US.

Household Food Waste

Generally, waste of households in developing countries is more contained. In fact, 'low-income' families make more unacceptable to waste food. However, the situation in developed countries is different, as they waste considerable amounts of food during distribution, and in restaurants, food services, and homes. Let's then analyze this situation in different developed countries around the world.

According to the data provided by USDA, in the United States waste happens mostly at homes and in restaurants or food services (and this situation is similar in most of the Western World countries). In fact, during the distribution are wasted 2.5 million tonnes of food (equivalent to 2% of the overall supply), however, approximately 41.3 million tonnes are wasted by consumers in their own homes or in restaurants (corresponding to 26% of food available for human consumption every year). The most wasted product remain fruits and vegetables, milk, grains, and meat. Another study shows that the total waste in the United States amounts to 55.4 million tonnes, 60.9% of which is due to household waste (Fig.34).

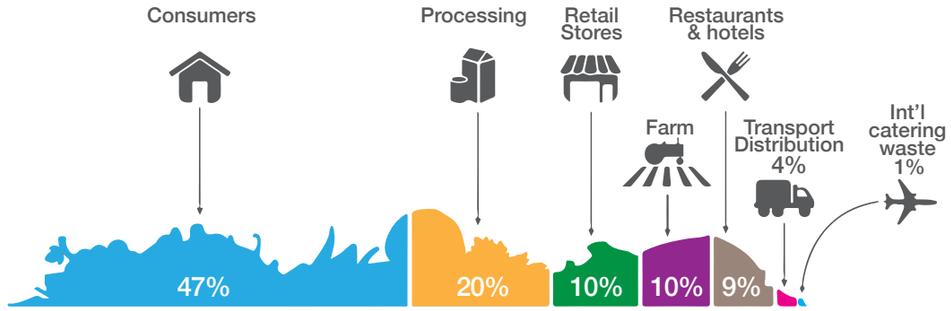


Fig.35 The cost of Canada's annual food waste. 2014

On the other hand, Canada spent around $27 billion on food waste in 2014. The biggest waste was produced at consumer level, accounting around 47%, meanwhile retail stores produced much less impact, which made up 10% of the total food waste.[54] This report also shows that among the most wasted products at home are fruit, vegetables, roots and tubers (Fig.35).

According to data provided by WRAP, British families wasted one-third of food purchased, the equivalent to 7.2 million tonnes of food in 2010.[55] More than half of this waste (4.4 million tonnes) was made up of food and drinks that are still edible, referred often as "avoidable food waste". The major part of food bought and thrown away without being consumed, are in particular salad and fresh vegetables, which makes up 23% of the total household waste (Fig.36).

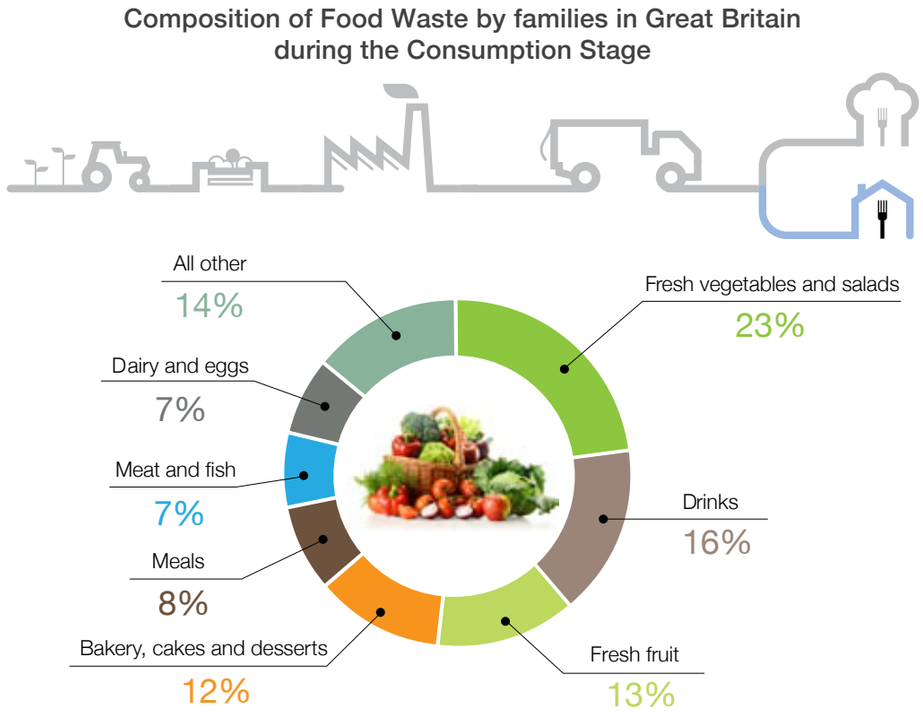
In France, every year a French citizen wastes, on average, the equivalent of 20kg of food products, of which 7kg are still in their original packaging and 13kg are attributed to meal leftovers, such as damaged fruits and vegetables. From about 9 million tonnes of the total amount of food waste produced every year, over 6 million tonnes are attributed to the consuming stage, 2 million tonnes to restaurants and food services, and only 626.000 tonnes to the industry.[56]

In Italy, according to data provided by survey conducted in 2011, Italians consumers thrown away about 43% of fresh produce consisting of dairy products, eggs and meat, followed by 22% of bakery products, 19% of fruits and vegetables, 10% of cold cut meats and about 4% of pasta. However, some data showed that because of economic crisis, Italians have reduced food waste by 57%. To combat waste and save food many respondents commented they started to shop more wisely (47%), reduce the quantity of food purchased (31%), increase use of leftover products in meals (24%), and pay more attention to expiration dates (18%).

54 *A Food Loss and Waste Strategy for Canada (http://www.nzwc.ca/focus/food/national-food-waste-strategy/Documents/NZWC-FoodLossWasteStrategy.pdf)*

55 *WRAP (2011), New estimates for household food and drink waste in the UK, November.*

56 *Eurostat, 2010 (2006 data).*



Source: WRAP, 2009

Fig.36 Food and drink waste by families in Great Britain.

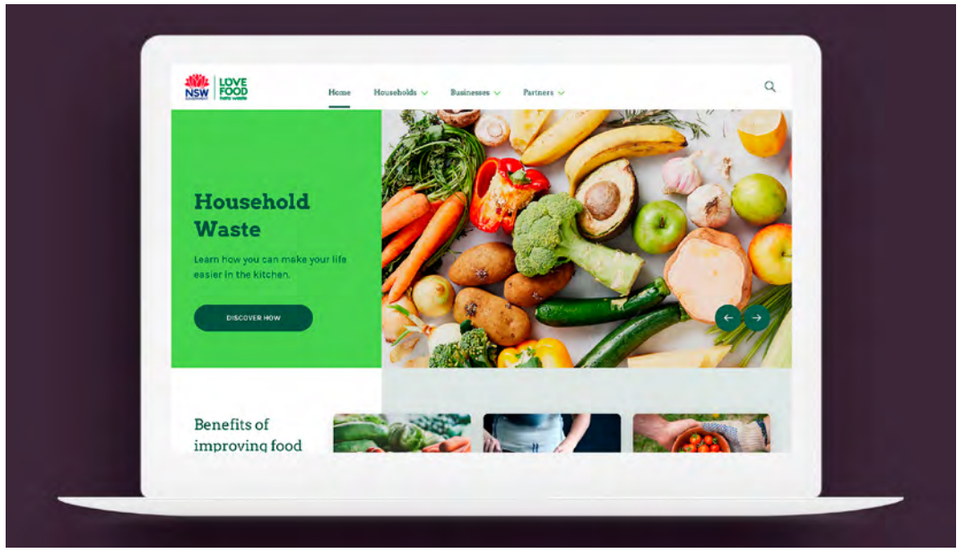


Fig.37 Love Food Hate Waste program shows NSW households and businesses how to avoid wasting food.

Main Causes of Wasting Food at Home

According to the recent research carried out in Great Britain (WRAP, 2018), the results showed the main 2 causes of avoidable household waste. On one hand, cooking, preparing, and serving too much food produces leftovers, which may also include damaged food during cooking (e.g. burned food). On the other hand, big amounts of food that are not consumed in time, which are actually thrown away because the expiration date, deterioration, or because they no longer seem to be edible.

Although, there are other causes that also have an impact on **household food waste**, such as:

- wrong interpretation of food label, as normally consumers do not understand the difference between "best before" (which relates to food quality) and "use by" (which refers to food safety). In this case, "best before" means that after the date it is provided on food label, its quality may be affected, but it is still perfectly edible. Actually, Great Britain, abolished "best before" warning on food labels in term to reduce the consumers' margin of error in interpreting them.
- incorrect purchase planning, leading to purchase excessive quantities of foods taking advantage of promotional offers;
- improper food storage and little attention to the instructions stated on the labels. Storage conditions vary depending on the climate and the temperature in the home.
- inadequate wrapping and use of materials which affect healthy preservation of food and reduce the consumption period (referred to leftovers);
- limited knowledge of food preparation methods to consume more efficiently and reduce waste (e.g., how to use leftovers from meals in another way or how to create dishes with available ingredients);
- short shelf-life of highly perishable food such as fresh fruit and vegetables;
- lack of awareness of the amount of waste one produces and its economic and environmental impact.
- relatively cheap price of fruits and vegetables may influence consumers to perceive them as 'cheap goods' what can lead them to throw fresh produce more easily.

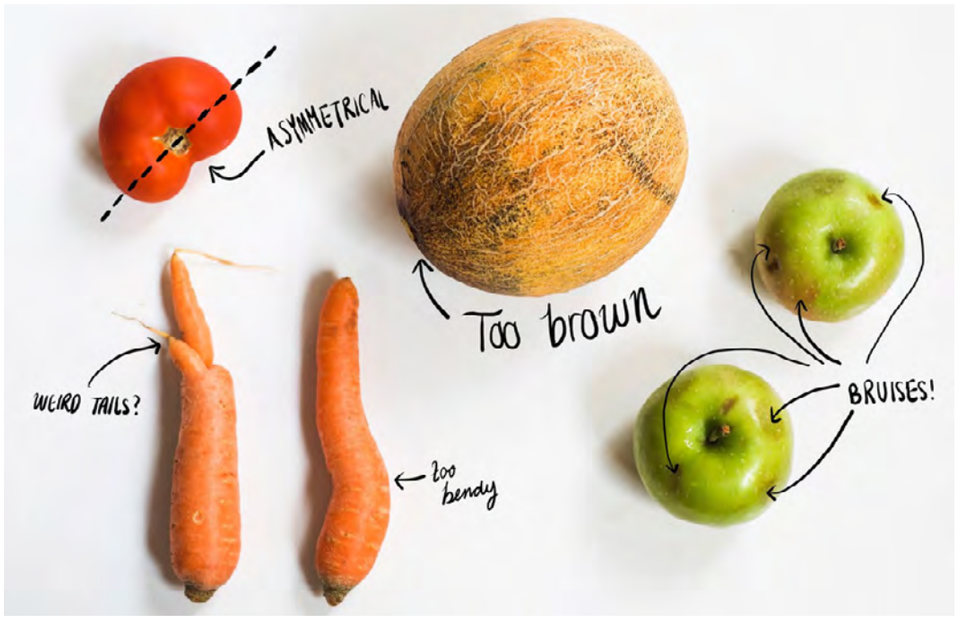


Fig.38 Some causes of current food waste such as bruised, asymmetrical, overly ripe fruit and vegetables.

Furthermore, there are several factors causing variability in the **amount of waste generated** at the household level:

- family size and composition (adults waste more than children, and larger families waste less per person compared to smaller families);[57]
- family income (as low-income families waste less food);[58]
- culture of origin (for example, in the United State, families of Hispanic origin waste 25% less than non-Hispanic families);[59]
- seasonal nature of products (more food is wasted in the summer than other seasons of the year, mostly due to high temperatures);[60]
- gender (women on average waste more than men).[59]

57 *Parfitt J., M. Barthel and S. Macnaughton (2010), Food waste within food supply chains: quantification and potential for change to 2050, The royal society.*

58 *Lyndhurst, B., Food Behaviour Consumer Research – Findings from the Quantitative Survey, in "Briefing Paper", WRAP, 2007.*

59 *Jones, T. W. (2006), Using Contemporary Archaeology and Applied Anthropology to Under- stand Food Loss in the American Food System, Bureau of Applied Research in Anthropology, University of Arizona.*

60 *Muth M. K., K. M. Kosa and S. A. Karns (2007), Explanatory research on estimation of consumer level food conversion factors, RTI International.*

Food Loss and Food Waste Impacts
As a result, such quantities of wasted food will produce strong environmental, economic and social impacts.

Regarding the *environmental impact*, food production will use huge amounts of water resources, energy consumption and fertilizers. Consequently, it will waste part of water resources and energy consumption, while increasing greenhouse gas emissions and soil degradation.

The *economic impact*, on the other hand, provides the sum of the costs of all those activities aimed at the production, processing and distribution of food. As a result, every kg of food wasted and thrown away must also be associated with significant waste of time and money for any company.

The *social and ethical impacts*, evidences the current situations of malnutrition and food access difficulties in some parts of the world, while in other parts, the quantities of food that is wasted continue increasing.

Targeting Fruit and Vegetables' Waste
Fruits and vegetables (as already mentioned on different occasions) are the most wasted food category. EU households waste approximately 35.3kg of fresh fruit and vegetables per person annually. According to the European Commission Joint Research Centre, 14.2kg of that waste is avoidable, what means that was once edible food before people threw it away. On the other hand, 21.1kg of that food belongs to unavoidable waste, arising from food preparation and also consisting of parts of the food that is not edible under normal circumstances.

To reduce the amount of fruits and vegetables that are lost or wasted, it would be possible if we could take action at each of the stages of the FSC, but this is not an easy task at all. However, the most realistic changes can mostly be done at a domestic level, where the vast majority of people will be able to take part. People hate wasting food. And at this point, the most obvious and effective changes that can be made worldwide, will require promoting a conscious consumption through assigning an appropriate value to the food we eat.

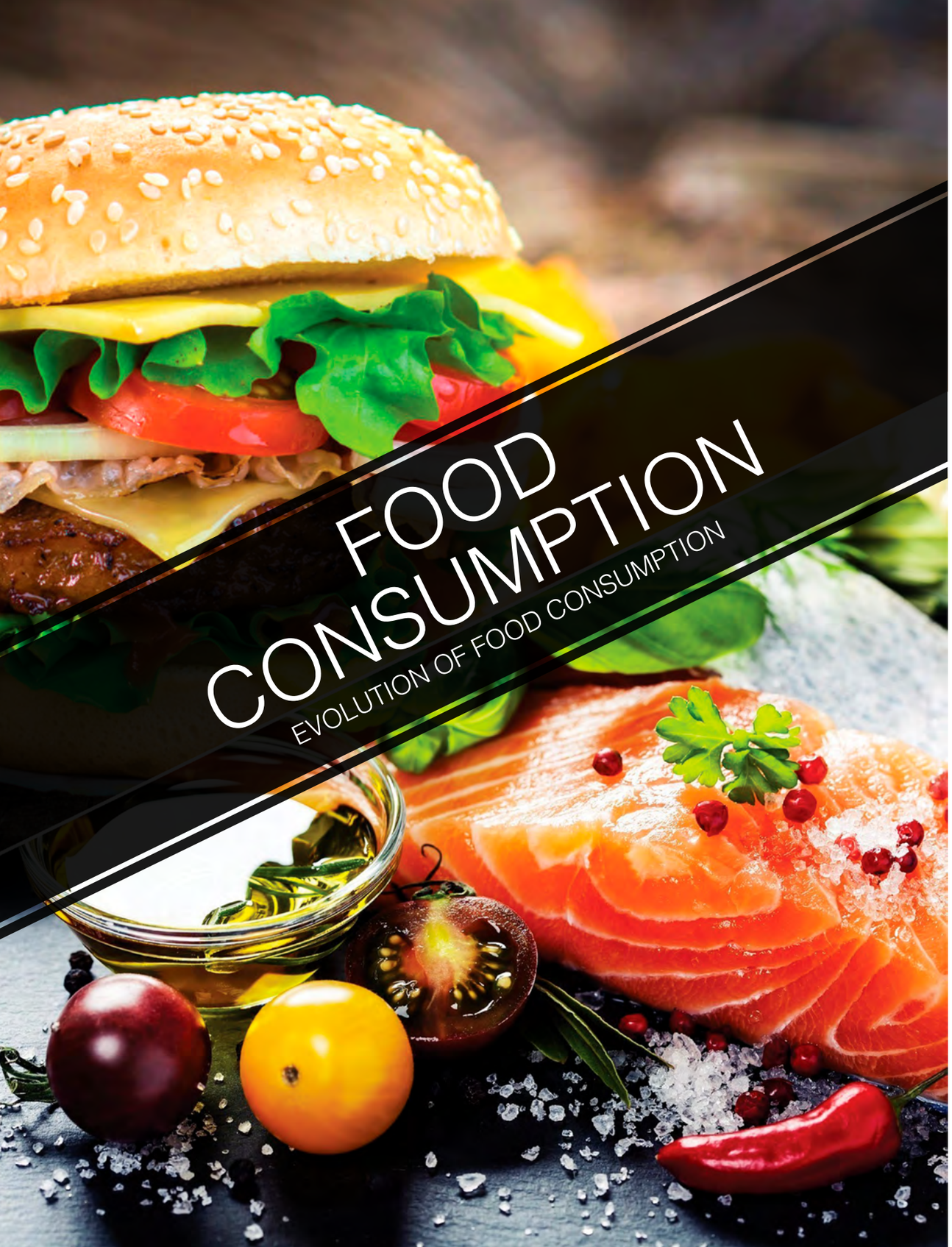
On the other hand, it is also important to educate consumers on preserving perishable food properly, since most of the time, they are not well informed about the most appropriate techniques for preserving fresh fruit and vegetables (meanwhile this data is only provided on food labels of all packaged products such as fresh meat and fish, or most part of processed food). Furthermore, we also should analyze if the conservation techniques at home level are the most appropriate and if they could be improved.

A very important fact to keep in mind is that from the data released by the United Nations in the How to Feed the World report in 2050, it is indicated that the world population will reach almost 10 billion inhabitants by 2050 and this will have to increase the production of food by 70%. Three-fifths of the supply required by 2050 could be guaranteed by the reduction of food waste through all stages of the food supply chain.[61]

61 *Contro lo spreco, sconfingere il paradosso del food waste. Barilla Center for Food and Nutrition. 2013. (pp.8-12). (https://www.barillacfn.com/m/publications/bcfn-magazine-controlospreco.pdf)*

CHAPTER 02

Food Consumption and Food Preservation



2.1 FOOD CONSUMPTION

2.1.1 Evolution of Food Consumption

Analyzing the history of our ancestors' diet, human survival depended on being omnivorous. They adopted a diet consisting of animals obtained from fishing and hunting, along with plant-based food. Also, gastroenterologists support this idea as the human intestine is designed to digest both animal and plant food.

Before the industrial revolution, people relied on chemical-free hand-farmed produce. Farmers were providing the society with high-quality meat, as the animals were fattened up healthily, and healthy fresh produce as most of the chemicals that we see today didn't exist. After the industrial revolution, food production and consumption have changed. It has evolved from agricultural-craft-commercial system to a modern industrial system, trying to improve the relationship between society, food, and wellbeing, thus increasing life expectancy. The industrial revolution focused on massive food production in an industrial way, improvement of conservation methods, as well, as sterilization and freezing processes. It has also influenced the development of transport, hence the consumption of exotic fruits (importing them from other countries) and off-season produce.

Since the twentieth century, changes began to occur in the food industry. With technological development, people moved to pursue more scientific methods for food production. Using food processing and wide range of food additives, food were padded with lots of sugars, fat, salt, flavorings, and colorings. This period decreased the role of home cooking and implied the appearance of the fast food industry (McDonald's, 1948). Natural farming procedures got shunned as people embraced the eating of processed food, which had

Fig.39 Double Burden Effect of Malnutrition. Global Alliance for Improved Nutrition.

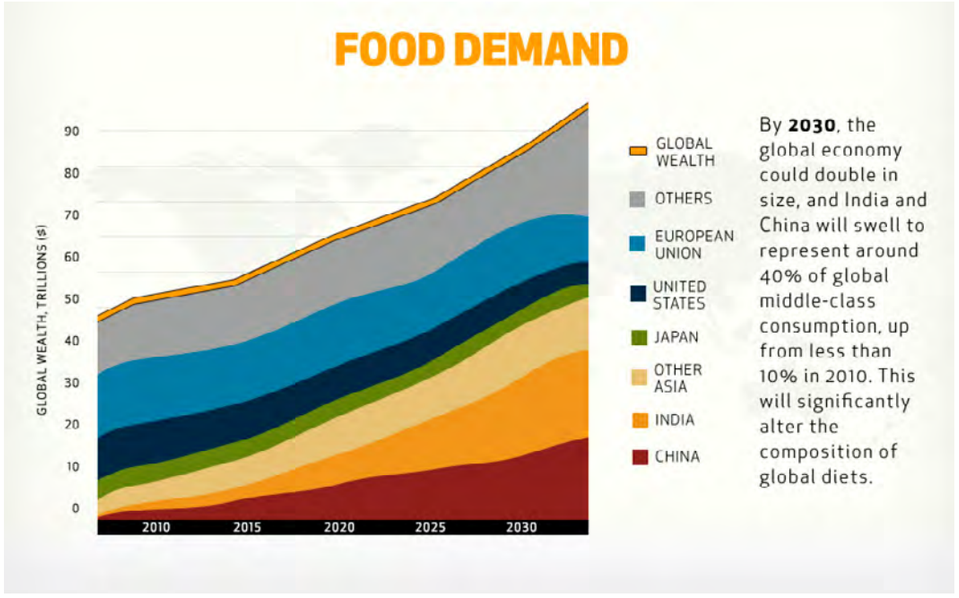


Fig.40 Food Demand Predictions for 2030 in Terms of Global Wealth.

gotten grown through the use of chemicals and fertilizers. Products coming from the farm got inferior quality and less nutritional value, concerning the immune system of the population. Studies show that people born as from the 1960s have a higher prevalence of lifestyle diseases as compared to those who were born earlier.

Nowadays, almost 2 billion people worldwide are suffering from overweight and obesity, and this number has doubled those of malnutrition (Fig.39). The root of this problem lies in the overconsumption and the improper imbalance of wealth and resources, affecting almost every country around the world. The increasing world population has also a huge impact on our society, and predictions show that the food demand will double by 2030 (see Fig.40). As a result, this factor is pushing our society to develop a more efficient food supply chains with a purpose to fulfill the increasing food request. Meanwhile, people are advocating for more sustainable farming processes and a healthy-grown produce.

The development of technologies and the improvement of food sciences over the last decades have created a huge impact on the food we consume today. It allowed improving the processes for food production and conservation, enhancing nutritional quality and providing more detailed information about the food we eat, as well, trace its origins and improving food security together with food safety. The evolution of food consumption in countries with an advanced economy is being characterized by more diversified protein intake, consuming less meat and more fish. They have also reduced the consumption of many processed food such as fast food, limiting their intake of saturated fats, and replacing them with those of vegetable origins, especially by extra virgin olive oil. Furthermore, this also has implied a constant increase in the consumption of fresh fruits and vegetables, together with a consolidation of cereals in the diet. However, this situation is very different in the developing countries, where the consumption of low-quality food and other processed products is still quite high. In addition, some studies in the United States show that this situation can also be observed in the poorest neighborhoods of the cities, where mainly due to economic problems, high quantities of processed products are consumed every day. Products such as fast food and sodas are usually cheaper and look more affordable for low-income families, as they are not able to aspire to better quality food which often cost more. Unfortunately, these food are less nutritious and its long-term consumption leads to different health problems.

MOST OUTSTANDING

FOOD TRENDS

2.1.2 Most Outstanding Food Trends

The values of society throughout history have been changing based on the canons and aspirations of the moment. This is very visible in art, since throughout different periods of history we can see how the concept of “beauty”, mainly of women, has been changing until today. The same happens in the consumer industry, where in terms of food, consumption patterns have also varied throughout the history. Today, we live in a moment where the influence of technological advances has allowed us to enhance our food industry, and to increase the quality of food. We have improved and innovated many food productive processes and food preserving techniques. But also we have also made a breakthrough in the food consumption area, reaching deeper into the chemistry of food. Now we understand better the changes that occur in food during different cooking processes, and how we can control them, at the molecular level. We have been studied for a long time how the food we eat impacts on our health, and these data allow us to understand better the direct relationship between man and food.

Humanity has always been searching to improve health and to get a better quality of life. Numerous scientific studies and technological discoveries have provided data concerning human health and how different factors, both internal and external, may affect it (see Fig.8). And as the sciences have been gaining ground over the past decades, this has made people trust more in health professionals and pay more attention to their advice. As a result, this has caused changes in our consumption behaviors and has also affected our lifestyles.

Health and Wellness

Over the course of history, people have always paid attention to food's healing properties, however the recent interest in promoting and safeguarding health has gained a higher level of attention at the scientific and institutional levels. Different factors have pushed governments, researchers, and healthcare and food industry professionals to find a way to effectively manage changes in population that may be influenced by adopting a correct diet and lifestyle

In recent years, the trend towards health and wellness has grown, people trust health professionals and try to pay attention to their advice. Influenced by different factors, our society are changing their eating habits towards healthier and more responsible consumption. When compared to previous times, many have changed to healthier lifestyles and behaviors, leaving behind some bad habits like smoking, drinking, or reduce the consumption of junk food, at least partly. People have started to take more care of their health, and a big part of the population has become more active, lately. Sports such as running, cycling and yoga, among others, have become very popular and the percentage of people going to a gym has also grown. However, those who have less time to exercise, try to change their habits moving around the city by walking or cycling, instead of using the car. On the other hand, the rapid growth and development of cities often make them more stressful environments than less urban areas. This means that in order to cope with so much stress and anxiety, exercises such as meditation and mindfulness have become popular these days, and the approach towards mental health in current society is at its peak.

The concept of diet no longer appears to be linked exclusively to the concept of nutrition, but is more broadly linked to the improvement in people's overall well-being. It matches the search for a benefit where food is not only the means to pursue sensory and emotional pleasure, but also to preserve physical health. So is the example of a functional food[62], that aside from its nutritional effects, are health promoting and have a beneficial effect on one or more bodily functions.

The market has always been oriented towards consumer needs, and for this reason, the food industry has been pretending to satisfy these demands. Attention to health by consumers are decisively marking the innovation strategies of many companies, pushing them to adopt this market trend also in their advertising campaigns. Nowadays, it is quite common to see companies advertise their products with marketing strategies that promote the consumption of healthy and fresh food (see Fig. 41 and 42). The predominance of fruits and vegetables in the diet continues to gain importance and it is estimated that this trend will continue to grow.

The health and nutritional needs of people change over time, and so do their diets. Consumers are increasingly disposed to follow new paths to implement healthier nutrition and improve their health and well-being. As a result, some of them choose different food diets such as gluten-free, low-carb, paleo, vegan or vegetarian, promoted as beneficial to health by different food organizations. On the other hand, the emphasis on food quality is also growing and this is where some industries are now investing more capital.

62 *Functional food. British Nutrition Foundation. (https://www.nutrition.org.uk/nutritionscience/foodfacts/functional-foods.html?limitstart=0)*

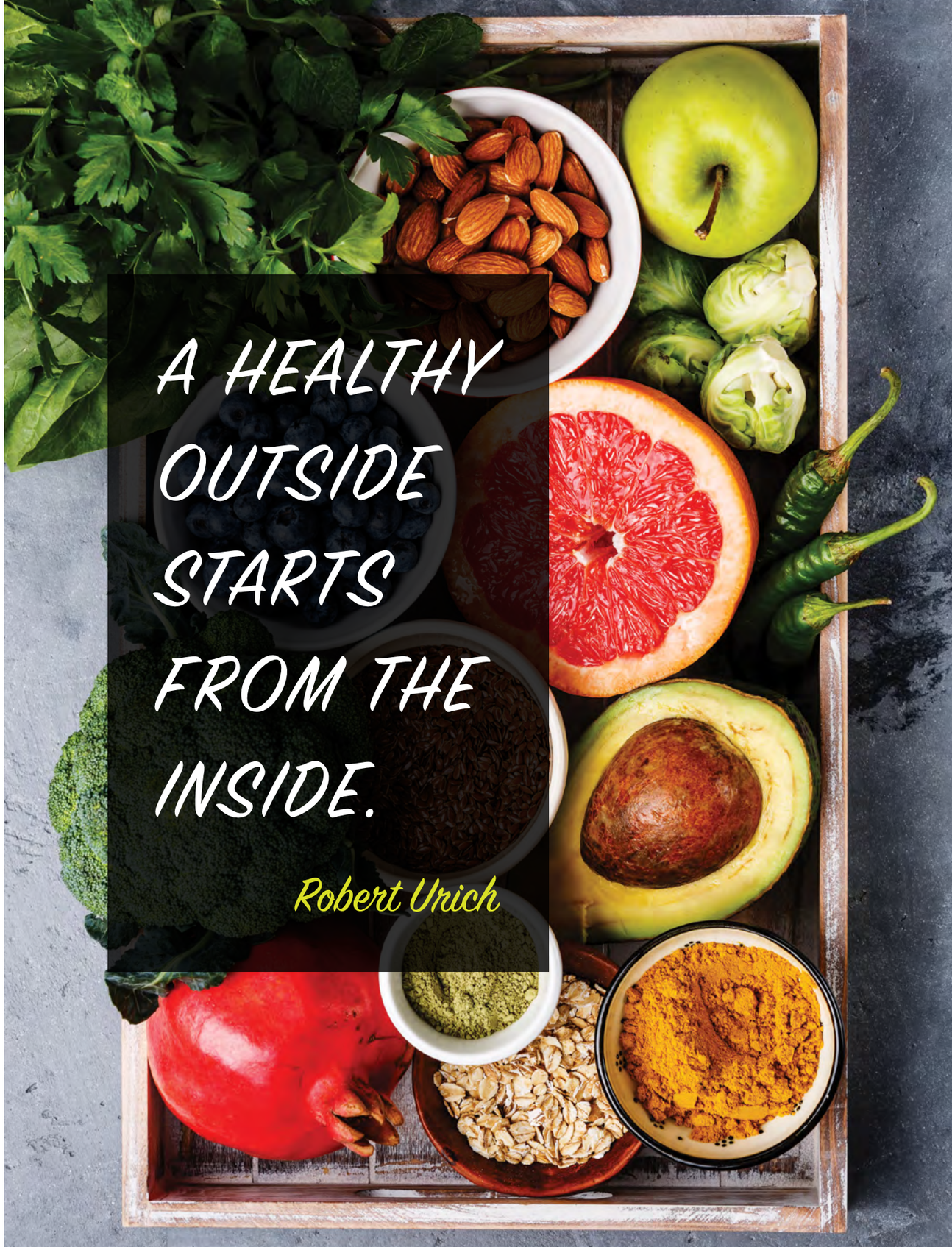


Fig.41 Homemade broth "Gallina Blanca", made with fresh vegetables, 100% natural and without preservatives.

Fig.42 "Gallo Nature" is a range of multi-ingredients pasta made with a mixture of vegetables or cereals and superfoods

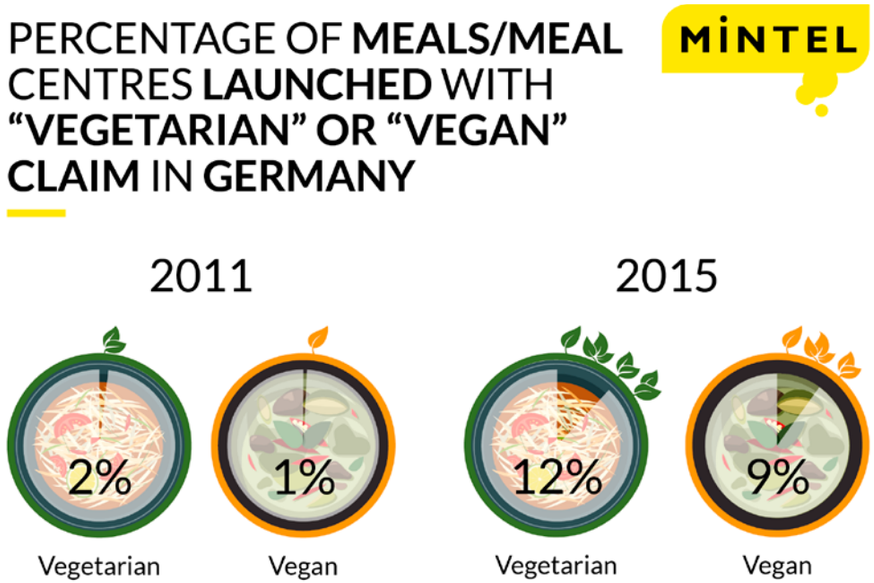


Fig.43 The growing of "Vegan" and "Vegetarian" consumption during the last years in Germany.

Naturalness

In opposition to the adulteration of food, there is a trend toward naturalness and simplicity, which can be understood as a reduction to the minimum of handling in the various phases of the agricultural production chain, or as a not excessively invasive use of technology and with attention paid to the sustainability. The concept of naturalness is usually linked to organic food, produced through organic agriculture, which takes advantage of the soil's natural fertility and prefers to limit external interventions.

Due to different technological and chemical factors that try to accelerate the productive processes, the consumption of organic products has increased exponentially in the last decades. The use of substances such as hormones to reduce time and accelerate the growth of animals, often have a great impact on the health of consumers, who end up ingesting part of these hormones along with meat, and that unbalance their own hormonal system. The use of herbicides, fertilizers, and other chemicals also increases the risk of food safety during production of plant-based food. These chemical compounds are largely used for improving soil fertility and plant protection during growth and storage stage. However, uncontrolled use of chemicals is hazardous for the contamination of soil and water and usually generates toxic compounds in plants that worsen the food quality[63]. The accumulation of different chemicals in the food

63 *Physical Factors for Plant Growth Stimulation Improve Food Quality. 2012. (https://www.researchgate.net/publication/221922791_Physical_Factors_for_Plant_Growth_Stimulation_Improve_Food_Quality/stats)*

Fig.44 Amazon Fresh, a food service that delivers fresh groceries from organic producers to your doorstep.

Fig.45 Slow Food promotes good, clean and fair consumption.

is dangerous for the health of consumers, and that is why a bigger attention is being payed to sustainable and organic agriculture. In fact, in recent years there has been a great growth in the consumption of organic food, which logically has provided an increase in organic production, such as 'organic farm agriculture', 'urban community-managed organic agriculture or 'sustainable Km 0 production', which are responsible for providing fresh and organic food, that gradually begin to predominate in supermarkets, restaurants and consumer homes.

Another factor that will certainly have a great impact on organic production and healthy consumption in the coming years, is the Amazon service called 'Amazon Fresh', which promotes to deliver food from organic producers right to your doorstep (Fig.44). Of course, this will have a huge impact on the food production and consumption, will improve the relationship between small organic producers and sellers, and finally, will enhance the general situation and the quality of the food we consume.

In fact, organic production promotes environmental biodiversity, reduces the use of chemicals and reduces the consumption of genetically modified organisms[64]. The preference for whole and organic food is getting additional acceptance today, but also the way these dishes are prepared.

Taste

The search for pleasure as a feeling of satisfaction through the culinary experience is growing, and this satisfaction presumes that sensory needs will be fulfilled, especially those of flavor. As an extreme example of this approach is the *Slow Food* movement (Fig.45), founded by Carlo Petrini in 1986, which believes that pleasure is included in the sphere of human rights. This non-profit organization promotes food as bearer of pleasure, culture, traditions, identity and a lifestyle that in addition to diet, is respectful of local territories and traditions.[65] It also opposes the standardization of flavors and the consumption of fast food as purely physical satisfaction. However, the consumption of junk food is a choice for only some groups of people. Unfortunately, for others it becomes a necessity, because it is more affordable.

Local and Regional Food

The trend to local and regional eating refers to the proximity of the place of production to the place a food is eaten, which is a guarantee of authenticity. This "*zero mileage philosophy*" promotes the sale and consumption of products that are characteristic of the territory and which do not have to travel great distances before reaching the consumer. As a result, eating local products is advantageous since it contributes to environmental sustainability and promotes the region's food heritage, in addition to guaranteeing a fresh, healthy, and seasonal product. Local food is the cultural expression of that place or region, its traditions, products and flavors, synonymous with the authenticity. However, it is usually limited to seasonality of products and to geographical limitation, as in case of food globalization that presumes accessibility to different products, anytime and anywhere.

64 *Genetically Modified Food - Frequently Asked Questions. World Health Organization (WHO) (https://www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/)*

65 *www.slowfood.it*

Globalization of Flavors

The globalization of the economy and the growing mobility among countries have changed the culinary landscape. This exchange between food cultures is the characteristic feature of the globalization of flavors, which actually opposes the uniqueness and exclusivity of local and regional food. Globalization and intercultural exchange feeds the sense of curiosity towards ethnic cuisines such as Chinese, Indian, Mexican, Spanish or Italian, as a goal to discover new tastes and cultures. *Fusion cuisine*, for example, is mainly developed in those countries that do not have strong cultural food traditions, and it combines different flavors and elements from other cuisines. On the other hand, there is a loss of diversity and local traditions due to intercultural exchange and constant mobility, which generates uniformity of eating habits worldwide, like in case of McDonald's and many other food industry giants.

Orientation to the Past/Future

Food is a culture expression and the culinary traditions of a certain place that can be preserved over time and appreciated. This memory of the past enhances and preserves traditions, and food actually, can be identified as one way to go back in time and remember these traditions, childhood and the family. Therefore, food is of an intrinsically local nature, as it is linked to specific cultural differences and to people's diverse culinary habits and origins. Compared to the faster and more frenetic lifestyle which characterizes the current era, past culinary habits induce a feeling of nostalgia, and they are usually perceived as more simple, secure, and relaxing.

In complete contrast to this situation, future oriented food approach promotes progress as an opportunity for innovation. This food innovation can be easily translated into the invention of new food, dishes, and culinary styles whose goals is to propose solutions to the current food scenario. Due to some of the current concerns, such as the constant increase in the prices of food products, overpopulation, environmental issues, the attention paid to the creation of new food or food which will replace current food is growing. According to many researchers and scientists, the predictable increase in meat prices will lead to include insects into Western food diets. Although the idea of eating insects may appear unusual to some people, their consumption by human beings is actually fairly common in many parts of the world. In addition, algae can also be introduced into the diet, offering a solution to the worldwide food scarcity. At the same time, experiments with the production of lab-grown meat through the use of stem cells is growing and some scientists want to replace meat by 2030.

Today, the creation of new dishes, recipes, and preparation techniques, may be archived by applying scientific knowledge to cooking processes. As a result, new culinary techniques such as *"molecular cuisine"*, that studies the transformations that occur in food during their preparation, are currently spreading.

Technology

Since the ancient times, food production technologies have been refined and developed to improve the quality of food, their shelf-life, flavor, and appearance. Because of the growing attention to health and well-being, the food industry has directed the innovation and the implementation of technologies towards the development of functional food. On the other hand, new technologies are innovating food preparation methods, as for example, the proliferation of *ready-to-eat* food. These technology innovations are also speeding up purchasing procedures, offering a wide range

Fig.46 Hello Fresh offers delicious, chef-made recipes that will be delivered to customers doorstep every week.

Fig.47 Molecular gastronomy is commonly used to describe a new style of cuisine and new culinary possibilities.

Fig.48 Examples of discounts for fresh food products at some supermarkets.

Fig.49 Some examples of ready-to-eat food that will make you save your time.

of automated solutions at sale points and large restaurants. Combined with the smartphone innovation over the last decade, *online shopping* and *food delivery* in big cities are growing too (Fig.44 and Fig. 46). Furthermore, there is great attention paid to food safety, which through different sophisticated software programs, allows tracing food origin and its composition, and protect the consumers. However, excessive reliance on food engineered technology leads to change eating habits towards more natural and organic consumption.

"Luxury" Food

In the current world, greater attention is paid by the consumer to food risks, places of origin, and food production methods. As a result, some consumers often prefer to pay higher than average prices to purchase those products which meet the requirements of authenticity and naturalness, such as organic food or those produced locally. These food are more expensive because their production cost more and its exclusivity is justified by higher quality and the difficulty of finding them. For this reason, it does not mean that "luxury" food are those food that are considered symbols of luxury as caviar or truffles, but those common food which have become premium and special items such as chocolate or some condiments. However, their higher cost normally reduces its accessibility and leads to a sort of discrimination at the economic, social and cultural levels.

"Low-Cost" Food

Right the opposite of the exclusivity of luxury food is accessibility, which is widely represented by low-cost food. In recent years, the attention to these food has increased, and the price is still a decisive factor that influence the consumption of food by a large part of our society. As a result of the increase in the prices of agricultural raw materials on the market[66], there is a tendency to purchase discounted food products or those in offer (Fig.48). However, this trend is not only recorded by families with lower financial resources, but even the wealthier groups are changing their purchasing habits. Furthermore, there is a growing purchase of "white-label" products in supermarkets, which are usually those sold under the retailer's brand. As a result, low-cost products improve food security through its accessibility and availability around the world. However, these products are usually presented as low-quality products, because "underpriced" products are normally linked to lower than average level of quality.

Speed and Time-Saving

With the spread of eating patterns since the last half decade, there was a huge growth in fast food restaurants all around the world. Living in the fast-paced and hectic world, we have less and less time to spend with our families, and less time to dedicate to cooking and meals. As a result, this has marked a substantial difference in how people structure their lives today, but also produced a change in methods and types of purchases. For long time people have been searching to "save" their time, and this is the main reason fast food industry had so big growth during the last decades.

Today, most people spend less time in the kitchen preparing their meals, and some of them consider cooking is a waste of time. As a consequence, eating at home gets worse and worse, and it is always more hurried. Food has become increasingly more "mobile" these days, and eating at odd hours or on the way from home to work has hugely increased.

66 *The FAO reported that Food Price Index, between July 2010 and February 2011, increased by 38%.*

Consumers are paying more attention to food that are easy to purchase and prepare. *Convenience food*, such as *ready-to-eat* or *semi-ready* food can be cooked in a microwave or just heated up, are a clear example of the technological innovations that have occurred in the food industry. Therefore, all this leads not only to a reduction in the time dedicated to meals, but also to a generally poor level of attention paid to a diet's nutritional aspects.

Furthermore, snaking, as meal replacement, is experimenting a high growth. Many consumers are currently snacking multiple times per day, and a small part of them are reporting they do not eat meals at all anymore. Although the snack category is growing, healthy snacking is actually outpacing indulgent and premium snacks (Fig.50). Consumers that prioritize a healthy lifestyle have switched towards products with "natural" and "organic" characteristics, but now "fresh" is emerging as a top attribute. This shift toward healthier snacks was predicted long ago but the latest evolution of this trend has happened rather suddenly.

Individualism

Family structure and household shape have been changing over the years, and a big part of today's society, mostly in big cities, is made up of single people or those who live alone. Hence, eating has been gradually losing the nature it has historically as a ritual in the preparation of meals, socialization, and interaction. Family bonds and habits have been partly lost, and people living alone are less inclined to care about cooking. As a result, food is being eaten individually and in the shortest time possible.
The trend toward individual consumption derives from the general acceleration of life's pace and, consequently, from new family dynamics. However, individualism allows for greater personalization of food, which favors the development of food that increasingly responds to customers' specific needs, as in the case of some diseases or allergies to some specific food.

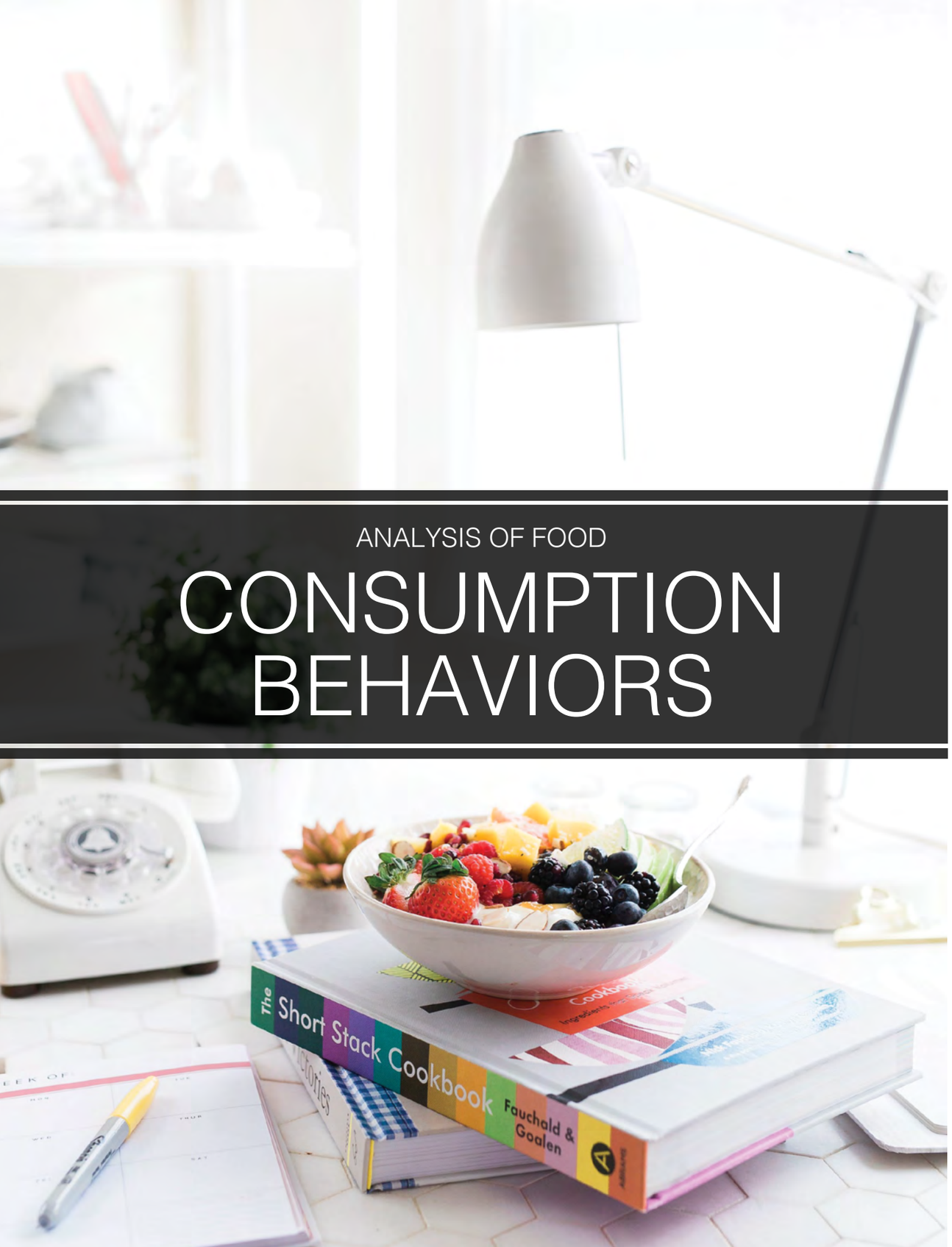
Sustainability

The trend towards food security and sustainability is growing, and today many consumers pay more and more attention to sustainability issues and ask food industry companies to take greater responsibility in safeguarding the environment and the products' quality. These "responsible" consumers want to interact with the producer, get actively involved in the production processes and during purchasing strategies as "*co-producers*".

Food production during the last decades has been characterized by the extensive use of fertilizers and pesticides, and as many studies have confirmed, the use of these chemicals has harmful impacts on our health and the environment.[67] Consumers begin to pay more attention to sustainable products and processes, and many of them have changed their eating habits. *Sustainable agriculture* and the consumption of *organic food* have grown lately, increasing its emphasis on the quality of the products, while spreading organic shops around the big cities. Today's food industry has become more sustainable and it is easy to find many food labeled as healthy or organic, even in the smallest supermarket in the city.

67 *Effects of Chemical Fertilizers and Pesticides on Human Health and Environment. International Journal of Agriculture, Environment and Biotechnology. (http://ndpublisher.in/admin/issues/IJAEBv10n6f.pdf)*

Fig.50 The evolution of snack industry towards "healthy", "organic" and "fresh" products is continuously growing.



ANALYSIS OF FOOD

CONSUMPTION BEHAVIORS

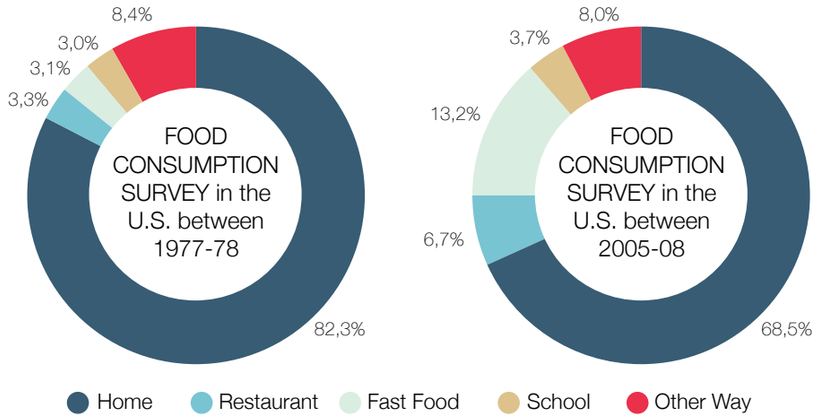
2.1.3 Analysis of Food Consumption Behaviors

Eating At Home vs. Away From Home

Until recently, food represented much more than just an act of supplying the body with energy that will eventually be used as the "fuel" for our body. It was part of the culture and traditions, which was often used to unite family and loved ones on special occasions. It represented an act of socializing with others, of continuing traditions and culinary recipes that have been passed on from generation to generation for centuries. However, the expansion of cities and the urbanization of today's world have led to a crisis of cultural identity in our society.

Life in big cities has undergone many changes in the last decades. Their accelerated rhythms drive a hectic and quite stressed lifestyle. In such an accelerated life the demands increase, and its inhabitants have less and less free time for themselves, their families, and even to rest or eat. The interval for the food has been reduced notably and family meals in large cities are becoming less frequent. As a result, eating out has become a widespread habit in our society, especially among young people, who often decide to eat with friends in a pizzeria, a restaurant, or stay for dinner at one of their homes.

Different factors try to explain these behaviors and an obvious explanation refers to changes produced in the family structure of the population of large cities. Often, factors such as changes in the composition of the family members, the distance from home to work or university, and the different schedules of each member, make consuming food away from home has become not only comfortable, but a necessity. In this way people avoid having to make the shopping, prepare the meal and then clean the kitchen, which allows them also to save one of the most important factors of life in the city, their time. In fact, it is estimated that in the next decades, a considerable part of meals in big cities will be bought ready or consumed away from home.



Source: USDA, Economic Research Service analysis using data from the 1977-78 Nationwide Food Consumption Survey and the 2005-08 National Health and Nutrition Examination Survey.

Fig.51 Consumption survey focused on the evolution of the meal consumption in the U.S.

Food consumption has evolved throughout history, changing our habits and behaviors. In the United States (but also in the rest of the world), the consumption of food at home has been reduced significantly in the last decades, while the consumption of fast food has experienced a great growth (see Fig.51). However, even though the consumption of food at home has been reduced over decades, it is still the main way of feeding our society every day[68].

Focusing on Europe, Italy represents one of the main consumption markets in Europe, with a food and beverage consumption value of 230 billion euro in 2015[69] (see Fig.52). Compared to 2005, food consumption in Italy increased overall by 13% at current values, a growth that is mainly related to "away from home" consumption (+ 30%), which currently represents a third of total F&B consumption. This share is sharply lower than the ones recorded in countries such as UK and Spain (where the on-trade represents respectively 44% and 46% of total food consumption), but higher when compared to Germany and France. But we must take into account that these data only show how much money we spend eating at home or away from it, but not the real consumption share due because eating away from home will always be more expensive, due mainly to price of a meal in the restaurant. As a result, and despite the different current and future trends, it is important to pay attention to what we consume away from home, however, we should pay even more attention to our diet at home.

68 *Food Consumption and Nutrient Intakes. Data on food consumption and nutrient intake by food source and demographic characteristics in 2007-10, provided by ERS. USDA, 2016. (https://www.ers.usda.gov/data-products/food-consumption-and-nutrient-intakes/food-consumption-and-nutrient-intakes/#Food%20Consumption%20Estimates)*

69 *Food consumption of Italy and the leading European countries (http://www.agrifoodmonitor.it/en/food-consumption)*

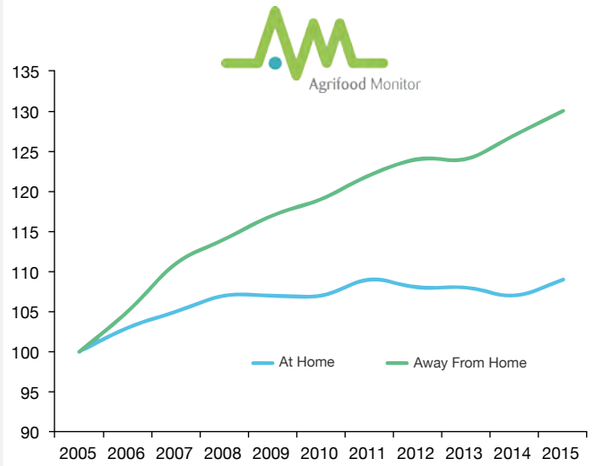
F&B* Consumption trend in Italy: At Home vs. Away From Home (index numbers, 2005=100; current values)

TOTAL F&B CONSUMPTION 230 BN € (2015)

AH 153 bn €

AFH 77 bn €

Source: Agrifood Monitor elaborations based on Istat and Eurostat data



At Home and Away From Home F&B* Consumption: Italy vs. leading European Countries (current values, Bn €, 2015)

Total F&B Consumption

AFH Share On Total Consumption

At Home Away From Home

* Including alcoholic beverages

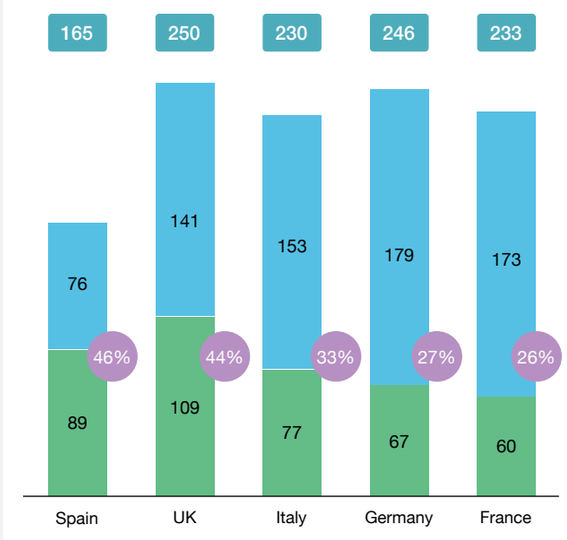


Fig.52 Food consumption based on values of money spent in Italy and other European countries.

Fig.53 Eenmaal is the first restaurant located in Amsterdam which has been designed for those who often eat alone.

Single' Lifestyle

Today, a growing number of families is composed of only one person, including single people, elderly people, and those who work or study in a different place from the one in which their family lives. In Europe, more than 30% of the current population is composed of single person household and this number exceeds 200 million people. The expenditure of a single person is generally considerably more than half the expenditure of a couple, due mainly to the fact that expenses are not shared, but also to a lifestyle of singles that is different from others.[70] On the other hand, singles spend a lot on food too, and as a consequence, the food industry increasingly produces more products focused on this profile of consumers. Singles increasingly turn to packaged single-serving meals and individual-portioned food, including salads that are ready to eat, peeled fruit, eggs in packs of two, sliced cold meats for a sandwich, among many others. Singles have a greater interest in preprepared or directly ready meals for immediate consumption. Their way of eating is quite disorganized, often without respecting the schedules, and in general they pay little attention to the diet and the most basic nutritional standards. Furthermore, this lack of organization in the diet places singles among the consumers who also most often consume food away from home.

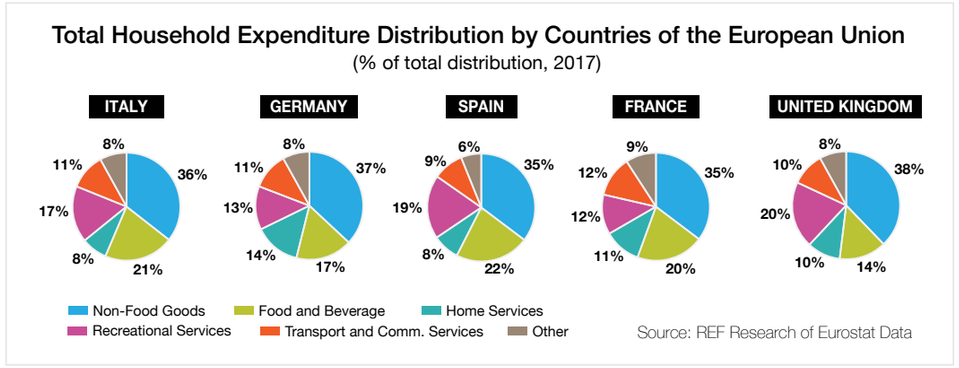
70 *Analysis of EU-27 household final consumption expenditure. Eurostat, 2013. (https://ec.europa.eu/eurostat/statistics-explained/pdfscache/21759.pdf)*

Changes in Food Purchasing Habits

In the past, people fed on food that they normally obtained from hunting and farming. As now, those food came from vegetable and animal origin, although the diet of that time was very different from the current one. Social development has brought many advantages to our life and has also changed the way we live. Nowadays, the majority of food products required for the growing world population are provided by the food industry. The purchase and consumption of food in our society, depend on a set of demographic, economic and cultural factors. Thus, the availability of time for the preparation of food, the size of the family, the location of the house with respect to the work and purchasing power, are just some of the main factors that influence our lifestyle and purchasing habits, as well as the food eat. According to the data provided by Eurostat in 2017, on average about 18% of all household expenses among the countries of the European Union were spent on food and non-alcoholic beverages[71] (see Fig.54). An interesting fact of these studies, is that richer countries spend a smaller fraction of their income on food. And this makes intuitive sense. There's an upper limit on how much food a person can physically eat. So as countries get richer, they start spending more of their money on other things. But this relationship doesn't always hold. It depends, at least in part, on what kind of food people favor, patterns of eating out, and the specific food prices and subsidy schemes in their country.

Among the European countries, Spain and Italy are the ones that spend the most on food, since around 20% of their expenses are destined to this area. As a result, in Italy the average annual expenditure on food is € 2428, however, and as a result of different factors, in Spain that expenditure is only around € 1817.

71 *Household expenditure by consumption purpose - COICOP, EU-28, 2017, share of total. (https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_consumption_by_purpose)*



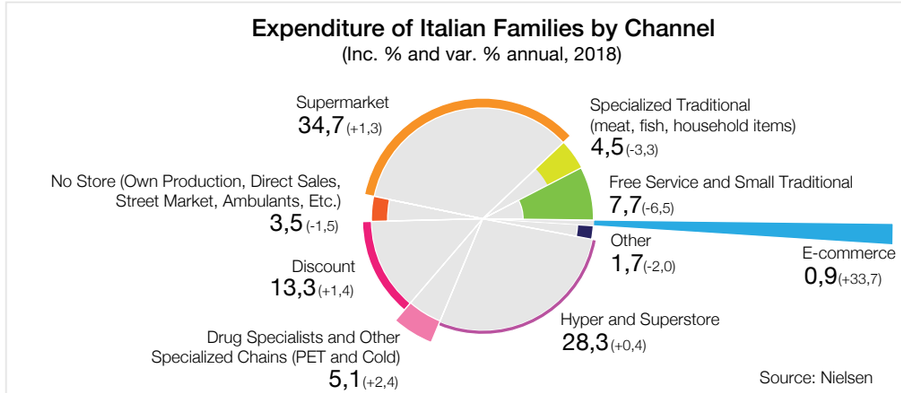
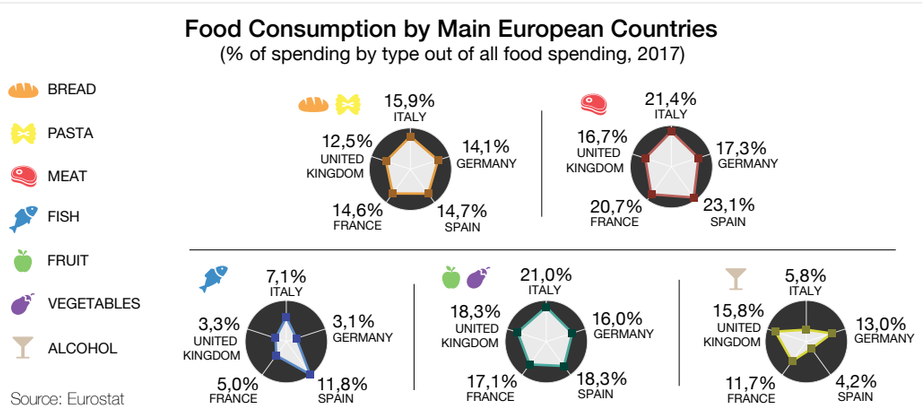


Fig.54 Total household expenditure in Europe. Average expenditure of Italian families by channel. Source: Eurostat.

Analyzing the situation of food in Italy, and according to Istat and COOP Report 2018, last year the country spent 21% on food and beverages with respect to the total household expenditure.[72] On average, Italian families spent € 457 per month on food (+2.0% with respect to 2016). However, individual expenses have a different weight within the food basket. The most important food items remain meat (€ 94/month), bread and cereals (€ 76/month), vegetables (€ 63/month) and milk, cheese and eggs (€ 58/month). Among these items, the only one to record a substantial increase compared to 2016 is that of vegetables (+4.2%), and fruit (+3.8%) (see Fig.55a).

In Italy, the profile of people who spend the most on food are entrepreneurs and employees, while those who spend less are the unemployed. On the other hand, it is also observed that the expenses are greater in large families and couples with a child. While young

72 *Spese per consumi delle famiglie. Istat, 2018. (https://www.istat.it/it/files/2018/06/Spese-delle-famiglie-Anno-2017.pdf)*



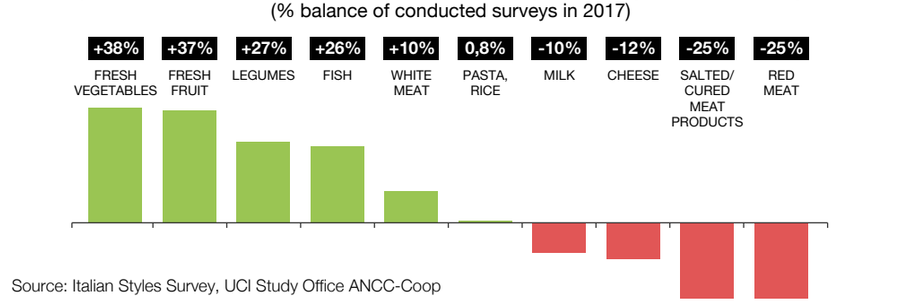


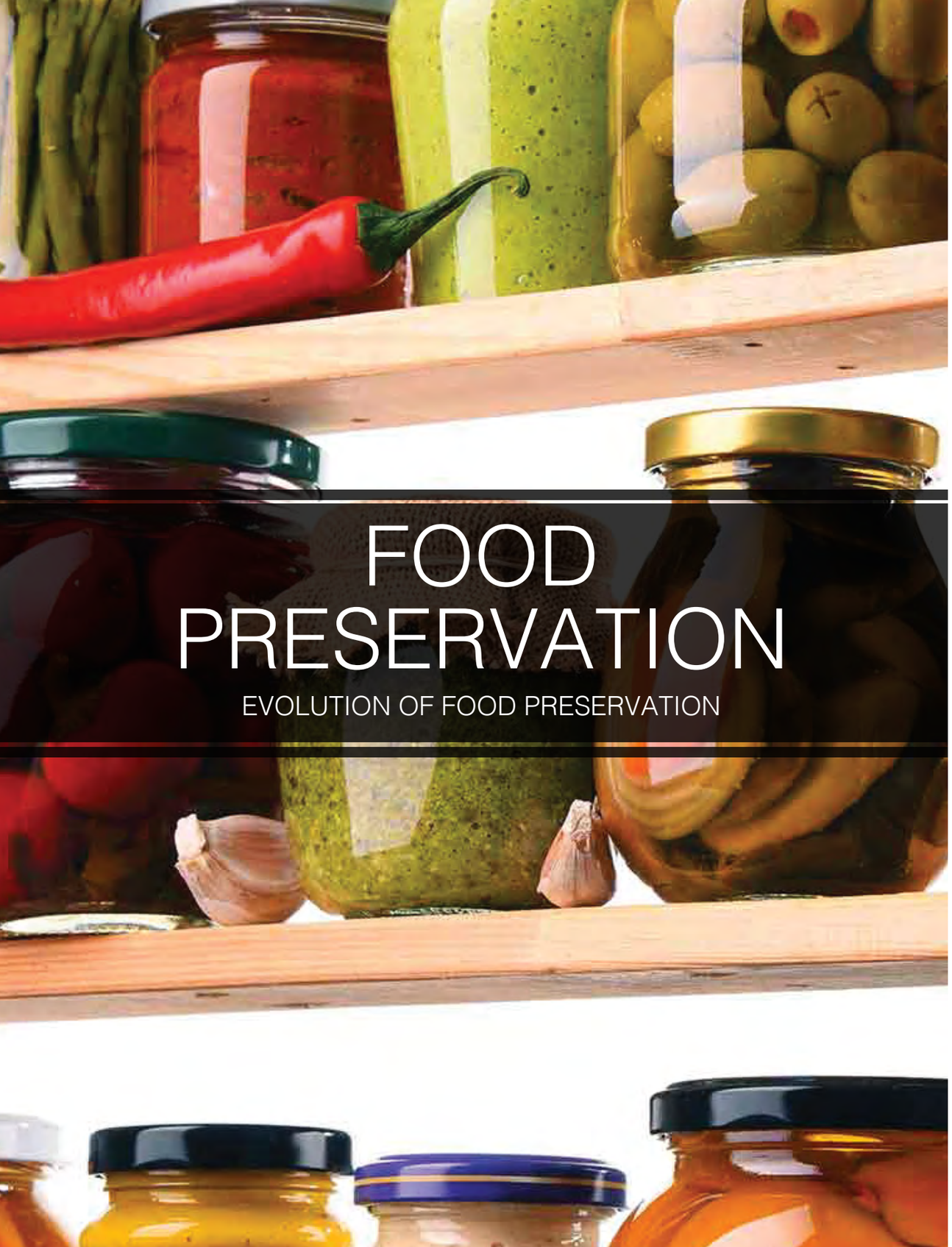
Fig.55 Food consumption in Europe. Projection of food consumption in Italy. Data source: Istat, Eurostat.

singles, are the ones who tend to spend less money among all.[73]

The most used shopping channels in Italy in 2018 were supermarkets (34.7%), hyper and superstores (28.3%), and discount stores (13.3%). However, although the average expenditure of e-commerce constitutes only 0.9% of the total, its growth in the last year was around 33%. The predictions say that this trend will continue so it is recommended to pay attention to it in the incoming years.

With regard to food prices, since 2016 the total food inflation has grown by +1%. However, while other products have barely experienced price rises, fruit and vegetables have increased their value by 6.8% in the same period. Despite this fact, the consumption of fresh food continues to grow, and the predictions ensure that this trend will continue in the coming years (Fig.55b).

73 *Rapporto Coop 2018. Economia, consumi e stili di vita degli italiani di oggi (http://www.italiani.coop/wp-content/uploads/2019/01/coop-consumi-2018-web-definitivo.pdf)*



FOOD PRESERVATION

EVOLUTION OF FOOD PRESERVATION

2.2 FOOD PRESERVATION

2.2.1 Evolution of Food Preservation

Food conservation is usually achieved through the processes of biochemical and physical transformation of food. These modifications alter the organoleptic characteristics of the food, for example, the characteristics perceived by our senses (external appearance, color, aroma, taste, consistency) and the nutritional and chemical characteristics (digestibility, protein charge, vitamins, starches, etc.). One of the most representative aspects of the food is that inside it often live different organisms, such as microbes and bacteria, which affect most of its perceived qualities, but also play a very important role in the "shelf life" of the food. Therefore, preserving food products essentially means protecting them from the action of microbes.[74] In other words, this means opposing its transformation and in particular its alteration, without, however, causing the nutritional substance to lose its nutritional properties and its characteristic organoleptic qualities.

Food preservation has had a great importance in human history. The prehistoric man was mostly linked to his habitual place of residence as traveling was dangerous because of the uncertainty of not finding food to survive. Today, the fact of improving traditional preservation methods together with the use of new conservation techniques, has allowed man to make himself much more independent. The technologies and methods of conservation have evolved in different countries and through centuries, taking advantage of the environment and technologies of the moment. Since the

74 *Micro-organisms in food and food preservation. USDA. (https://naldc.nal.usda.gov/download/IND43893659/pdf)*

Fig.56 Some examples of the traditional techniques of food preservation.

man has discovered the fire, cooking helped him to kill the bacteria and improved the taste of the food. Cooking, in fact, prolonged the shelf life of the products, but only for a couple of days. As a result, since ancient times people have sought to develop systems capable of maintaining food as long as possible.

Food preservation represents a victory in the history of science and industry, and also in the evolution of society. Nowadays people show great interest on food preservation and believe that it is very important to keep their freshness and nutritional values unaltered. The need to preserve food has developed wide number of techniques with different levels of effectiveness.

Since ancient times people used salting, smoking, drying, underground refrigeration, the use of spices, oil and acidic or alcoholic substances. More recently, methods such as hermetic cooking, freeze-drying, dehydration, pasteurization, heat gamma sterilization and the use of a wide range of chemicals have been put into use.[75]

Traditional Techniques

Most traditional food preservation techniques have their origin since agriculture was discovered. *Drying* is one of the oldest techniques, which consists of dehydration or drying of food that is used to prevent food products from rotting. Since 12 000 BC, the cultures of the Middle East and East began to dry food using the sun to dry fruits and vegetables naturally. *Curing* and *salting* consists in preserving the cuts of meat or fish with salt, that accelerates the drying process and also inhibits the growth of several common strains of bacteria. *Smoking*, also improves the drying process and adds antimicrobial agents that aid in preservation. Burial method is used for many root vegetables and even meat. It preserves food due to a variety of factors, such as lack of light, lack of oxygen, cool temperatures and pH level. *Sugaring*, tends to draw water from the microbes, killing them.

Cooling methods preserve food by slowing down the growth and reproduction of microorganisms and the action of enzymes that causes the food to rot. In ancient times, it was used rudimentary refrigeration in caves and root cellars. The introduction of commercial and domestic refrigerators has had a great impact on the lives of the people of the Western world by allowing to store for longer periods all kinds of fresh food, such as fruit and vegetables, dairy products, meat and fish, especially during the warm weather. *Freezing* is also one of the most commonly used processes, both commercially and domestically. Characterized by long-term storage technique, it is able to preserve a wide range of food, including prepared food. *Boiling* and *heating* methods, on the other hand, use high temperatures to kill microorganisms inside the food.

Pickling is a method of preserving food in an antimicrobial or fermented liquid, and sometimes it can involve boiling or heating. *Canning* involves cooking food, sealing it in sterilized cans or jars, and boiling the containers to kill or weaken any remaining bacteria as a form of sterilization. And finally, *fermentation* uses specific micro-organisms that combat spoilage, through conversion of starch and sugars into alcohol.

Modern Industrial Techniques

These techniques of food preservation are characterized by being developed in research laboratories for commercial applications.

Pasteurization was invented by Louis Pasteur in 1862, and it was developed for preservation of liquid food, which consists in heating liquids at about 70°C for few seconds to kill the bacteria present in it and then cooling it quickly to 10°C. *Vacuum* preservation strips bacteria of oxygen needed for survival which will kill them, and its commonly used to used for storing products to reduce loss of flavor from oxidization. Freeze-drying (or lyophilization), is a low temperature dehydration process which involves freezing the product, lowering pressure, and then removing the ice by sublimation. *Irradiation* method, uses the exposure of food to ionizing radiation by killing bacteria, molds, and insect pests, that reduce the ripening and spoiling of fruits. *Artificial food additives* can be divided into antimicrobial, which inhibit the growth of bacteria or fungi, including mold; or antioxidant, such as oxygen absorbers, which inhibit the oxidation of food constituents. *Modified atmosphere* (MO) preserve food by through modifying the gas composition of the internal atmosphere of a package, in order to improve the shelf life. However, this method of preservation may not retain nutrients, especially vitamins. *Controlled Atmosphere* (CA) instead, it controls different factors such as the gases present in the environment, temperature and humidity, and are normally used to conserve fruit on an industrial level in large refrigerated rooms.

75 *Methods of food preservation used by food industry. (https://sciencesamhita.com/methods-of-food-preservation/)*

2.2.2 Food Supply Chain Types and The Use of Cold Chain For Food Preservation

Short and Long Food Supply Chains

The Food Supply Chain (FSC) used by the food industry provides our population with different types of food (from the agriculture production) that are finally consumed in our homes or some restoration service. These food, being of animal or vegetable origin, are produced mainly in a field or a farm, and depending on the type of chain chosen for their supply, they will create different impacts on where, who and when those food will be consumed.

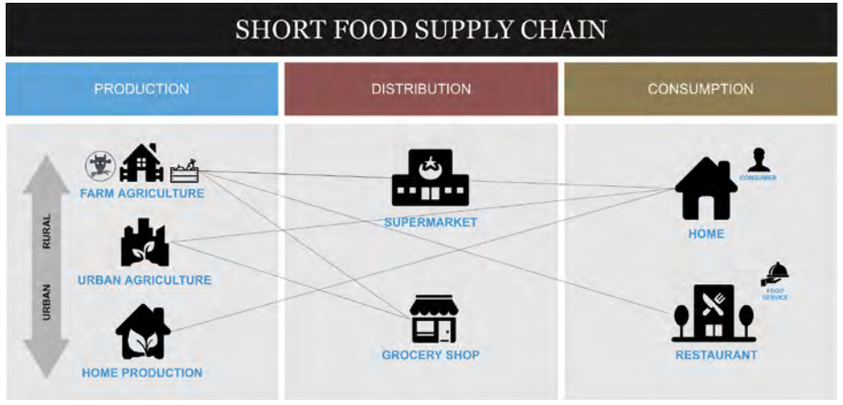
The food supply chain is divided into two types: short chain and long chain (Fig.57). *Short FSC* is characterized mainly by short distance or few intermediaries between producers and consumers. The type of food produced at this level are mostly defined as 'local production', and often they offer higher freshness and better food quality, because the times between harvesting and consumption are lower. The food produced at this level are directly provided to the consumer, or to the restaurant, often through previous agreements. On the other hand, part of the food of the short FSC may also be distributed to nearby supermarkets or grocery shops and then sold to the consumers. Conservation times here are usually quite short, offering better quality and their derived costs are usually influenced by the quality of the products and methods used during the phases of their production, that of the energy used during their distribution.

On the other hand, *long FSC* is characterized mainly by long distance or many intermediaries between producers and consumers, and it represents a food supply at a much wider level. This type of food supply is very common nowadays, and thanks to it we can consume food from practically any part of the world. This type of food supply chain is very common nowadays, and thanks to it we can consume food from practically any part of the world. The cold chain and other modern methods of food preservation have allowed that the distance is no longer a barrier for their distribution, offering at the same time a good quality of different foods worldwide. The value of food at this level are usually seen higher due to the costs derived from their storage, processing and the distribution. However, it is very difficult for these foods to exceed the quality of those produced locally, since there are many factors that could compromise their quality, such as interrupting the cold chain for their proper conservation. In addition, long FSC also represents greater environmental and economic impacts, derived mostly from the different stages of the supply chain (processing, transportation and preservation methods).

Cold Chain: Refrigeration and Freezing

Many of the foods that our population consumes are fresh foods, generally defined

FOOD SUPPLY CHAIN TYPES



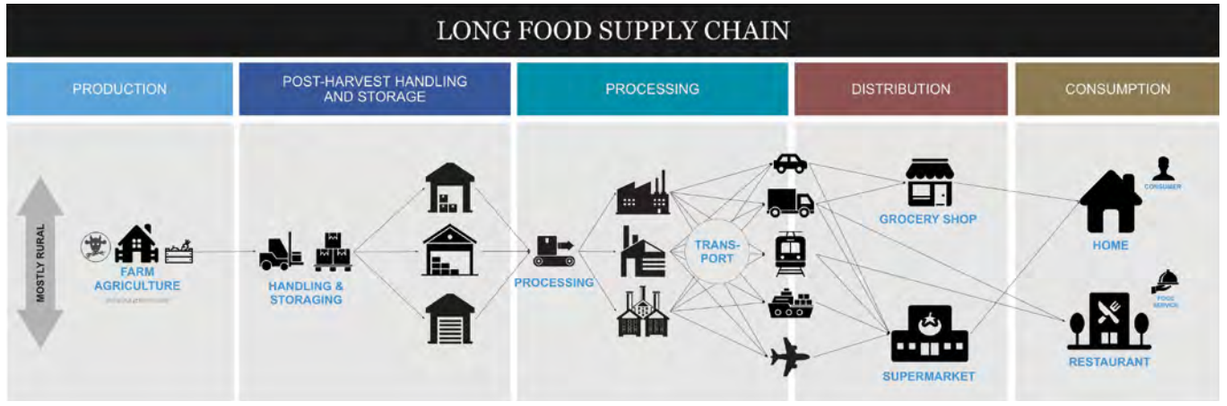


Fig.57 Different Types of Food Supply Chain: Short Chain and Long Chain.

as not processed, preserved or handled products. Consuming fresh foods (and if possible local products), provides our body with a supply of quality nutrients since these foods are free of additives (f.i. preservatives). Its nutritional value is commonly higher than if that same food was processed or preserved for a longer period. Focusing on consuming these food and avoiding processed products is the healthiest way to nourish our body, and these food behaviors are the most recommended by different food organizations worldwide (see chapter 1.1.3 and 1.2.1).

However, the vast majority of these foods are perishable products (f.i. meat, fish, fruit and vegetables) and can easily spoil, decay or become unsafe to consume. These products require specific conditions to be conserved correctly and for this purpose the cold chain is used (Fig.58). The cold chain is a controlled temperature supply chain, which guarantees consumers, as long as it remains intact, that consumer foods have been kept within a suitable temperature range for their conservation during production, transportation, storage and sale.[76]

Applying cold is one of the oldest methods in food preservation, which proposes to reduce the temperature in order to maximize the 'shelf-life' of the food. Low temperatures slow down the growth of microorganisms and the rate of chemical changes in food, being these two of the main causes of food spoilage. In addition, this process maintains the initial taste of the food (sensory characteristics), their original physical properties (organoleptic characteristics), and also their nutritional qualities (micro and macronutrients).[77] There are two different types of cold storage: refrigeration and freezing, and each of them is used based on different factors related to food.

Refrigeration is considered the best among all methods of food preservation since it is the one that produces fewer changes in food, offering the best food quality through keeping intact most of its nutrients and preserving the organoleptic properties of food. This method is used to preserve fresh and perishable food for the short or medium term, that will be usually consumed during next days or weeks, linked mostly to the 'short supply chain'. Its temperature usually ranges between 0ºC and 5ºC (degrees Celsius), that slows down the metabolism of the microorganisms present in the food, but does not kill them.

On the other hand, *freezing* is a process that uses temperatures that range between -12ºC and -18ºC. Unlike refrigeration, this method provides a long-term food preservation that overcomes periods of months, and is mostly linked to the 'long supply chain'. However, this method can break the physical structure of the food, causing changes in organoleptic properties and can lead to the loss of nutrients. As a consequence, the food industry often uses a modern method called 'deep freezing', which uses a much faster freezing and at temperatures below 40°C, in order to preserve the physical structure of the food.

Most of the food we eat has its animal or vegetable origin, and it turns out that the most food begin wet and warm. As a consequence, to preserve and maintain the quality of these foods throughout the different stages of FSC, specific conditions in each of these stages are required. Some food such as sugar or flour are considered non-perishable, as they do not require strict conditions for their preservation, and the relative humidity of the environment is one of their biggest enemies.

On the other hand, perishable food constitute the biggest part of the food we consume, and in most cases these food require special conditions for their proper preservation, such as controlled temperature and humidity (Fig.66). To rise humidity inside cold rooms, the use of humidifiers is requested.[78] These conditions became the most common among perishable products, although there are other modern methods such as modified atmosphere (MO)

76 *Refrigerated storage of perishable food (https://www.csiro.au/en/Research/Health/Food-safety/Refrigerating-foods)*

77 *¿Qué es la cadena de frío de los alimentos? (http://tucarnetdemanipuladordealimentos.com/la-cadena-frio-los-alimentos/)*

78 *Flow through humidifiers. (https://cellkraft.se/humidifiers/flow-through-humidifiers/?gclid=Cj0KCQjwnKHlBRDLARIsAMtMHDHwwvz7ANTOLEt4_mCOd4zcrsNhqCqVbzl4ZcW9AyloBryBZhld95UaAifpEALw_wcB)*

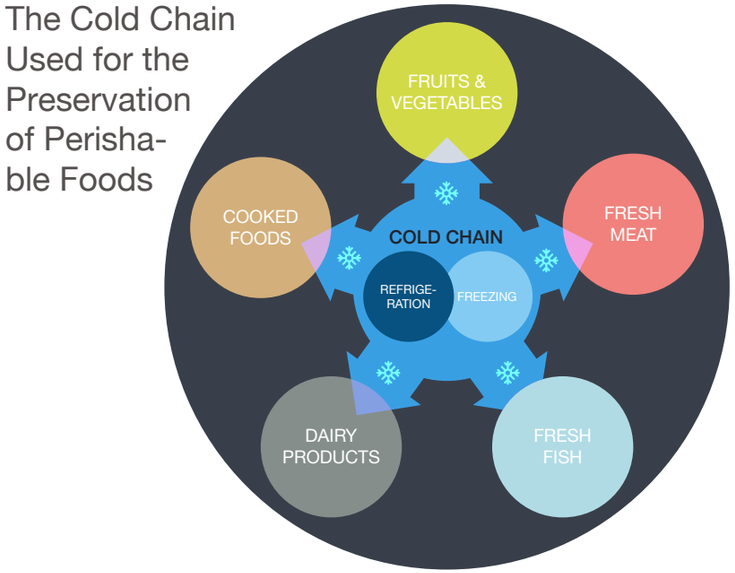


Fig.58 The most perishable food products that require cold chain for their optimum preservation.

and controlled atmosphere (CA) that are also being used together with the controlled temperature and humidity.

To storage perishable food, refrigeration or freezing method can be used, and this mostly depends on the estimated time until the product will be consumed. In the case of meat, for example, the estimated shelf-life of chilled chicken is from 7 to 10 days, stored at temperatures between -1°C and 0°C and relative humidity >95%.[79] This means that while the estimated time to consume this meat is set between the range of these days, it is not required to use the freezing process.

Storage of fresh products such as fresh meat, fish, seafood products, dairy products, as well as fruits and vegetables, will always require cold and wet conditions as these food are characterized by a high content of water (Fig.62). If these foods were stored in a dry environment, they would lose their water content by evaporation, causing a remarkable change in their appearance and significant loss in quality.[80,81,82]

79 *Storage conditions for chilled animal products. FAO (http://www.fao.org/3/t0098e/T0098E01.htm)*

80 *The dairy supply chain: from farm to fridge. 2015 (https://www.inboundlogistics.com/cms/article/the-dairy-supply-chain-from-farm-to-fridge/)*

81 *Cold chain management in meat storage, distribution and retail: a review. 2015 (https://www.researchgate.net/publication/320051361_Cold_chain_management_in_meat_storage_distribution_and_retail_A_review)*

82 *Storage of fresh fruit and vegetables. Agriculture and Food. Government of Australia. (https://www.agric.wa.gov.au/fruit/storage-fresh-fruit-and-vegetables)*

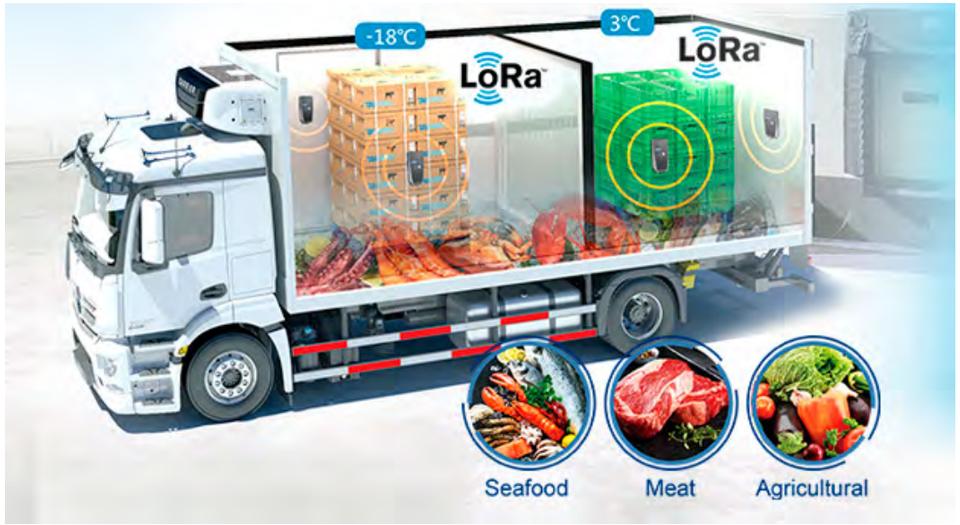


Fig.59 Representation of cold chain storaging (refrigeration and freezing) of fresh food during their distribution.

Fig.60 Cold storage room used for the preservation of perishable food products.

Fig.61 Refrigerated and packaged storage of fresh meat at butcher's shop.

As a result, most part of fresh meat is stored in refrigerator or packaged, what works well to prevent their water loss (Fig.61). Fish is usually stored on ice, which is a great technique to keep it cool and fresh. However, to reach the optimal conditions of temperature and relative humidity, some companies use humidification systems, that improve these conditions and extend product shelf-life (Fig.62). The preservation of fresh fruits and vegetables, also requires proper control of temperature and high relative humidity. Sometimes fresh produce can be packaged to reduce its water loss, although, the most common method to storage fruits and vegetables at supermarkets is through refrigeration (Fig.63). Unfortunately, it is still common today to see how different companies often do not respect the recommended conditions for the preservation of these foods.

But this situation is changing, and for a couple of years now, more and more supermarkets are betting to keep in mind the humidity factor during their preservation, relying on the use of ultrasonic fogging system[83] (Fig.64).

However, there are other factors that must be taken into account when preserving fresh foods. According to Alfredo Álvarez Cárdenas, expert engineer in the food industry and current professor at the National Autonomous University of Mexico, a series of elements are required during the conservation of perishable food. "The preservation of food through the cold chain is effective, when 3 basic aspects are respected, both in the case of refrigerated products and frozen products: starting from a healthy and quality product; applying the cold as soon as possible and keeping its

83 *Humidification of chilled fruit and vegetables on retail display using an ultrasonic fogging system. International Journal of Refrigeration. (https://www.researchgate.net/publication/223490194_Humidification_of_chilled_fruit_and_vegetables_on_retail_display_using_an_ultrasonic_fogging_system_with_waterair_ozonation)*

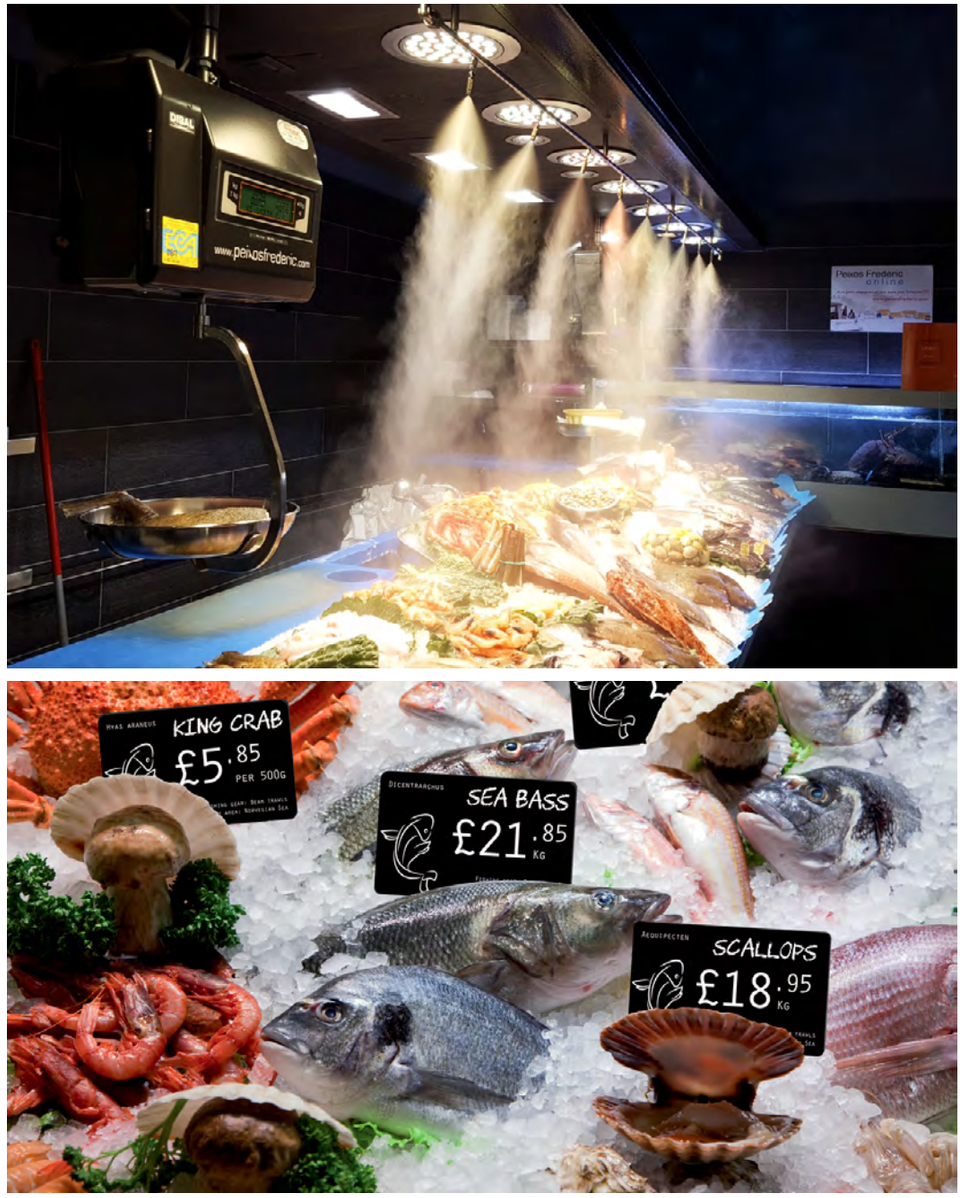


Fig.62 Refrigerated storage of fresh fish at fish market.

Fig.63 Refrigerated storage of fresh produce at grocery store.

Fig.64 Preservation of fresh produce at supermarket, using ultrasonic humidification system.

action constant and in the right degree". It is very important to ensure the integrity of the products from their production and storage, to their packaging, distribution, supply and consumption. If any of these stages is compromised, the quality and safety of the purchased food would be at risk.

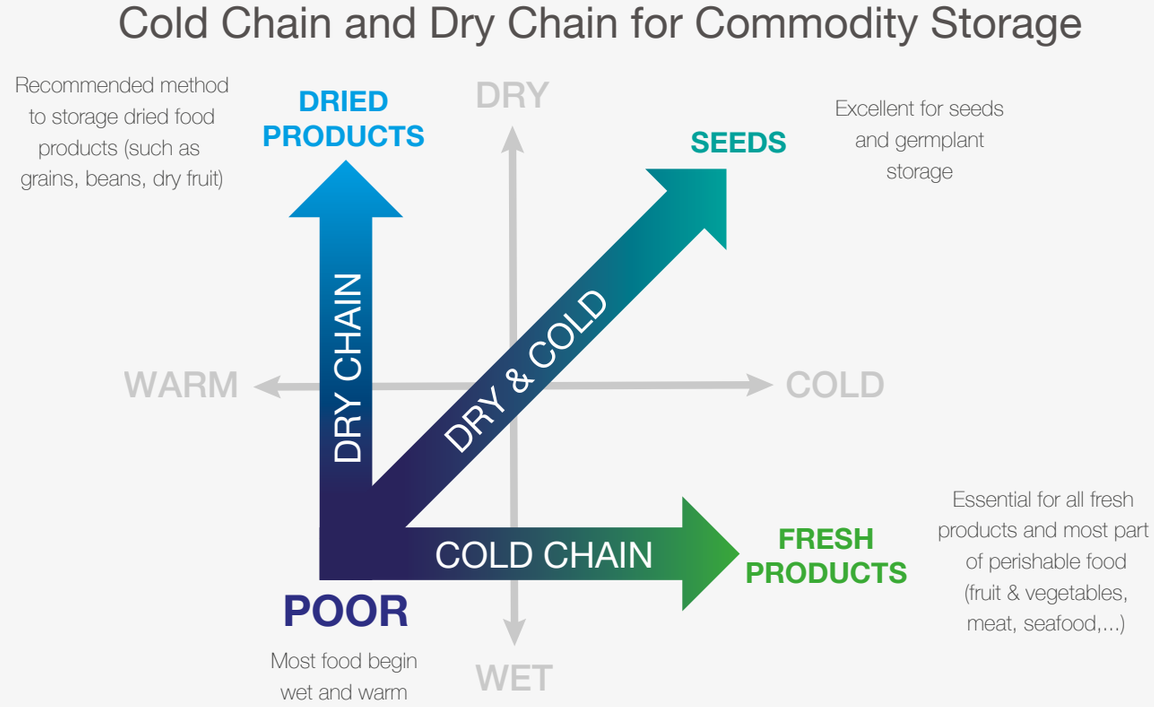


Fig.65 Differences between Cold Chain and Dry Chain for storage commodities.

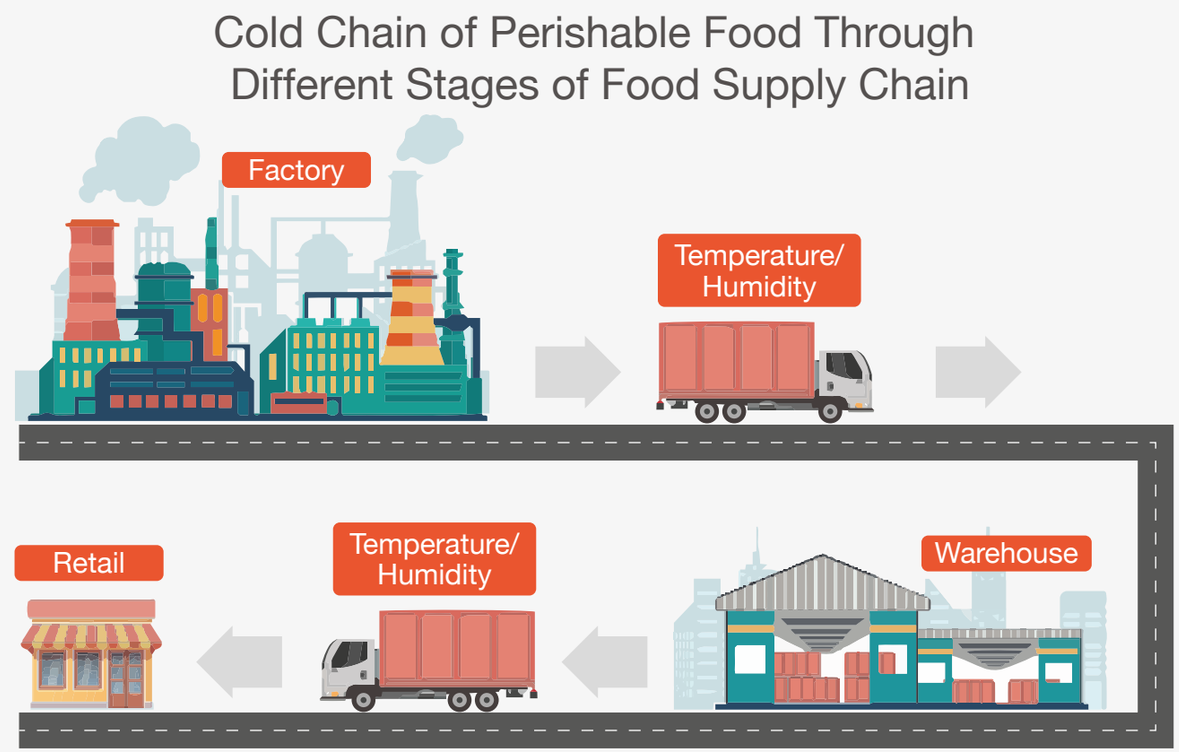


Fig.66 Cold chain of perishable food through different stages of Food Supply Chain

PRESERVATION OF FRESH PRODUCE:

FRUIT AND VEGETABLES

2.2.3 Preservation of Fresh Produce: Fruit and Vegetables

Fruit and Vegetables Storage Conditions

Harvested fruits and vegetables are living organisms. Since they are harvested, they maintain many of the biochemical reactions and physiological processes in the same way they did when they were attached to the growing plant. They keep their respiration process which consists on breathing oxygen (O_2) and emitting carbon dioxide (CO_2). However, their transpiration process is no longer available, since the plant can not nourish itself by different salts and minerals their roots was getting from the water. As a result, the harvested produce will rely on its own sources of energy and water to survive until its final consumption, since they can no longer be replaced from the growing plant.[84]

Since fruits and vegetables are harvested, it is practically impossible to improve their quality, for this reason it is very important to maintain the proper storage conditions for each food in order to prolong its shelf-life and also maintain its quality in the best possible way. Different types of fresh produce have different storage life, and this is due to different ***external*** and ***internal*** factors. Among the internal factors that most influence their shelf-life are usually '*metabolic and water-loss rate*". As a consequence, to counteract these processes, some external factors, such as controlled temperature and humidity are required, which will provide favorable conditions for their proper preservation.

84 *Storage conditions: fruits and vegetables. The University of Maine. (https://extension.umaine.edu/publications/4135e/).*

Physiological Processes of Fruit and Vegetables

RESPIRATION

Like all living beings, fruits and vegetables also breathe, absorbing O_2 and releasing CO_2, H_2O and heat.

TRANSPIRATION

Is the amount of water that a product discards in the form of steam to regulate its temperature. This can cause a loss of weight and a notable loss of quality.

RIPENING

During this process the fruits use the energy coming from proteins, fats, carbohydrates and some minerals for their growth process.

Fig.67 Main physiological processes present in fruits and vegetables.

Fruits versus Vegetables

Fruits are the reproductive organs of the plant that continues to develop even after harvesting. The most part of these fruits can be harvested green and then be ripened artificially, called as climacteric fruits. However, not all the fruits can be ripened outside the plant, and these are usually defined as non-climacteric fruits.

Vegetables instead, are the leaves, stems and roots of plants that are harvested when they have archived the required qualities. Unlike ripening fruits, they generally do not undergo dramatic changes after harvest, although they continue to function as living organisms. They need to be kept under the right conditions to minimize their quality loss, but these conditions are much easier to handle than in case of fruits.

Fruit Ripening

Ripening is the process by which fruits attain their desirable flavor, quality, color and other textural properties. On the basis of ripening behavior, fruits are classified as climacteric and non-climacteric fruits (Fig.68).

Climacteric fruits are defined fruits that continue to ripen after harvest stage. During the ripening process the fruits emit ethylene along with increased rate of respiration (Fig.69). Ripe fruits are soft and delicate and generally cannot withstand rigorous of transport and repeated handling. As a result, these fruits (climacteric fruits) are harvested hard and green, but fully mature and are ripened near consumption areas. To induce ripening process, small dose of ethylene is used under controlled conditions of temperature and humidity. However, the main disadvantage of climacteric fruits is their high '*respiration rate*', which *may produce high concentrations of* CO_2 *and* C_2H_4 *(ethylene) gases during the storage*. This requires special storage conditions, as high concentrations of ethylene, for example, as it can lead fruits pass quickly from maturation to senescence phase. Some of the climacteric fruits are: mango, papaya, banana, kiwi, apple and pear, among others.

Non-climacteric fruits do not ripen further once they have been harvested. They produce very small amount of ethylene and do not respond to ethylene treatment. Non-climacteric fruits do not experience the increase in respiration rate or increase in production of carbon dioxide. Some of the fruits that belong to this group are orange, grapefruit, cherry, among others.

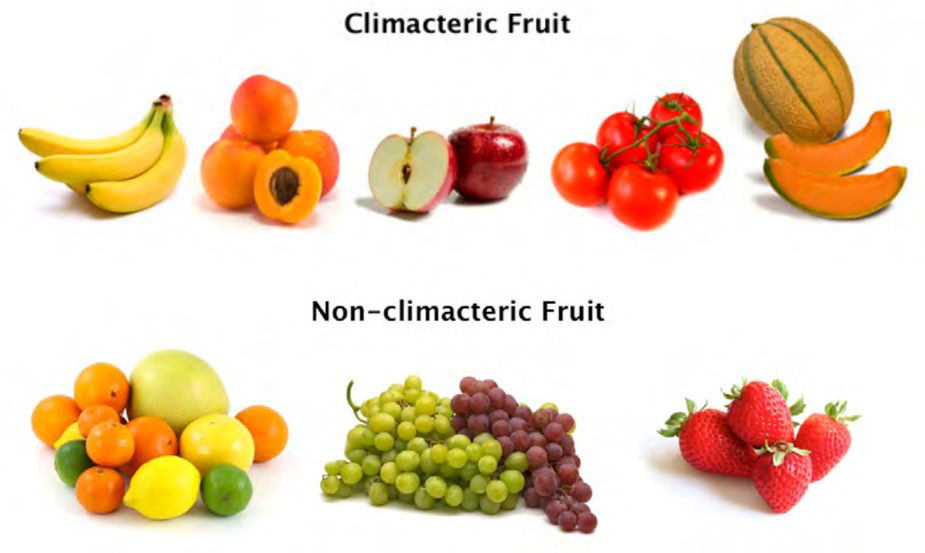


Fig.68 Some examples of climacteric and non-climacteric fruit.

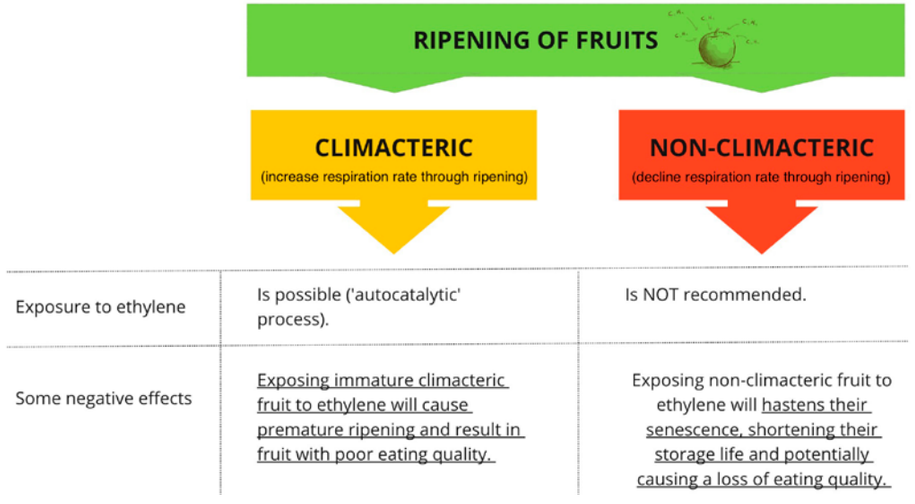


Fig.69 Ripening of fruits and how it affects climacteric and non-climacteric fruits.

Fig.70 Different stages of banana, through growing, maturation and senescence processes.

Factors Influencing the Quality

The quality of fruits and vegetables depends on many factors, which can usually be grouped as preharvest and postharvest factors.

Preharvest factors are those that in any way can influence the production of food and that consequently would compromise its quality before it gets harvested. Among the most common is the use of fertilizers, pest control, irrigation, climatic conditions (wind, rain, etc.), tree conditions (age, light penetration, etc.), which influences overall fruit quality in this phase.

Postharvest factors are those that will impact on the overall quality of fresh produce once they are harvested. There are many postharvest factors that affect quality of fresh produce. Some of the most important are the maturity stage, harvesting methods, precooling, time of harvesting, handling and packaging, storage conditions (temperature and relative humidity).

Factors Affecting the Storage Life

Different factors can create a huge impact on the storage life and eating quality of fruit and vegetables. They can decrease the shelf-life of fresh produce and produce many undesirable changes such as water loss, shrinkage, shriveling, cell wall degradation, softening, physiological disorder, over-ripening, disease attack, rotting, and many more. The following are the factors that the most affect the storage life of fresh fruit and vegetables. However, the management of temperature, ventilation, and relative humidity are the three most important factors that affect postharvest quality and storage life of horticultural produce (Fig.71).

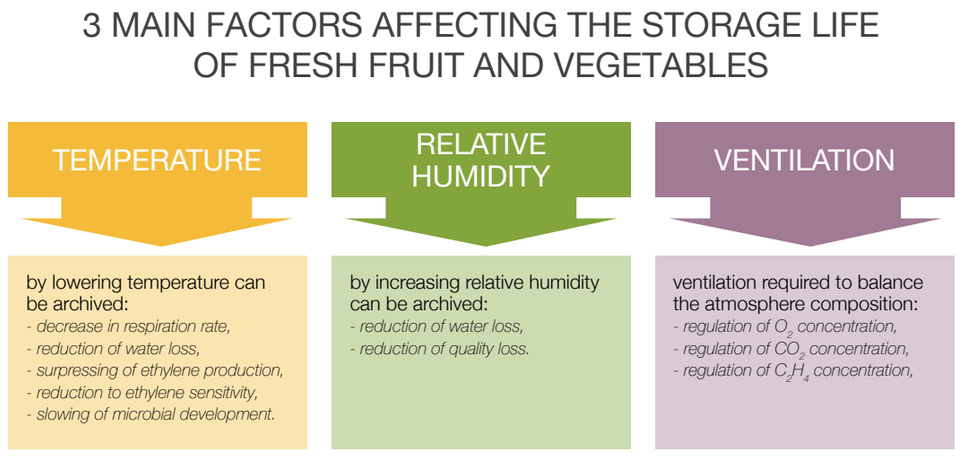


Fig.71 The most relevant factors affecting storage life of fresh produce are temperature, relative humidity and ventilation.

Time from harvest is a key factor for many types of fresh produce, especially for those products with high metabolic and water-loss rates, which as a result, deteriorate rapidly and are characterized by short storage life capabilities. Different studies have been demonstrating which are the optimum storage conditions required for all the different types of fresh produce and maintaining these conditions along the supply chain will ensure the minimal loss in their quality.[85,86]

Temperature is a key factor that is directly related to respiration and metabolic rates of fresh produce. Low temperatures slow down respiration rates, ripening and senescence processes, increasing the shelf-life of fruits and vegetables. Furthermore, they also reduce the growth of pathogenic fungi and bacteria that usually cause the spoilage of these products. Different fresh produce products require different temperature range for their preservation, and it mostly depends of the origin of the produce (see Fig.72). However, excessive refrigeration (f.i. -2°C) can freeze these products, which once defrosted, would end with breakdowns of tissues and consequently the loss of their nutritional quality. Some products can be repeatedly frozen and unfrozen without damage, while others can be ruined by freezing process, producing so called '*freezing injuries*'. On the other hand, some fruits and vegetables (most tropical fruits and certain vegetables) can also be irreversibly damaged by cool temperatures above freezing. This damage is known as '*chilling injury*' and also is irreversible. That is why managing the temperature adequately during the preservation is so important factor.

85 *Advanced preservation methods and nutrient retention in fruits and vegetables. Journal of the Science of Food and Agriculture, Volume 92, Issue 1. 2012. (https://onlinelibrary.wiley.com/doi/abs/10.1002/jsfa.4718)*

86 *Preservative Treatments for Fresh-Cut Fruits and Vegetables. University of California (https://www.researchgate.net/publication/267778743_Preservative_Treatments_for_Fresh-Cut_Fruits_and_Vegetables)*

Fruit	Temperature range (ºC)	Relative humidity (%)	Storage time
Apple**	**-1-4.5** **2-4.5**	90-95 95	4-32 weeks
Apricot**	-0.5-0	85-95	1-3 weeks
Avocado	0-2 4.5-13	**90-95** **85-95**	**10 days** **2-4 weeks**
Banana**	**13.5-15** **12.5-21**	85-95	**2-5 days** **4-21 days**
Blackberry	-0.5-0	85-100	2-3 days
Blueberry	-0.5-0	90-100	2 weeks
Boysenberry	0	90-100	2-3 days
Carambola	10-15	90	5 weeks
Cherry	0	90-95	3-7 days
Cherry	-1-0	85-95	2-4 weeks
Chico	15	85-95	2 weeks
Coconut	0-2	80-95	4-8 weeks
Cranberry	2-4.5	90-100	12-16 weeks

Vegetable	Temperature range (ºC)	Relative humidity (%)	Storage time
Artichoke, globe**	0	90-100	3-4 weeks
Artichoke, Jerusalem	-0.5-0	90-95	8-20 weeks
Asparagus*	0-2.5	85-100	2-4 weeks
Bean*	4-10	85-100	1-3 weeks
Bean, Lima	0-4.5	90	1-2 weeks
Beetroot, bunched	0	95	1-2 weeks
Beetroot, topped	0	90-100	4-20 weeks
Broccoli*	0	90-100	1-2 weeks
Brussels sprout*	0	90-100	2-5 weeks
Cabbage, early*	0	90-95	3-6 weeks
Cabbage, late*	0	90-100	4-16 weeks
Cabbage, Chinese	0	90-95	4-8 weeks
Capsicum	7-10	90-95	2-3 weeks

Fig.72 Recommended storage conditions for some fruits and vegetables, based on RH and Temp. University of Maine.

Unfortunately, this is a very common problem in homes, is that many consumers ignore the proper storage conditions for most fruits and vegetables. As a consequence, almost all fresh produce is usually stored in the refrigerator, causing in this way irreversible damage to these products, as well as shortening their useful life and reducing their quality.

Relative humidity is usually expressed by the moisture content of the air, and it determines the transpiration rate (water-loss) of the fruit and vegetables. When the relative humidity is high, produce maintains more easily its original weight, appearance, nutritional quality and flavor. Low relative humidity increases their transpiration rate, what means the water-loss of produce increases, hence producing the loss in quality and appearance. Leafy vegetables, injured produce and immature fruits and vegetables have higher transpiration rates. For this reason, high relative humidity and low temperature conditions are recommended to reduce the respiration rate of these products and preserve them for longer, while keeping the quality (see Fig.72).

Atmospheric composition can be modified during storage, as gas composition is altered due to metabolic rates of fresh produce. High respiration rate consumes oxygen inside the storage room or chamber and produces high carbon dioxide atmospheric concentrations. Increased carbon dioxide and low oxygen concentration slow down respiration rates of produce, but they need to be closely monitored and controlled along with temperature to ensure any negative effects on quality are avoided.

During the preservation of fresh produce at home, the concentration of different gases inside the refrigerator does not suppose a big problem. Once the door and/or the drawer is opened, these gas concentrations are released into the room air, and this process is regulated automatically. The main issue of atmospheric composition is mainly linked to the preservation of fresh produce in 'insulated cold storage rooms', where the air is in a closed environment and can only be regulated through specific ventilation systems.

Ethylene (C_2H_4) is a plant hormone (gas) released by some fruits and vegetables that affects many plant biochemical reactions and physiological functions. It causes fresh produce to ripen faster, but its high concentrations will shorten the storage life of most fresh produce types. Additionally, some fruits and vegetables are more sensitive to ethylene than others, and their exposure to this gas can create some negative effects on them (see Fig.69).

Pest and disease presence will accelerate the deterioration of fresh produce as they will damage the plant tissues. Damaged fruits and vegetables will release bigger amounts of ethylene gas which will accelerate the ripening process of other produce, shortening their shelf-life and leading to the senescence process. Furthermore, damages produce will spread the infection to other produce. To prevent it, postharvest treatment to control pest and disease is required before storage fresh fruits and vegetables.[87]

87 *Production is only half the battle. A training manual in fresh produce marketing for eastern Caribbean [1988]. FAO.*

Fig.73 Foodborne illness source attribution for Salmonella, E. coli, Listeria, and Campylobacter. Food Poisoning Bulletin.

Sanitation and Preserving Safety

The most important goal to preserve the quality and safety of the fruit and vegetables, focuses on reducing their micro-bacterial flora that normally leads to their deterioration. Sanitation in the washing step is the only way able to reduce microbial load through the production chain. Today, there are different eco-friendly methods, which can be grouped into 'antimicrobial washing solutions', 'biological-based methods', and 'phisical-based methods'.[88]

Among *antimicrobial washing solutions*, the methods most used by the food industry, are: peroxyacetic acid, chlorine dioxide, hydrogen peroxide, weak organic acids, electrolyzed oxidizing water and ozone. They are characterized by the use of chemical solutions that are safe and approved for food treatment. They are usually quite effective, capable of reducing the activity of a large part of pathogens (although not all these processes eliminate them completely). However, its use usually requires special facilities, since in some cases an adequate level of ventilation, control of the electric current or the monitoring of the composition of the chemical solutions is required.

88 *F. Artés-Hernández, G.B. Martínez-Hernández, E. Aguayo, P.A. Gómez and F. Artés. Fresh-Cut Fruit and Vegetables: Emerging Eco-friendly Techniques for Sanitation and Preserving Safety. 2016. (https://www.intechopen.com/books/postharvest-handling/fresh-cut-fruit-and-vegetables-emerging-eco-friendly-techniques-for-sanitation-and-preserving-safety)*

Fig.74 Ultraviolet Light Tunnel System. Source: Campden BRI.

Biological-based methods instead, focus on using certain viruses and other microorganisms, which are able to inhibit the microbial growth of some bacteria. The most used methods are: bacteriocins, bacteriophages, and biological control.

And finally, *physical-based treatments*, focused on using physical processes such as the application of heat, light, sound, high pressure, and electric fields, with the aim of inactivating most of the pathogens present in food. Among these techniques stand out: mild heat treatments, UV radiation, electric fields and pulsed light fields, cold plasma, ultrasounds and high-pressure processing. Many of these methods also need special installations for their use, since they require the use of pressure, electricity, high frequencies of sound, and heat. However, UV radiation technique stands out above the others, since it uses an ultraviolet light of 190-280 nm that offers several advantages: it is easy to use, it does not require extensive safety equipment, and it does not leave any residue on food (Fig.74).

According to the authors of this publication, "UV-C radiation in the range 250-260 nm is lethal to most microorganisms, including bacteria, viruses, protozoa, mycelial fungi, yeasts, and algae ..."[89] It is effective against pathogens of major concern in fruits and vegetables, such as *E. coli, Salmonella spp.*, and *L. monocytogenes (Fig.73)*. Hence, UV radiation is the most reliable and widely used technique today.

89 *idem.*

How Is Fresh Produce Stored Throughout Food Supply Chain?

Today, the food market has become globalized, and as a consequence we consume some products that we did not have access to before. This leads to new studies and publications that increasingly suggest improvements in methods to preserve fresh produce, without compromising their quality and maintaining the longest shelf-life. Most part of these researches agree that for the proper storage of different fruits and vegetables, are required adequate control of temperature, humidity and ventilation.

Analyzing different publications regarding the conservation of fresh fruit and vegetables, by the end of the previous century there were already publications that recommended more efficient methods to preserve these food (Thompson, 1999).[90] According to these publications, most fruits and vegetables could be divided into 3 main groups, defined by shared conservation characteristics. The main factors that were taken into account for their preservation were temperature and relative humidity. As a result, the first group focused on preserving produce at temperatures between 0°C and -2°C, and relative humidity between 90% and 98%. The second group, used a range of temperatures between 7°C and 10°C, and RH between 85% and 95%. And finally, the third group suggested temperatures between 13°C and 18°C, with RH between 85% and 95% (see Fig.75).

These groups share similar characteristics, and the recommended conditions for their preservation normally depends on the environment in which they were grown, their origin. In this way, temperate fruits (apple and strawberry) will require colder temperatures for their storage (around 0°C), as they are adapted to climates in the middle latitudes. Subtropical fruits (pineapple, passion fruit) will require less cold temperatures (7-10°C), as the climate in subtropical areas is also less colder. And tropical fruits (banana, avocado, star fruit) will require warmer temperatures (13-18°C), as they are grown and developed in high temperature climatic areas.

Most berry crops benefit from high RH in storage (95% or greater), which is effective in reducing water loss that compromise their quality. However, according to studies conducted by *Atlantic Food and Horticulture Research Center (Canada),* cranberries store better in lower RH, being between 65%-70%. This suggests that some fruits and vegetables may require lower RH for their storage, but most part of fresh produce have a positive response to high RH.[91]

According to *M.Siddiqui*, author of *Postharvest Quality Assurance of Fruits*, the temperature used for storage fruits and vegetables can not be lower than recommended, because it could produce 'cooling or freezing injuries'. Although, on the other hand, it should remain as low as possible, since lower is the temperature, slower will be the respiration rate and the growth of decay organisms. Furthermore, this also means longer shelf-life. As *M.Siddiqui* lately explains in his book, "water is the main component found in fruits and vegetables. The important factor in maintaining postharvest quality is to ensure that there is an adequate ***humidity*** inside the storage area. Water loss or dehydration means loss in weight, which affects the nutrition quality, appearance, texture and flavor... For most fresh produce, relative humidity of 90%-95% is required, and maintaining it during the storage is compulsory. In modern cold stores humidifiers are used for humidity generation."[92]

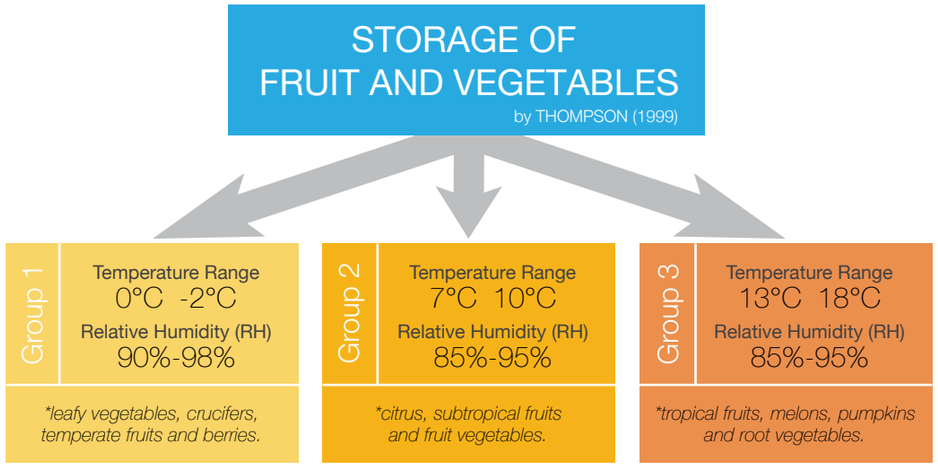


Fig.75 Recommended storage conditions for storage fruit and vegetables (Thompson, 1999).

Controlled Atmosphere (CA) and *Modified Atmosphere* (MO) are some of the examples of 'modern storage processes' used for preserving fresh produce (fruits and vegetables), but also other fresh food such as fresh meat and fish. These processes are used to manage different gas concentrations inside the storage room or packaging, in order to reach the proper storage conditions and extend the storage life of these food. However, these techniques are not cost-effective for storage fresh produce and are not exploited commercially.

Today, for preserving of fresh fruits and vegetables throughout different stages of food supply chain, '***cold chain***' storage is being used (see again Fig.65). This type of storage is the most efficient and cost-effective for preserving of fresh produce and it is characterized by the use of controlled 'cool' temperatures, high relative humidity, and also controlled air composition (or ventilation). For their optimum quality preservation and to extend their storage life, these storage conditions must be kept uninterrupted, in each stage of food supply chain. As a result, 'cold chain' storage is composed by different types of 'cold storage rooms' and refrigerated vans, which serve to transport these produce between different touchpoints (*check 2.2.2 and see Fig.66*).

To verify that all these data are right, I also decided to contact the biggest supermarket chain in Spain, Mercadona. And as they have confirmed lately, the methods they use for the preservation of fresh fruit and vegetables are defined by the use of the cold chain, where a continuous control of proper temperature, humidity and air composition is realized.

And all this makes sense, but what is happening in our homes?

90 *A.K. Thompson. Fruit and Vegetables: Harvesting, Handling and Storage. 1999*

91 *Optimizing the Storage Temperature and Humidity for Fresh Cranberries: A Reassessment of Chilling Sensitivity (2008). American Society for Horticulture Science. (https://journals.ashs.org/hortsci/view/journals/hortsci/43/2/article-p439.xml)*

92 *M. Siddiqui, M.S. Ahmad. Temperature and Relative Humidity. Postharvest Quality Assurance of Fruits. (pp. 27-28)*

HOUSEHOLD PRESERVATION OF FRUITS AND VEGETABLES

HOME REFRIGERATOR

2.2.4 Household Preservation of Fruits and Vegetables: Home Refrigerator

Evolution of the Refrigerator Through History

The purpose of using the refrigerator to conserve food in a domestic environment, arises from the 20s of the previous century. Taking into account the moment in which this appliance was introduced, the lifestyle of the people of that time was very different from the current one. The technological development began to provide society with processed products that were considered as ‘luxury’ item in those times. A few decades later, fast food appeared, offering a ‘speed service’ to busy commuters, travelers and wage workers that did not have enough time to sit down and wait for their meal (see 2.1.1).

Those innovations have influenced the culture and the lifestyle of those times, and the way people were consuming before, can be easily observed through the advertising (Fig.76).

Home refrigerator is considered home appliance that more time has accompanied ‘modern’ man throughout his life. It has been part of our lives and is part of our history. It is an object that can tell how we have evolved over time, and also how our diet has changed with us. Observing the advertising of the first models of the refrigerator, it is evident that food consumption consisted mainly of processed products, where the quantity of fresh products such as fruit and vegetables was limited, almost non-existent (Fig.76). Over time, the goals of society have changed and with them also our diet. The consumption of fruit and vegetables has increased considerably since those times, and currently, more than 20% of our diet is composed of fresh produce (Fig. 77) (see also 2.1.3).

Fig.76 One of the first refrigerators, introduced for domestic purposes during the 1930s.

How Does It Work?

Today, every family in the developed countries has a refrigerator. It mainly works offering two configurations: refrigeration, using temperature ranges of 4°C-0°C; and freezing, with a temperature range of -14°C-18°C. Another common characteristic in modern refrigerators, is that they work maintaining dry conditions in their interior, what means they keep low relative humidity. In fact, the food that is stored inside, normally contains moisture, that is released into the air. Additionally, every time the refrigerator door is open, the humid air of our home also gets into the refrigerator. As a consequence, dehumidification mechanism is used to reduce relative humidity in the interior, in order to preserve the food on its shelves for longer. This works well for the most part of product stored inside, as many of them are kept in own packaging. The reason of reducing the humidity, is because humid environment promotes the growth of bacteria, as they need water to live. Reducing the relative humidity also reduces bacteria activity and their growth. On the other hand, bacteria growth is also slowed by refrigeration process (low temperatures). Therefore, combining these two methods makes the refrigerator a very safe place against bacteria, that consequently extends the shelf-life of the products stored inside. But the main

Fig.77 How the modern refrigerator looks today.

issue of dry environment is that it increases the respiration rates of fresh food, which are usually characterized by a high content of water. This causes the water to evaporate, leading to water loss and consequently loss of quality.

Few decades before this was not a big deal, as previously our population was not eating large quantities of fresh products as we do today. Over time this situation has been changing, and the manufacturers of home appliances have been adapting their refrigerators to consumer requests. This leaded to the implementation of new features and new techniques, which improved the storage of fresh food. One of these features today, is a '*crisper drawers*', that come integrated in every single unit. These drawers usually provide better conditions to store different fresh food such as fresh meat, fish, and fresh produce, offering a temperature around 0°C, and a higher relative humidity when compared to the rest of the refrigerator space. The way in which it usually works, consists of blocking the air inside the drawer, preventing it from escaping to the main area of the refrigerator (dry area). In this way, the water that fruit and vegetables evaporate, remains trapped in the drawer, while raising its relative humidity. But it is hard to find any reliable information about what levels of relative humidity can be actually reached inside the 'modern' crisper drawers, as most refrigerator producers do not provide any information about it. What we know, instead, is that to reach the optimum conditions to storage fresh fruits and vegetables, the proper control of temperature, relative humidity and air composition is required (Fig.71).

ANALYSIS OF THE MAIN HOME REFRIGERATORS ON THE MARKET

BENCHMARK STUDY

2.2.5 Analysis of the Main Home Refrigerators on the Market

Benchmark Study

Taking into account the premises for the proper preservation of fresh foods such as fruits and vegetables, it is important, at this point, to analyze the most recent home refrigerators on the market to draw own conclusions. Different brands on the current market promote a wide range of innovations and almost all of them promote some innovations to preserve different fresh food better and for longer time (here understood as fresh fruit, vegetables, dairy, fish and meat). However, by conducting a deeper research into what processes are being used to achieve these results, I have noticed that most brands prefer not to share this type of information. Despite this, in the following pages I will analyze different products on the current market, providing information about my research and finally draw my own conclusions.

What refers to relative humidity management inside the refrigerators, as it has been explained on previous pages, the air inside the 'fridge' most time is kept dry as humid environment promotes the growth of bacteria. However, relative humidity inside the 'crisper drawers' is always higher, since this condition is necessary to reduce the water loss of fresh products and keep their quality for longer. But the data collected below will show that not always the recommended level of relative humidity is reached as many companies promote it. In terms of temperature management for the proper preservation of fresh produce, there is no remarkable innovation, as since the invention of the refrigerator, they offer two temperature ranges: around 0ºC for refrigeration and around -18ºC for freezing. In terms of ventilation of fresh produce (which refers to the emission of ethylene), different brands have chosen to introduce some innovations that I will later analyze in more detail. Then let's start with different case studies.

Fig.78 Smart Samsung Family Hub Refrigerator can manage itself and your entire home.

Fig.79 Smart Samsung Family Hub Refrigerator helps you to manage a wide range of tasks from its screen.

Case Study: Samsung

I have decided to start my analysis by the company Samsung, since it is the main reference in the area of home appliances and is the company that has innovated over the last decade, not only their refrigerators, but also other electronic products like mobile phones, tablets, etc. As a consequence, their latest model of the refrigerator '*Family Hub*', incorporates a wide range of functionalities that it goes beyond being a simple refrigerator, standing out against its competitors. Samsung Family Hub refrigerator proposes to make the kitchen the center of your home. It helps you to manage your home and your life, with Food Management, Family Connection, entertainment and connected living capabilities, which can be controlled from a 21.5" touchscreen (see Fig. 78).

When it comes to identify which processes and/or technologies Samsung uses to preserve food such as fruit and vegetables, these are not too clear. The latest innovations in which the company has focused its time, have to do more with the connectivity of the refrigerator with the user (user's phone) and the rest of the house, than with the internal improvements and innovations of the product (see Fig. 79). The only information that can be found on Samsung's official website regarding their new *Twin Cooling Plus™ Technology* (used also for fruits and vegetables), is that it ensures to maintain the humidity level up to 70%.[93] According to senior manager of product training at Samsung, Chris Thornton, "food already has moisture trapped inside it and releases that into the air. In a crisper drawer, you're putting the food in an enclosed space where the humidity can't escape. ...You can also use crisper drawers to divide fruits into those you want to ripen faster and those you don't."[94]

93 *New TMF Refrigerator Locks in Moisture & Keeps Food Fresher Longer. (https://www.samsung.com/levant/news/global/samsung-new-tmf-refrigerator-rt7000-locks-in-moisture-and-keeps-food-fresher-longer/)*

94 *How do refrigerator crisper drawers work? 2018 (https://thetakeout.com/how-do-refrigerator-crisper-drawers-work-1826545233)*

What Samsung proposes in this case (although also other companies do), is to use the moisture that the same fresh food loses through the process of transpiration (used to regulate its temperature), in order to maintain a medium-high level of RH in the drawers dedicated for that purpose. But after a short reflection, it is evident that, if there is no external moisture source to regulate the humidity inside these drawers, the fruit will gradually lose its own water content. Besides, this process makes more sense to be used at industrial level, where the doors of the refrigerator remain closed for much longer periods. But at a domestic level, we usually open the refrigerator several times a day, including the fruit and vegetable drawers.

On the other hand, this raises another question related to the level of RH recommended for an optimal conservation of fresh produce that has already been mentioned on previous pages. As already shown on Fig.72, most of fruit and vegetables (excluding tubers) require high RH levels (85% - 95%) for their proper preservation. As already explained above, the air inside the refrigerator is usually quite dry, in addition the excess moisture is extracted in order to reduce the bacterial activity inside, and prolong the shelf life of the food. However, nowadays, the great part of the food we consume comes with its own packaging, hence the possibility of bacterial contamination is reduced. So what humidity levels do the refrigerators use today compared to the previous decades?

Despite this observation, it is important to mention that when observing the design of the drawers dedicated to the preservation of fruit and vegetables (both in Samsung as we will see in other brands), their design is usually not completely hermetic, what makes doubt if they are able to maintain high levels of RH that are actually required for fruit and vegetables (see Fig.80). For that reason, the humid air of the drawers can easily pass to the dryer area of the refrigerator, making it difficult to keep the proper level of humidity in these 'crisper drawers'. In addition, each time we open these drawers, the humid air inside escapes into the air of the house, which is normally between 45% and 65%. In this way, by reducing again the levels of RH inside the box, the fruit returns to "sweat" to balance the humidity of its interior with that of the air on the outside, which increases its "water loss" and decreases the quality of the product.

Analyzing the design of the 'crisper drawer' of Samsung refrigerator, there is no evidence that inside of it there may be much humidity since in such a case, its excess would be deposited on the bottom of the drawer, and it would be necessary to isolate the fruit from the water through some furrows.

In addition, it would be recommended to remove excess water to prevent bacteria from reproducing in it (remember that water is the ideal place for its reproduction). But observing the design of said drawers, no mechanism is observed for this purpose. In addition, in the case of water formation, it would be recommended to extract its excess to prevent bacteria from reproducing in it, but once again, no feature is observed for this purpose.

These theoretical reflections can be very interesting and constructive, but science requires tangible data to be able to measure and demonstrate the facts. For this reason, my next step was to measure with a hygrometer the actual moisture levels and temperature of both "crisper drawers" and to check to what extent my assumptions are true.

Fig.80 Samsung Family Hub Refrigerator has only two drawer dedicated to store all fruits and vegetables.

Fig.81 Samsung RS66N8101S9EF, a simplified version of Samsung Family Hub Refrigerator.

Fig.82 Samsung Twin Cooling Plus™ Technology provides independent freezer and refrigerator cooling compartments.

Fig.83 Open view of the Samsung RS66N8101S9EF, showing the purpose of different storage compartments.

The refrigerator that I am about to analyze below is a Samsung RS66N8101S9EF, which is the simplified version of the *Samsung Family Hub*, since it does not incorporate the touch screen (see Fig.81). Its *Twin Cooling Plus™ Technology* (same as in the previous model), provides two independent cooling systems, one for refrigerator (right side) and other for freezer compartment (left side) (see Fig.82). Taking a look to the internal distribution of this model, it can be seen that Samsung proposes two big drawers dedicated to the conservation of fruit and vegetables, located both in the lower right part of the refrigerator (Fig. 83). However, no

Fig.84 The left side of Samsung refrigerator (freezer side) uses conditions of 60% RH and temperature around -19°C.

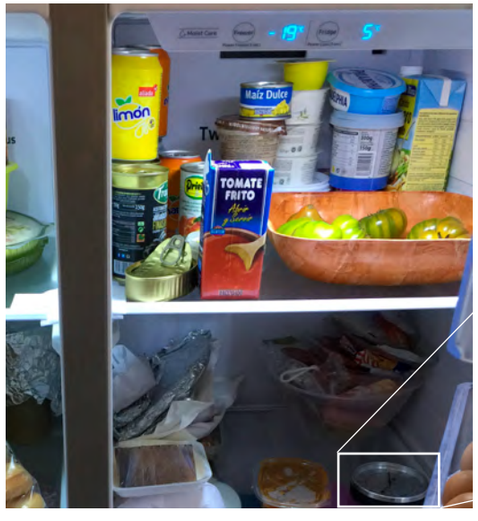


Fig.85 The right side of Samsung refrigerator, uses conditions of RH 85% RH and temperature around 10°C.

Fig.86 The view of Samsung 'crisper drawers' located in the lower bottom side.

type of differentiation between these drawers can be appreciated. Furthermore, it is not even being taken into account the fact of separating the climacteric fruit from the one that is not.

After measuring the humidity in different compartments of the refrigerator, it is observed that the humidity in the freezer area (left side) is usually around 60%, with a temperature of -19°C (Fig.84). Meanwhile, the main area of the refrigerator (right side), keeps RH around 85% and a temperature almost of 10°C (Fig.85). It is not usual for this area to keep so humid conditions, but this is a fact, and there will be some reasons why this brand has made it so.

But what exactly happens inside the 'crisper drawers' of this model (Fig.86)?

Fig.87 Upper 'crisper drawer' of Samsung refrigerator provides conditions of 70% RH and temperature of 5°C.

Measuring the conditions of the first crisper drawer, it is found that the average humidity is about 70%, with a temperature around 5°C (Fig.87). Meanwhile, the second drawer presents conditions of 55% RH and the same temperature of 5°C (Fig.88). However, according the icons they show it is supposed they keep the same storage conditions.

As mentioned on previous pages, 'crisper drawer' stays for a compartment with a high relative humidity that helps to keep fresh produce fresher for longer times. As suggested by different food organizations and several studies, most fruit and vegetables require RH between 85%-95%, but in this case of study Samsung does not reach these conditions. Furthermore, different fruits and vegetables require different temperature ranges for their optimal conservation (Fig. 72). Unfortunately, this condition is not being respected either, since the temperature of both drawers is 5°C. And finally, no mention about ethylene gas is made, so users don´t know if they should keep climacteric fruit away from the rest of 'fresh produce' to avoid the rotting process.

Fig.88 Lower 'crisper drawer' of Samsung refrigerator provides conditions of 55% RH and temperature of 5°C.

Fig.89 Bosch Refrigerator Series 2.

Case Study: Bosch

The next case study is the brand Bosch. First of all, my analysis will focus on the model of the refrigerator series 2, as shown in the image above (Fig. 89). In order to better understand the conditions of food preservation of this refrigerator, as in the previous case, I had to measure the levels of relative humidity and temperature in each of its compartments.

So after analyzing the main compartment of the refrigerator, the results show that its relative humidity is around 60%, with an operating temperature of 5ºC (Fig. 90). In case of 'crisper drawers' these conditions are kept the same (Fig.91). On the other hand, the box dedicated to preserve fresh meat and fish, maintains a temperature of 2ºC and RH of 50% (Fig.92).

It is important to mention that once again, the refrigerator analyzed here does not maintain the recommended conditions for the proper preservation of fruit and vegetables according to the data provided on previous pages. As in the previous case study, it is easy to observe that 'crisper drawers' are not isolated from the main compartment, and therefore they are not able to keep high RH levels. No different temperature ranges are used here as those recommended on Fig. 72. Neither, the company propose to separate climacteric fruit from the rest of fresh produce, in order to avoid these products ripen faster and decay.

Fig.90 Analyzing Bosch Refrigerator Series 2.

Fig.91 Measuring RH and temperature inside the 'crisper drawer' of Bosch Refrigerator Series 2.

Fig.92 Measuring RH and temperature inside the 'crisper drawer' of Bosch Refrigerator Series 2.

Fig.93 New Fresh by Design™ Bosch Refrigerator.

Fig.94 This refrigerator comes with FarmFresh System™ that keeps your fresh food fresher and for longer.

Case Study: Bosch II

The following case study is the new *Fresh by Design*™ refrigerator produced by Bosch for an American market. The brand describes it as the world's most advanced refrigerator with a new, best-in-class freshness system and innovative features designed to keep your food fresher and for longer (Fig.93). The aim of this refrigerator is to provide proper preserving conditions not only for fresh meat and fish but also for fresh fruit and vegetables.[95]

A new FarmFresh System™ technology used in this model, incorporates four different features (Fig.94):

VitaFreshPro™ is responsible of automatic temperature and humidity control (Fig.95).

FreshProtect™ prevents food from ripening too quickly (Fig.96).

AirFresh® Filter absorbs odors (Fig.97).

MultiAirFlow™ feature ensures to keep a consistent temperature inside the main compartment (Fig.98).

It is true that this model is only available on the American market, and here in Europe they do not sell it, but *VitaFresh* technology developed by Bosch is also being incorporated into European refrigerators, so we can preserve our food for longer, even on this side of the ocean. On the following pages I will analyze these technologies in more detail and compare all the data gathered about it.

95 *Fresh by Design™ by Bosch. Official website (https://www.bosch-home.com/us/specials/fresh-by-design)*

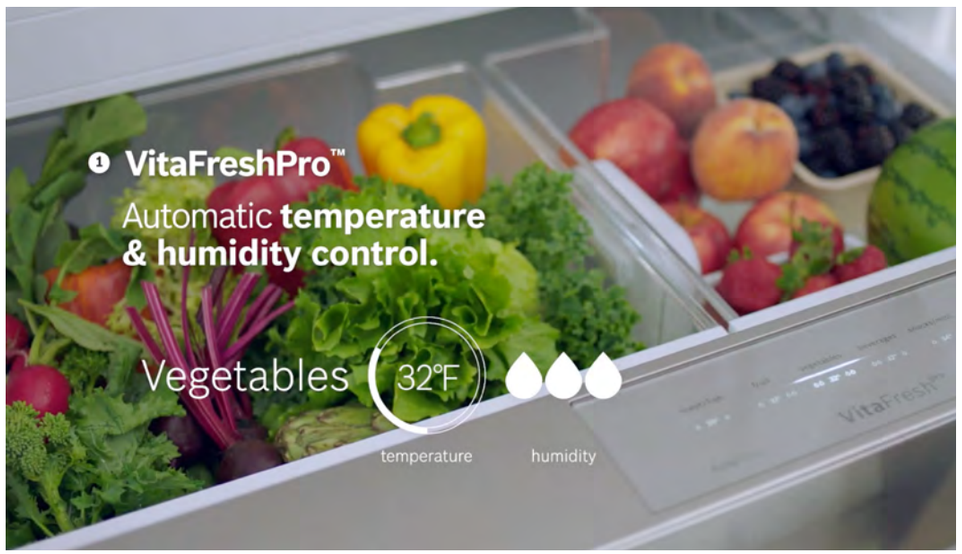


Fig.95 VitaFreshPro™ feature of Bosch refrigerator controls automatically temperature and humidity.

Fig.96 FreshProtect™ feature of Bosch refrigerator prevents food from ripening too quickly.

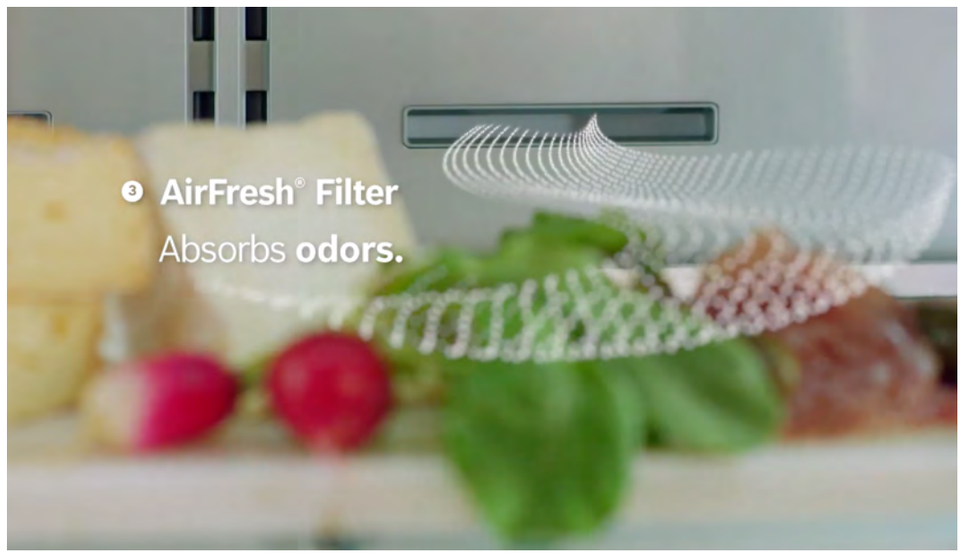


Fig.97 AirFresh® Filter of Bosch refrigerator absorbs odors.

Fig.98 MultiAirFlow™ feature of Bosch refrigerator ensures to keep a consistent temperature.

Fig.99 VitaFresh Pro Technology by Bosch, is able to keep your food fresh up to 3 times longer (European refrigerators).

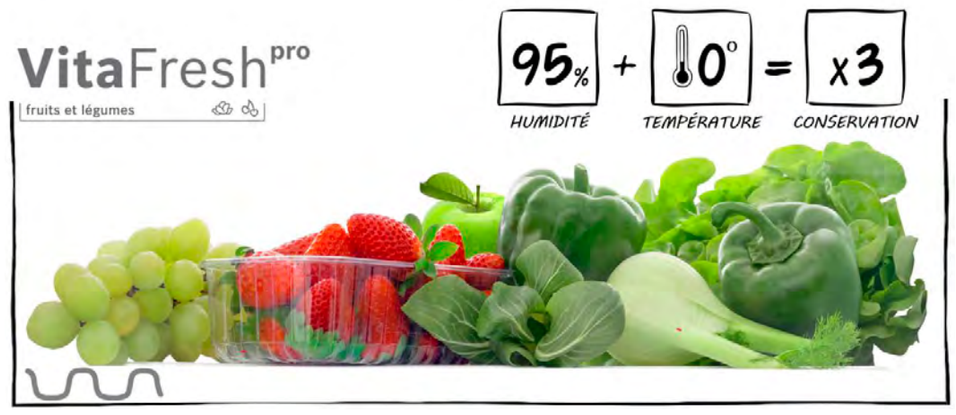


Fig.100 VitaFresh Pro Technology by Bosch, can reach till 95% of RH to extend the shelf-life of produce.

As it can be found on the official website, the new *VitaFresh*^{PRO} Technology is able to preserve your food fresh up to 3x times longer (Fig.99). It has an independent cold circuit that allows to regulate the temperature of this zone independently of the rest of the refrigerator. A temperature between -1ºC and 3ºC can be selected, and it is stable and precise in this area. It consists of two drawers: one for meat and fish, and another for fruits and vegetables with a humidity regulator and three possible positions: high humidity (for vegetables), intermediate (mixed produce) or low humidity (for fruits).[96]

According to the research carried out throughout this thesis, the three main conditions for the optimal conservation of fresh foods such as fruit and vegetables are the control of humidity, temperature and ventilation (mainly focused on reducing ethylene concentrations). And as we can observe, the latest technological innovations in Bosch refrigerators try to cover each of these aspects.

Unfortunately, today, this type of refrigerator is only available in the US market and in Canada. European versions of the Bosch refrigerators are only presented with the *VitaFresh*^{PRO} Technology, but do not incorporate ***FreshProtect***^{TM} feature, the filter used to trap the excess of ethylene gas, responsible for making the fruit mature excessively quickly, while shortening its shelf-life. But beyond the technological preferences of the company in different markets, I have decided to contact Bosch company to find out exactly how the *VitaFresh*^{PRO} system works. After a long conversation, the Bosch Home Appliances team told me that *VitaFresh*^{PRO} system works by using the condensation produced by stored fruit and vegetables, and that there is no any external moisture source to control these levels.

Even if these drawers appear to be better hermetically sealed if compared to other case studies. They obtain the moisture released from the fresh fruit and vegetables stored inside of them. And each time these drawers are opened, part of that humidity gets lost, and it will raise again only if these fruits and vegetables begin to 'sweat' again, leading to water-loss of fresh produce.

On the other hand, it is important to keep in mind that Bosch does not make a big mention of the differences between fruit and vegetables, in fact they propose to preserve these foods in the same drawer as shown on the European versions of their refrigerators (Fig.99). Only in the Fresh by Design™ model (produced for American market), it can be observed that these products are kept separately. While using the same technology for different markets, this fact seems contradictory.

What refers to ethylene gas emissions by climacteric fruits, Bosch proposes to use a filter that absorbs this gas, and even this feature is only available for American market, this is a great great solution against ethylene gas. This filter seems to be a great solution but users must keep in mind it should be replaced every time its filtration capacity decreases. Another innovative feature this brand proposes is the use of 'air filter' able to absorb different odors, in order to avoid bad smell inside these drawers, which may impact on organoleptic properties of these foods.

96 *A Comprehensive Guide to your Fridge's Humidity Drawers. Bosch. (https://www.bosch-home.com.sg/experience-bosch/living-with-bosch/fresh-reads/a-comprehensive-guide-to-your-fridges-humidity-drawers)*

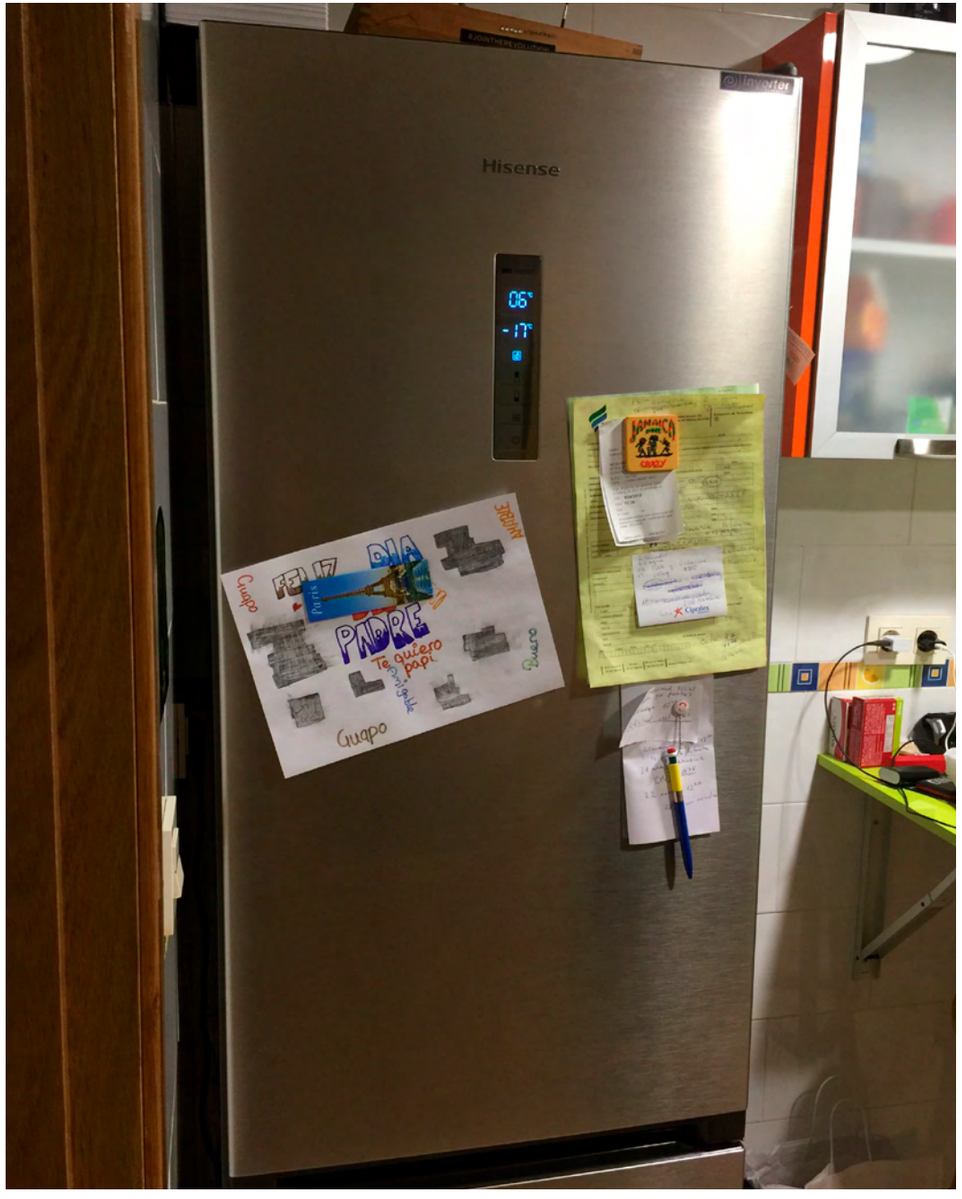


Fig.101 Hisense refrigerator

Fig.102 The main compartment of Hisense refrigerator

Case Study: Hisense

In the case of the company Hisense, the analysis carried out has provided additional data on humidity and temperature levels in different areas of this refrigerator. As can be seen on the pictures above, the operating temperature of the main compartment is about 7ºC, with a relative humidity of 65% approximately (Fig.102). This model of refrigerator presents two 'crisper drawers' for the preservation of fresh food (Fig.103).

The upper box is intended for the preservation of fresh meat and fish, keeping the temperature around 0ºC, and relative humidity around 60% (Fig.104). On the other hand, the lower drawer is intended for the preservation of fresh fruit and vegetables, and its working temperature is of 5ºC, while the humidity is set at 75% (Fig.105).

As in previous cases study, it is assumed that RH is obtained from the condensation of water fresh fruit and vegetables release. These drawers aren't insulated, and although the humidity level in the second drawer is high, it can still be improved. This refrigerator incorporates only one drawer for all fruit and vegetables, what means climacteric fruits are not separated from the rest of the produce. Furthermore, no ethylene filter could be observed here and this will lead to ethylene injuries.

Fig.103 Hisense refrigerator incorporates two different drawers for the preservation of fresh food.

Fig.104 Hisense upper drawer is intended for the preservation of fresh meat and fish.

Fig.105 Hisense lower drawer is intended for the preservation of fresh fruit and vegetables.

Fig.106 Siemens refrigerator with its HyperFresh Technology used for the preservation of fresh food.

Fig.107 Siemens control display.

Case Study: Siemens

Siemens, in turn, offers a technology called *HyperFresh*, which, like Bosch, claims to be able to extend the shelf-life of fresh foods up to 3x times longer. However, there is no more information on the method and technologies they use to keep the moisture inside the drawers. The company neither provides any additional information about the humidity levels used to the proper preservation of fresh food by their refrigerators.

But taking into account previous cases study and observing the design of these 'crisper drawers', it does not seem to be different from the others. So, once again, it can be assumed that this *HyperFresh* technology does not create humidity inside the drawers, but retains that released by the produce.

Siemens provides only one drawer to preserve fresh fruits and vegetables, what makes clear they do not take in consideration the differences between climacteric fruits and the rest of produce. What they suggest is that fruits should be stored in low humidity environment. Mixed produce (fruit and vegetables together) should be kept in medium humidity, and wet conditions are required for storage of vegetables. No separation between storage of fruit and vegetables is observed (Fig.108). Furthermore, there is no evidence of any ethylene filters inside the drawer, used to trap its concentration to avoid fresh produce to spoil too quickly. *HyperFresh* and *HyperFresh Plus* technologies integrated into the most recent Siemens refrigerators allow you to control humidity level by sliding and steering wheel mechanisms (Fig. 109).

Fig.108 Siemens HyperFresh and HyperFresh Plus drawers intended for the preservation of fresh food.

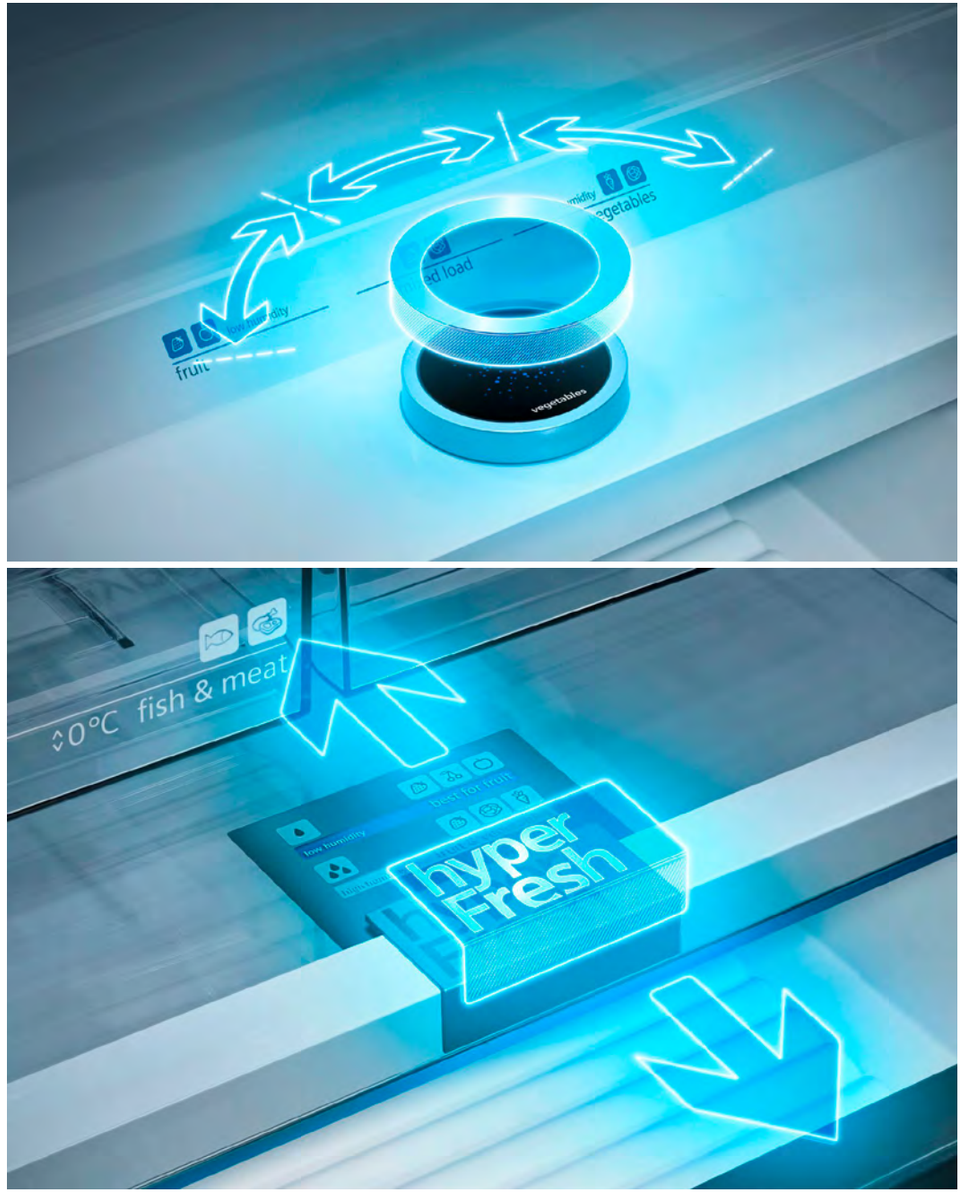


Fig.109 Siemens HyperFresh and HyperFresh Plus wheel and slider mechanisms used to regulate the humidity.

Fig.110 Whirlpool refrigerator.

Fig.111 Look into the Whirlpool crisper drawers.

Case Study: Whirlpool

Whirlpool, like its competitors, has also innovated the drawers for fruit and vegetables. In fact, on their FAQs page, it is said that moisture in the vegetable drawer is normal. "As the water in the vegetables evaporates, it strikes the cold surface of the refrigerator, hence resulting in formation of water droplets. The humid air over the vegetables is however swept away by the dynamic airflow inside the refrigerator, keeping your vegetables fresh."[97] But, how much moist can be reached then?

The company does not provide any additional information about it, but what is clear is that this humidity comes from the food stored in the drawers. The only system that is used here is a humidity slider that allows to open or close these small grooves that increase or reduce the airflow between these crisper drawers and the main compartment of the refrigerator (Fig. 111). Anyways this doesn't seem to be the best solution to humidity issues as without any external source of moisture, these food will keep losing their water content, hence decreasing their nutritional quality. On the other hand, there is not a separation between climacteric and non-climacteric fruits, as they use mixed produce storaging. Furthermore, any ethylene filter could be observed what means that its amounts will rise time by time (in cases when these drawers haven't been opened for long periods of time) and fasten the rotting process of the produce that is susceptible to this gas. However, since 2015 Whirlpool corporation

97 *Whirlpool FAQs page. (https://www.whirlpoolindia.com/faq/refrigerators#gref)*

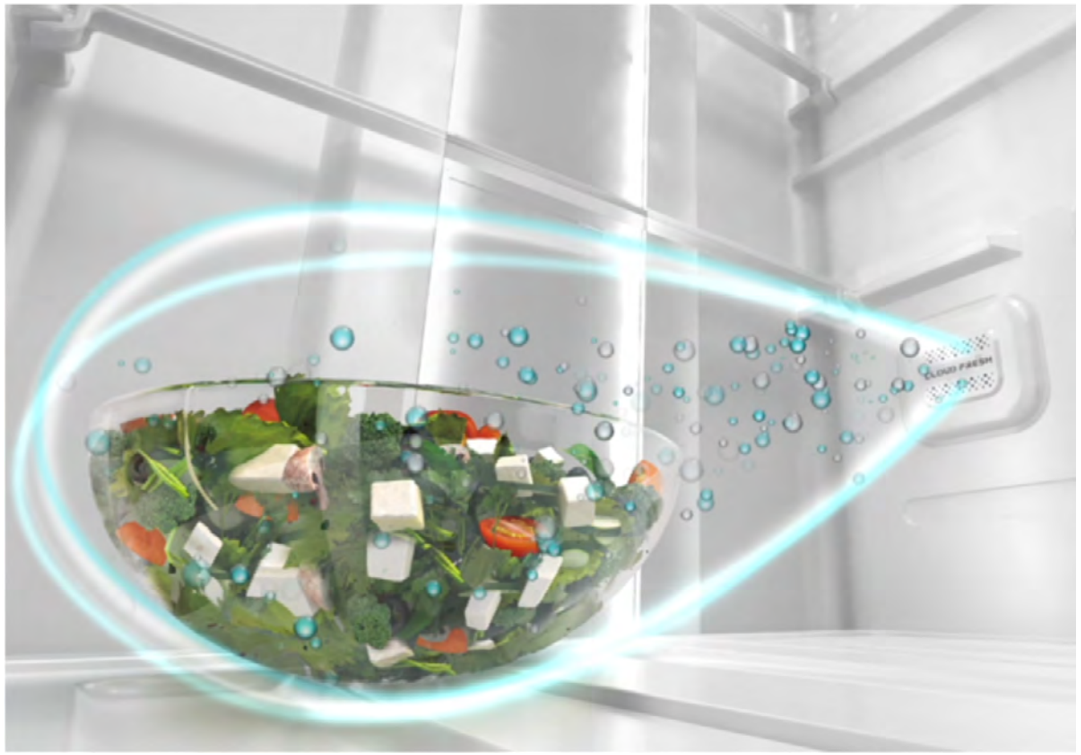


Fig.112 Whirpool's Sense CloudFresh Technology.

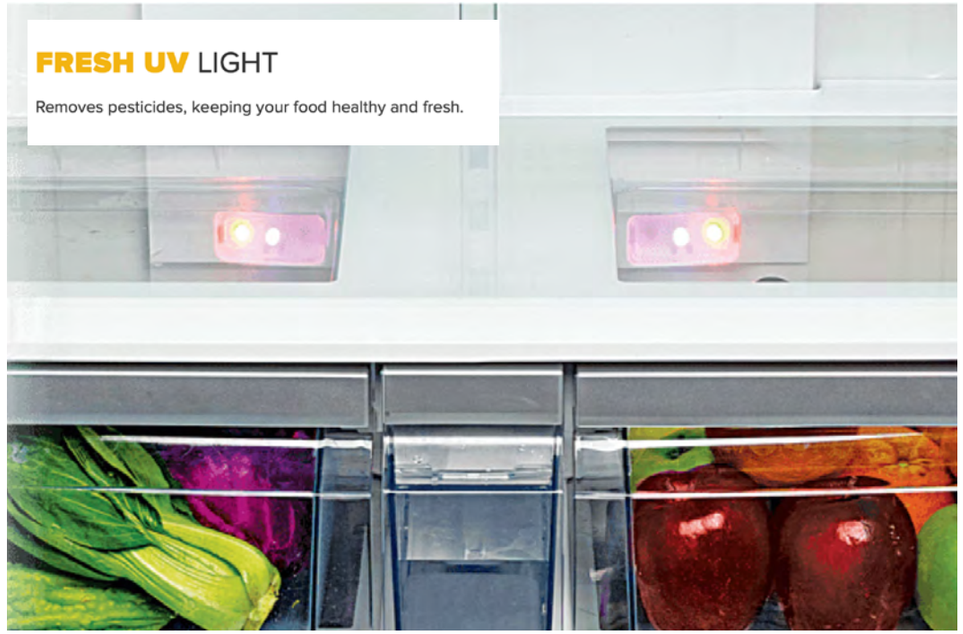


Fig.113 Whirlpool's Fresh UV Light that aims to remove pesticides and bacteria.

has patented a new system to remove ethylene concetrations via a photocatalytic process that converts ethylene into carbon dioxide and water. The result is not only is the ethylene reduced, the carbon dioxide produced limits the ripening of the produce it surrounds.[98]

The main reason why I included this brand is because Whirlpool has added some interesting features to improve the preservation of fresh produce in their refrigerators (including mentioned above). They have also been innovating their Sense CloudFresh Technology (6th version) which creates a cloud of multi-ions that are able to remove 99,9% of bacteria but also odors that some fruit and vegetables produce (Fig. 112). As a result, this becomes a very interesting feature to take into account in the following steps of the development of this project.

On the other hand, this company has also developed Fresh UV Light system which removes pesticides and kills bacteria and reduces pecticides that may be present on the surface of these foods (Fig. 113). However, UV wavelenghts only kill bacteria on areas where this light reaches, what means there are still shaded areas where bacteria and molds can keep growing.

98 *The link to this patent. (https://patentscope.wipo.int/search/en/detail.jsf?docId=US152767151)*

STUDY CONSLUSIONS AND

DESIGN POSSIBILITIES

Study Conclusions and Design Possibilities

After the analysis of the previous case studies, different points have been taken into account. In first place, what concerns **relative humidity**, many papers and researches suggest most part of fruit and vegetables require high relative humidity levels for their proper preservation. Modern 'crisper drawers' usually trap the moisture released by fresh produce stored inside of them. These drawers commonly integrate different 'sliding mechanisms' able to open tiny slots which will release part of the moisture from these drawers into the main compartment of the refrigerator, or just keep it. In any case, none of the refrigerator analyzed previously was able to reach these recommended ranges, what suggests that an external source of humidity will be required to accomplish this need.

In second place, it is difficult to imagine that by using water evaporated by fresh fruit and vegetables in the crisper drawers, it will be possible to achieve high humidity conditions (90-95%), since certain factors would prevent it from getting there. According to the laws of physics, at lower temperatures (here 0ºC) the evaporation decreases, hence the water content released into the air by fruit and vegetables would be also lower. The transpiration rate (water exchange) of fresh produce decreases at lower temperatures (2.2.3). As a result, fresh produce won't be able to release so large amounts of water to get high RH ranges inside these drawers. Making a hypothesis that the drawer stores large amounts of fresh produce, this fact could help to reach these amounts faster. But after several uses of the refrigerator per day (by opening and closing of these drawers), part of that humidity will be releasing into the room. As a result, the humidity will be lost time by time, what confirms the need of any alternative system to increase humidity levels, the same way as it is done in other *Food Supply Chain* stages.

During the analysis of food refrigerators concerning **temperature management**, it was noted that any single company has provided different temperature ranges to storage fresh produce. As you have seen on previous pages (see Fig.72), different fruits and vegetables may require different temperature ranges, and if these requirements are not respected, several injuries could occur (p.131). Among all the companies analyzed here, only *Bosch* advices their consumers that some fruits and vegetables should not go inside the refrigerator, but must be stored outside of it.

Going back again to the case studies, it has been mentioned that fridge producers often suggest preserve fruits in low RH conditions, while vegetables in high RH conditions. It doesn't make sense, as different studies showed that most part of fresh produce require high RH ranges (mostly 85%-95%) for their proper preservation. The main reason why most brands might suggest this, is because "low humidity" means drawer sliders should be set as open. This releases humid air and a mix of gases from these drawers into the main compartment of the refrigerator. One of these gases is ethylene. So, when these brands propose to use low humidity settings for fruits, what they really pretend is to reduce ethylene concetrations inside the crisper drawers. This brings us to the next point, air composition.

Storage conditions concerning **air composition management**, are also an important factor when it comes to storage fresh produce. The gases contained in the air that surround

Fig.114 Dyson UV light technology able to kill 99,9% of bacteria in the water.

these foods can impact on the respiration rate, accelerating it (high O_2 levels) or reducing it (high CO_2), or otherwise accelerate its rotting process (high C_2H_4). In terms to avoid negative impacts on storage life and the quality of these food, a management of these gases is required. The advantage of the home refrigerator in these terms is that, unlike the industrial storage rooms, its use is more frequent. People use their refrigerators several times a day, what helps to improve air ventilation, specifically inside the crisper drawers. This reduces the issue of the increased concentrations of some gases, but it doesn't really solve this problem. However, **ethylene** is the most harmful among them, as it accelerates ripening and senescence processes in fresh produce.

Therefore, ethylene management is of importance along the supply chain. Generally, most fruit handling companies and storage facilities rely on various traditional methods such as air ventilation, the use of ethylene adsorbers and oxidizers, or the use of air filtration equipment based on catalytic oxidation / photocatalysis and ozone generators.

Currently, there are two main types of inhibitors to highlight. On one side, the use of ethylene filters able to reduce ethylene gas concentrations when its level rises. These filters are already being used by some brands in home refrigerators, but the drawback is that every time their effectiveness is compromised, they must be replaced. To make it work properly, an ethylene sensor should be used to analyze its concentrations and remind the user to replace the filter when required.

On the other side, for the ethylene removal in fruit storage at the industrial level, *Photocatalytic Oxidation* (PCO) and *Vacuum Ultraviolet Light* (VUV) *Photolysis* are being used.[99] These systems do not require maintenance by the user (as with filters) and they can keep low ethylene gas concentrations automatically. Analyzing these two processes in depth, it has been found

99 *Efficacy of photocatalysis and photolysis systems for the removal of ethylene under different storage conditions. Postharvest Biology and Technology. Volume 147, January 2019, Pages 68-77*

CRISPER DRAWERS

MAIN PROBLEMS

UNAPROPRIATE HUMIDITY LEVELS

- RH levels newer reach 90-95% (as recommended),
- They use humidity released by 'fresh produce',
- Not properly insulated to reach high RH,
- When open, they lose part of stored RH.

UNAPROPRIATE TEMPERATURE RANGES

- Some produce (exotic fruits) require warmer temperatures for proper storaging as commonly used temperatures (0-2°C) can lead to freeze injuries.

UNAPROPRIATE ETHYLENE TREATMENT

- Most refrigerators don't use any system to treat ethylene gas produced by 'climacteric fruits',
- High concentrations of this gas shorten the 'shelf life' of fresh fruits and vegetables.

UNAPROPRIATE SHARED STORAGING

- Climacteric and non-climacteric fruits should not be stored together due to ethylene gas injuries,
- Most brands use mixed storaging for fruits and vegetables (only one drawer, etc.)

'POOR' DESIGN

- Recommended storage conditions are newer met,
- Brands don't explain and don't guide users to storage fresh fruits and vegetables properly,
- Icons on the drawers aren't very useful (or clear).

that under conditions of high relative humidity and low temperature, *VUV photolisis* is more effective, so it would be the most recommended to use in the future refrigerator concepts (more detailed information will be provided in the next chapter).

While the problem of humidity management can be improved by the use of an external humidifier, a new problem is appearing. High humidity levels also promote the **bacteria growth**, even if it is slowed down with low temperatures. However, as discussed previously (pp.88-89), the use of UV Radiation could be a great solution for this case (or some other technologies). In fact, this technology is already being used by food industries for decontamination and safety reasons for fruit and vegetables. Recently, also Whirlpool started using this UV light in their 'crisper drawers', to remove pesticides and bacteria. In addition, since 2015 this technology has been also used by Dyson in their Home Humidifier, which is capable of killing 99.9% of bacteria present in water that it evaporates (Fig.114).[100]

At this point, the possibility of using this 'bacteria-killing mechanism' to disinfect the produce, is gaining ground. To prevent the bacteria growth inside the 'crisper drawers' is possible through the use of UV light in the similar way as Whirlpool does. The main drawback of this technology is that it's only effective on surface (only areas where the light can reach), since it can't penetrate to the internal tissues. This leads to the shaded areas where the bacteria won't be killed, thus must be solved in any different way. By using this method, it would be required disinfect each fruit and vegetable separately (one by one), or make them go through the UV light tunnel, as it is done by large food industry. Even though, UV light still kills bacteria and its efficacy much higher when compared to not using any "bacteria killing" system. Hovewer, in the next chapter these methods will be reviewed to decide which one is the most recommended for home use.

Another point to analyze here is linked to the RH in these drawers and **excess water draining**. Using high RH levels for the preservation of fresh produce leads to high water condensations in the air. This condensation is also deposited on the surface of the food in the form of small water drops, that may trap different bacteria, pesticides and dust. This excess of water is then deposited on the bottom of the drawers, and should be drained out from them.

At this point, the first option is to create a "closed water recycling system" able to collect that water into the water chamber, but previously filter particles and disinfect it from bacteria, the same way Dyson does. As a result, this water will be cleaned and could be reused by the humidifier again. However, part of that humidity will be lost each time these drawers are open so the user will be requested to fill out this chamber time by time.

The second option, is to use a "continuous water system", in which the refrigerator is connected to a water inlet that provides a clean water for the humidifier, but also for the ice maker system (this system in Samsung refrigerators already uses this type of water inlet). The excess water formations in the drawers is drained out the same way a sink does. This ensures that the humidifier always use clean water that is free from bacteria and many impurities.

100 *Dyson's Humidifier Uses UV Light To Kill Germs. (https://www.gizmodo.com.au/2014/10/dysons-humidifier-uses-uv-light-to-kill-germs-in-its-water-reservoir/)*

Eating more vegetables is sustainable for the planet and is sustainable for the body.

CONCLUSIONS

CHAPTER 01 - CHAPTER 02

Conclusions: Chapter 01-02

Food plays a very important factor in our lives, since it is the source of energy that our body uses to breathe, think, move, and generally to live. When we eat, our body absorbs different macro and micronutrients from the food, and transports them to different parts of the body, which are used for the correct functioning of our organs. In this way, consuming quality food is essential, as it will help to enjoy good health and improve our quality of life.

Over the last decades, our diets have been changing, and we are continually moving towards the healthier and nutritionally rich consumption. A healthy and balanced diets that many nutritionists promote around the world, usually include big amounts of fruit and vegetables, due to their high content of macro and micronutrients, such as minerals, vitamins and fiber, they promote our health. Even though our consumption has improved over time, the human population keeps growing and projections say that by 2050 we will require another 70% of extra food. This has become a huge problem, and different organizations are looking for new solutions.

One of the biggest problems of the modern society is the **food waste**. One-third of all the food produced worldwide is wasted. In developing countries, the biggest part of this waste is produced even before it gets to the consumer. In developed countries, instead, we waste more during consumption (mainly at home and restaurants), over 20% of which are fruit and vegetables (see again Fig.32).

Food waste has become a huge problem of the modern society, mainly because it leads to different economic, environmental and social impacts. While in some parts of the planet people die of obesity (mostly developed countries), in many other parts (mostly developing countries), people die of hunger. Reducing this food waste has become a matter of international urgency, and it is the only way to keep a sustainable population growth. Preventing the food from being wasted could help to feed part of today's society, but also the future generations.

Fresh fruits and vegetables are the most recommended and also the most wasted around the world. These foods are perishable and they require specific conditions for their proper preservation. As a result, these were the main factors of my research and the turning point in my subsequent approach, in terms of finding out the main reasons we waste so much fresh produce at home, and how this waste could be minimized.

There are different factors affecting the quality and storage life of fresh fruit and vegetables. These are usually divided into preharvest and postharvest factors. With the focus on developed countries (Western World), their wealth allows to use more efficient processes and technologies during food production, what allows to waste less in these phases and provide top-quality produce. Even though less food is thrown away during its production, storage and distribution, consumers waste more during consumption.

Once collected, fruit and vegetables require specific storage conditions to preserve their quality and extend their shelf-life. Time from harvest, temperature, relative humidity, air composition, pest and diseases are the most important factors taken into account to reach these objectives when preserving fresh produce throughout the different stages of *Food Supply Chain* (FSC). However, after having analyzed different modern refrigerators on the market, it has been found that there are some discrepancies between the industrial methods used for storage of these produce, and those provided by main manufacturers of home appliances.

In the **next chapter**, I will focus on redesigning the modern refrigerator by enhancing its capabilities. The aim is to improve this product at home level (in developed countries) by extending the shelf-life of fresh produce, thus reducing its waste. As the modern refrigerator works well and it properly preserves the most of the foods we consume today, I will only focus on the part that concerns the preservation of fruit and vegetables, while keeping the rest of the refrigerator in the same way. Enhancing the performance of today's 'crisper drawers' is still possible through the implementation of the most efficient techniques used in different stages of *FSC* for the preservation of fresh produce. These techniques will maintain quality and nutritional value for longer, extend shelf-life, and help consumers to save their money. Another requirement will be to design an interface to help the user with food preservation and guide him in each phase of the use of the new refrigerator at home.

THESIS OBJECTIVES

REDUCE FOOD WASTE OF FRUITS AND VEGETABLES (AT HOME)

+

IMPROVE CURRENT PRESERVING TECHNIQUES OF HOME REFRIGERATOR

MAIN REASONS

What food am I going to preserve? + Where is it going to take part? + How am I going to do it?

WHY

They are the healthiest and the most recommended foods to consume, due to their high contents of macro and micronutrients.

20% of our diet is already made up of fruit and vegetables, and their consumption trend is also growing.

They are easily perishable products that require specific conditions to be stored properly.

WHY

In developed countries almost 50% of all food is wasted during consumption (20 of that food are fruits and vegetables).

Preserving fruits and vegetables at home can still be improved.

This will help to reduce amounts of food we waste, thus reduce economic, social and environmental impacts it produces

WHY

Fruits and vegetables require specific storage conditions for their proper preservation.

Storage conditions used in home refrigerators don't match those used through different stages of Food Supply Chain.

Home refrigeratos should guide the user to storage fresh produce properly but also explain the advantages of following these advices.

CHAPTER 03

SmartFresh PRO

Advanced Preservation
of Fresh Produce
at Home

DESIGN BACKGROUND

Explain what relevant research data is used as the main focus of the project.

3.1 DESIGN BACKGROUND

3.1.1 Premises

The world we are living in is developing very quickly. Cities are growing more and more, displacing large masses of the population to these urban areas. This shift has influence on our family composition, on our habits and behaviors, and on the way we consume.

As our society continues to grow, the consumption of resources also increases. The consumption of food has also increased over the last decades. According to the predictions, to fulfill the future demand of the food, we would have to increase its production by 70% by the 2050. However, not all foods are perceived in the same way. Foods such as fruit and vegetables are considered the healthiest and the most recommended for our health, due to the large amount of macro and micronutrients they contain. But the biggest drawback of the fruit and vegetables is that they are perishable, and their preservation is much more complex since it requires specific storage conditions. As a result, this means that fresh produce is the most wasted worldwide, so reducing their waste has become a very important issue today.

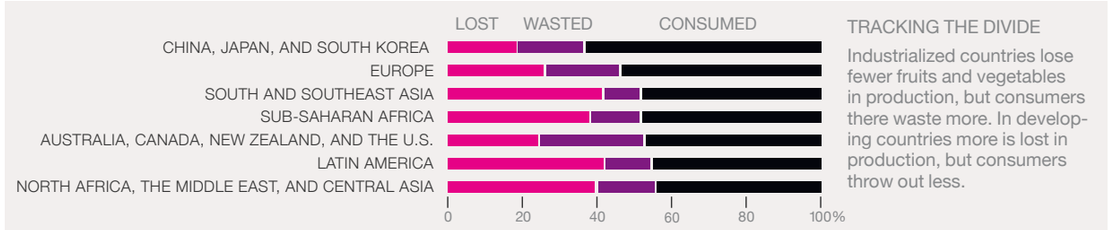
According to data provided by FAO, around 50% of the world's production of fruit and vegetables gets wasted (see Fig. 115). Taking into account that 55% of the current world is urbanized and this trend continues to grow, looking for solutions to reduce this waste in big cities is gaining ground. Developed countries can afford to use the latest technologies in the food industry (FSC), which is translated into proper preservation techniques during these stages, higher food quality, lower food waste ranges, and optimum food conditions when they reach the consumer. The way these produce will be handled and stored at home, will basically define their final quality and shelf-life, as well as the amounts that will be discarded in the end. For this reason, we have a huge responsibility on how the food in our homes will be consumed and what part of it will be lost or wasted.

Fruit and Vegetables Supply Chain

Along the supply chain fruits and vegetables are lost or wasted at higher rates than other foods. Easily bruised and vulnerable to temperature swings en route from farm to table, they're also usually the first to get tossed at home.

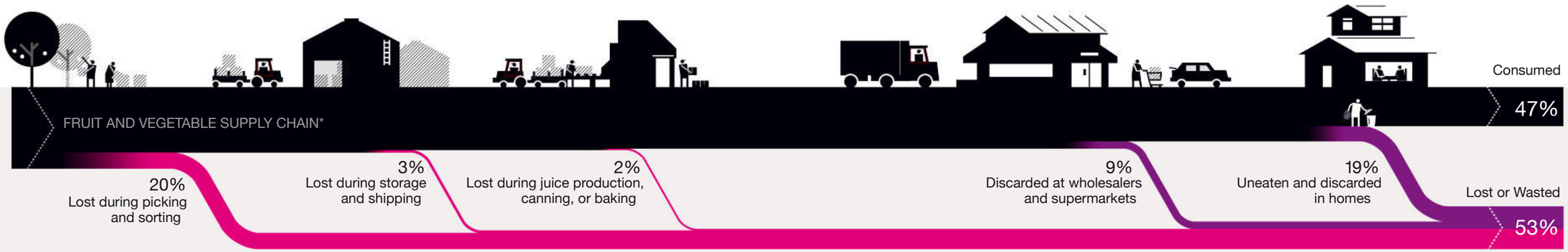
LOST
Produce abandoned or discarded during harvesting, shipping, or processing.

WASTED
Produce discarded by vendors or consumers, often because of damage or expiration dates.



TRACKING THE DIVIDE

Industrialized countries lose fewer fruits and vegetables in production, but consumers there waste more. In developing countries more is lost in production, but consumers throw out less.



*AUSTRALIA, CANADA, NEW ZEALAND, AND U.S. DATA ONLY

MANUEL CANALES, NGM STAFF; TONY SCHICK. SOURCE: FAO

Fig. 115 Waste of Fruit and Vegetables during different stages of Supply Chain. Data provided by FAO.

DESIGN SCENARIO

How the project approach is applied to a specific scenario for further development.

3.1.2 Design Scenario

The waste of fruit and vegetables we usually generate at home, can occur for different reasons. Among the most common factors are: buying too much food, storing them inappropriately, not consuming them in time, considering them as “cheap“ goods, etc.

Hovewer, extending the shelf-life of fresh produce, could cover some of these factors. This will also maintain the quality of fruit and vegetables for longer and significantly reduce the amount of its waste.

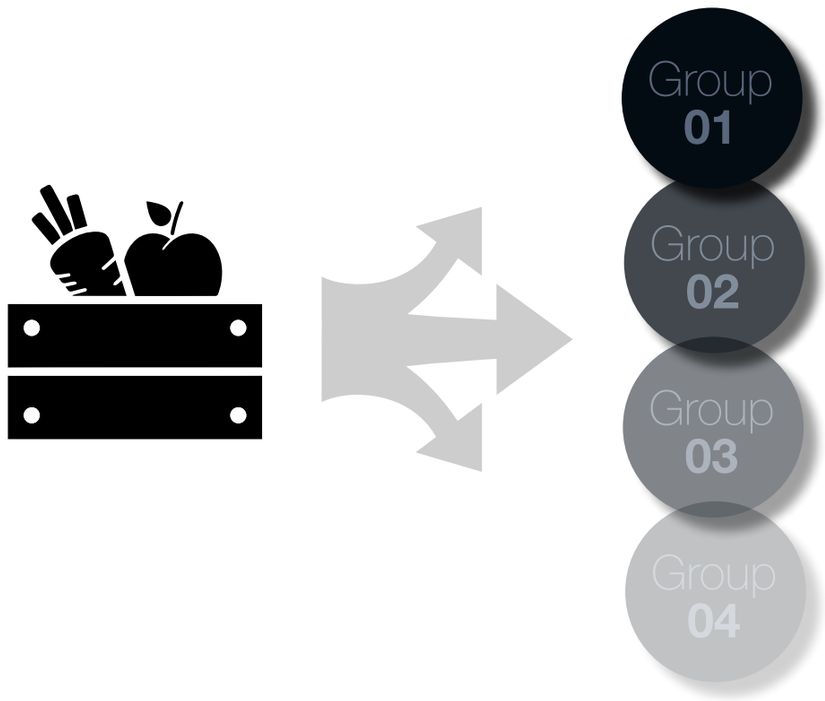
What if the fridge in your home could teach you how to cook, how to preserve food, how to reduce food waste and also help you to save your money?

Proper preservation of different types of fresh produce requires the use of special storage techniques. Throughout the whole FSC, including restaurants and supermarkets, workers are trained about how to handle and store these products properly. On the other hand, consumers at their homes most time ignore these rules, and this leads to the data we already know. The lack of ‘food labels’ on fresh produce is another huge problem, as the useful information that is normally provided on them (such as nutritional value and recommended storage conditions) is missing. Moreover, as explained in previous case studies, the home refrigerator doesn’t preserve these products correctly, leading to shortening their shelf-life and quality in different ways.

In order to improve the preservation of fruit and vegetables at home, the techniques used by the food supply chain should be reviewed and implemented into a home refrigerator. As a consequence, this will require to redesign current ‘crisper drawers’ into a much more sophisticated ones, and then provide a system able to guide the user towards the correct food preservation at home.

REDEFINING FOOD GROUPS

Analyze different types of fruit and vegetables and divide them into new compatible groups. Hence, the data obtained will be used to proceed with the development of this project.



3.2 REDEFINING FOOD GROUPS

3.2.1 Data Analysis

Among the key variables affecting the storage life and eating quality of fruit and vegetables are:

- *time from harvest*
- *temperature*
- *relative humidity*
- *atmosphere composition*
- *ethylene*
- *pest and disease*
- *pre and postharvest treatments*

As mentioned before, the management of temperature, relative humidity, and ventilation, are the three most important factors that affect postharvest quality and storage life of horticultural produce. Storage of compatible groups of fruits and vegetables together, (those that share similar storage requirements) is advisable and necessary. During this process, lowering the temperature to the lowest safe level is of paramount importance for enhancing the shelf-life, reducing the losses, and maintaining fresh quality of fresh produce.

When analyzing the data different food organizations provide on the optimal conditions for the storage of fresh fruit and vegetable, it is observed that most of them require high ***relative humidity*** conditions (around 95% RH). This is quite obvious, since they are fresh foods with a high water content. In order to avoid their water-loss through transpiration processes, high humidity conditions are required for their preservation. In contrast, ***temperature*** setting varies due to the origin of these fruits and vegetables, and they change according to different climate regions where they have been grown. There are three main climate regions used to define fresh produce origin: temperate zone, subtropical zone and tropical zone (Fig.116). Because the temperature conditions of each zone change, foods that have been

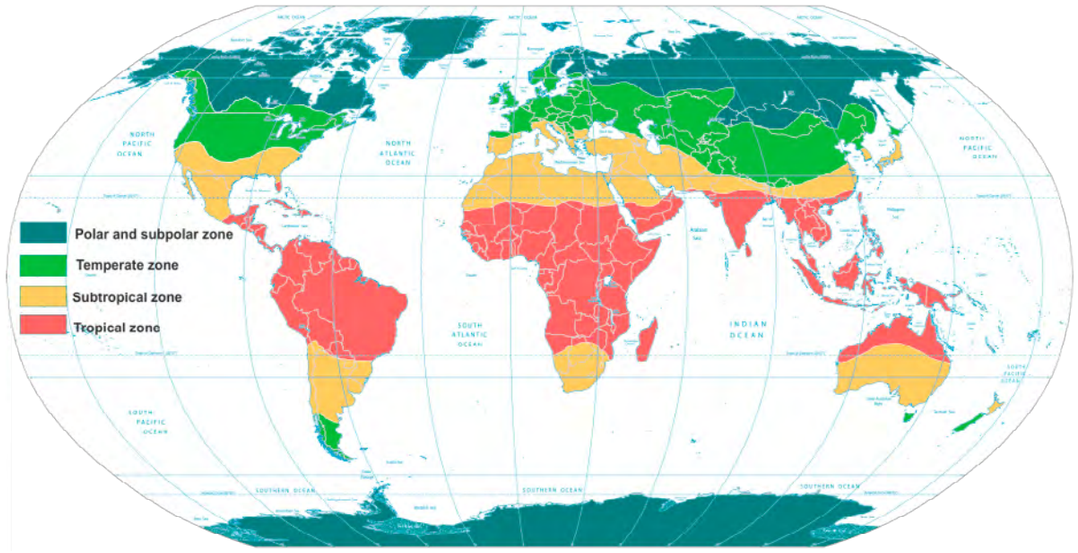


Fig.116 Climate regions (zones) around the world and how they influence the recommended storage temperature. Temperate fruit will require lower storage temperature (around 0°C) as they have grown in colder conditions, meanwhile tropical fruits will require warmer storage temperatures to avoid 'freezing injuries' during storage.

grown in different areas will also require different temperature settings during their storage. This means that if one fruit has grown in temperate zone and another in tropical zone, tropical fruit will require much warmer storage conditions because the climate where it comes from is much warmer (f.i a banana and an apple).

Regarding the ***ventilation*** conditions, mainly due to the presence of ethylene gas, the situation becomes much more complex. First of all, keep in mind that fruit and vegetables are quite different food products. Fruits are the reproductive organs of the plant that continue to develop (ripen) even once detached from the plant. Vegetables are plant leaves, stems and roots that are harvested when they have achieved the qualities required. Unlike ripening fruit, they generally do not undergo dramatic changes after harvest, although they both continue to function as living organisms.

Some fruits are climacteric (ethylene producers). They produce large amounts of this gas, which, in large concentrations, accelerates the ripening process and shortens the shelf-life of produce. On the other hand, a large part of the fruits (both climacteric and non-climacteric) together with some vegetables are considered "sensitive to ethylene" since even at low concentrations of this gas, several injuries can be produced. Finally, a third group of fruit and vegetables is "not ethylene sensitive", since in its presence, no changes in this produce are observed. To understand better how ethylene gas affects the storage of fresh fruit and vegetables, check the image on the right (Fig.117).

Ethylene in Fruits and Vegetables

Correctly store fruits and vegetables to reduce food waste.

What is ethylene?
Ethylene is a gas released by some fruits and vegetables that causes produce to ripen faster. Some fruits and vegetables are more sensitive to ethylene than others.

Why should I care?
Fruits and vegetables that are stored incorrectly spoil quickly. This could mean lost profit for you.

What can I do?
- Do not store fruits and vegetables that produce ethylene with those that are sensitive to ethylene. For example, do not store bananas and apples next to each other. This applies to produce that is refrigerated and not refrigerated.
- Do not store produce in bags or sealed containers. This will trap the gas and cause the produce to ripen faster.

Do not display fruits and vegetables that are sensitive to ethylene near fruits and vegetables that produce it.

Ethylene Sensitive

Apples
Asparagus
Avocados
Bananas
Broccoli
Cantaloupe
Collard Greens
Cucumber
Eggplant
Grapes
Honeydew
Kiwi
Lemons
Lettuce
Limes
Mangos
Onions
Peaches
Pears
Peppers
Squash
Sweet Potatoes
Watermelon

Ethylene Producers

Apples
Avocados
Bananas
Cantaloupe
Kiwi
Peaches
Pears
Peppers
Tomatoes

Not Ethylene Sensitive

Blueberries
Cherries
Beans (Snap)
Garlic
Grapefruit
Oranges
Pineapple
Potatoes
Raspberries
Strawberries
Tomatoes
Yucca

Fig.117 How ethylene gas affects the storage of fruits and vegetables. Data by UC San Diego School of Medicine.

Short-term Storage

Group	Temperature	Crops	Status of commodities
Group 1	0–2 °C and 90–95 % RH	Apple, Apricot, Asian Pear, Grapes, Litchis, Plum, Prunes, Pomegranate, Mushroom Turnip Peach	Produce ethylene
Group 2	0–2 °C and 90–95 % RH	Asparagus, Leafy greens, Broccoli, Peas, Spinach, Cabbage, Carrot, Cauliflower, Cherries	Sensitive to ethylene
Group 3	0–2 °C and 65–70 % RH	Garlic, Onions dry	Moisture will damage these crops

Fig.118 Compatibility groups of fruits and vegetables for a short-term storage. Source: Thompson (1999)

Although today there are many publications that collect relevant data of the optimal conditions to preserve different fruits and vegetables properly, deciding how these foods should be divided into groups with similar recommended storage conditions, is not an easy task. The most difficult part here is deciding what factors should be taken into account and to what extent. For ***short-term preservation***, the factors that can affect the quality of these foods are less important. Despite not respecting the recommended storage conditions for each food, the nutritional losses here are relatively low, and does not usually affect the quality of these foods to a great extent. However, when it comes to ***long-term preservation***, each and every one of the factors can affect the quality and shelf-life of the produce. So if not managed correctly, nutritional losses will be unavoidable.

According to *Thompson* (1999)[101], for the optimal preservation of most fruit and vegetables, they should be divided into 3 main groups (see again Fig. 75 or Fig.118). Factors such as temperature, RH and ventilation are being considered here, but what regards the temperature ranges proposed here, all produce is kept at 0-2°C (red lines). It differs from those recommended for subtropical and tropical fruits, as shown on the table on the right (Fig.119). These fruits have been grown in much warmer climates and, in terms of avoiding chilling injuries, they require higher temperature conditions. In conclusion, it has been confirmed that the method proposed by *Thompson* focuses mainly on a short-term preservation of fresh produce, as it doesn't take in consideration the chilling injury issue.

According to the publication of *Postharvest Technology Research and Information Center*[102], a long-term storage of fruit and vegetables should be divided into 7 main groups (see Fig.120). This result is obtained by grouping them all by their shared storage conditions such as temperature, humidity but also ethylene properties.

101 *Thompson, J., Kader, A., & Sylva, K. (1999). Compatibility chart for fruits and vegetables in short-term transport or storage. University of California, Publication 21560.*

102 *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition). Lisa Kitinoja and Adel A. Kader. University of California, Davis. Postharvest Technology Research and Information Center (2002). (http://ucce.ucdavis.edu/files/datastore/234-1450.pdf)*

Fruit	Temperature range (ºC)	Relative humidity (%)	Storage time
Apple**	-1-4.5 2-4.5	90-95 95	4-32 weeks
Apricot**	-0.5-0	85-95	1-3 weeks
Avocado	0-2 4.5-13	90-95 85-95	10 days 2-4 weeks
Banana**	13.5-15 12.5-21	85-95	2-5 days 4-21 days
Blackberry	-0.5-0	85-100	2-3 days
Blueberry	-0.5-0	90-100	2 weeks
Boysenberry	0	90-100	2-3 days
Carambola	10-15	90	5 weeks
Cherry	0	90-95	3-7 days
Cherry	-1-0	85-95	2-4 weeks
Chico	15	85-95	2 weeks
Coconut	0-2	80-95	4-8 weeks
Cranberry	2-4.5	90-100	12-16 weeks
Custard apple**	10-20	85-90	2-3 weeks
Currant	-0.5-0	90-95	1-2 weeks
Date	0-32	<75	24-48 weeks
Duku	10	85-90	2 weeks
Durian	10	90	1 week
Feijoa	0-4	—	4-5 weeks
Fig**	-1-0	85-95	1-3 weeks
Gooseberry	-0.5-0	90-95	1-4 weeks
Grapefruit	10-16	85-90	4-10 weeks
Grapes	-1-0	85-95	12-24 weeks
Guava	7-10	90	2-3 weeks
Kiwifruit**	-0.5-0	90-95	8-16 weeks
Langsat	11-14	85-90	2 weeks
Lemon	0-5 14.5-15.5	85-90	2-3 weeks 4-24 weeks

Fig.119 Storage of fresh fruit and vegetables. Data provided by Agriculture and Food. Government of Western Australia.

Long-term Storage

Group	Temp./ RH	Crops	Status of commodities
Group 1	0-2°C and 90-95% RH	Apple, Apricot, Cherries, Coconuts, Grapes, Mushrooms, Nectarines, Peaches, Pears, Plums, Prunes, Radishes	Many produce ethylene
Group 2	0-2°C and 95-100% RH	Artichokes, Asparagus, Bean Sprouts, Berries, Broccoli, Carrots, Cabbage, Celery, Grapes, Kiwifruit, Lettuce	Many are ethylene-sensitive
Group 3	0-2°C and 65-75% RH	Garlic, Onion	Moisture will damage them
Group 4	4.5°C and 90-95% RH	Clementine, Cranberries, Lemons, Lychees, Oranges, Tangerines, Ugli fruit	
Group 5	10°C and 85-90% RH	Beans, Cucumber, Eggplant, Olive, Peppers, Potatoes, Squash, Tamarind	Ethylene-sensitive, chilling sensitive
Group 6	13-15°C and 85-90% RH	Avocados, Bananas, Boniato, Carambola, Mangoes, Papaya, Passionfruit, Pineapple	Produce ethylene, chilling sensitive
Group 7	18-21°C and 85-90% RH	Pears (for ripening), Sweet Potatoes, Tomatoes (mature green), Watermelon	

Fig.120 Food groups setting for a long-term storage. Data source: Postharvest Technology research and Information Center. University of California, Davis. 2012. (Research based on: McGregor, B.M. 1989. Tropical Products Transport Handbook. Washington, D.C.: U.S. Dept. of Agriculture, Office of Transportation.)

Taking into account the fact that my approach in this project is focused on a long-term preservation of fresh produce, the data provided by the *University of California, Davis*[103], is probably the biggest reference until now. However, we should bear in mind that using up to 7 different storage conditions is only profitable for big food industries. After harvesting or during different phases of food storage, huge amounts of just one type of produce, or produce that share similar storage conditions are stored in cold storage rooms (see Fig. 121). For this reason, it is quite easy to manage it, because the storage conditions rely on those recommended for that specific produce.

However, this situation becomes very complex

103 *Postharvest Center, University of California. Archive Postharvest Resources. (http://postharvest.ucdavis.edu/Library/Selected_Postharvest_References_466/)*

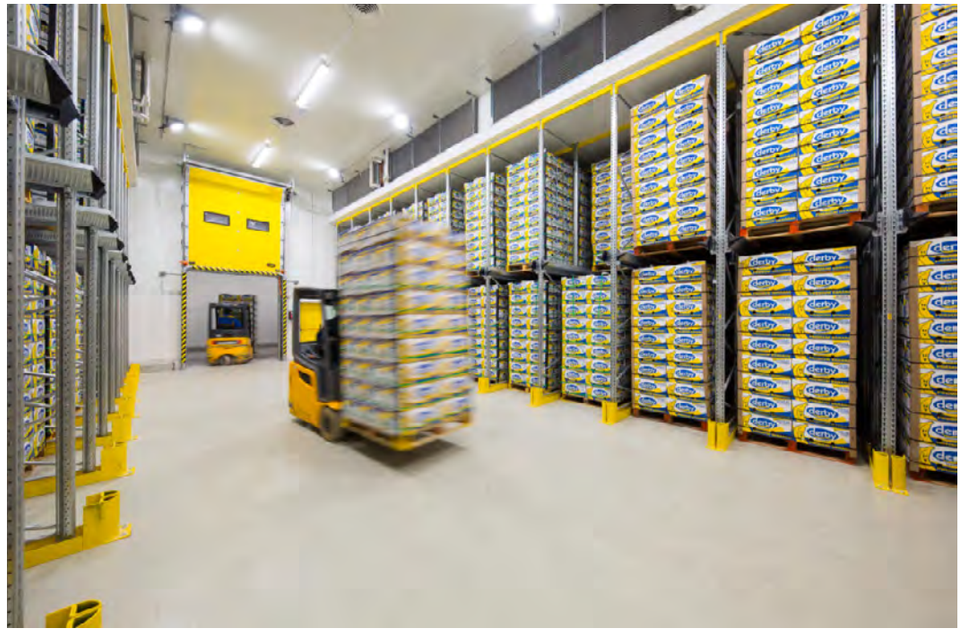


Fig.121 Green banana storage. EHO company, Slovenia.(www.eho.eu/en/)

when it comes to store a wide range of fruit and vegetables at home. The biggest disadvantage of the home refrigerator is that its storage space is quite small, and it must be consciously optimized to meet the consumer needs.

Nowadays, to preserve fresh produce in a refrigerator, the manufacturers are forced to look for a balance between the comfort of use and efficiency (as much of the space). For this reason, as has already been observed during benchmark study, the vast majority of manufacturers opt for the simplest option, offering a basic 'crisper drawer' where consumers can store all the fruit and vegetables they consume. The most innovative manufacturers commit much more, looking for different ways that improve these conditions in some way, usually by implementing different filters and mechanisms.

In spite of this, the differences between the storage conditions for fresh produce used at the industrial level differ greatly from those at domestic level. At this point, my purpose is to analyze these differences and look for a viable solution, in order to improve these conditions also at home. Based on references from previous studies, I have decided to combine them into new data that will allow to take out my own conclusions. These results will be grouped on the following pages, and then used to divide all fresh produce into different groups, hence store them properly inside the home refrigerator.

3.2.2 New Classification for Fresh Fruits and Vegetables

To proceed with the group classification, it was required to analyze in detail the storage conditions of fruit (Fig. 122) and vegetables (Fig.123), such as such as temperature, humidity and ethylene activity. The aim here is to find the optimum way to preserve most part of fresh produce at home.

What refers to the ***temperature***, recommended ranges for fruit and vegetables are very different, as they are set between -2 and +20 ºC. Fresh produce should be always kept at lowest temperature possible, but never go beyond it as it could lead to freezing injuries. At this point, it is required to use a new approach to provide a more effective solution for the preservation of these products at home. In order to reach these needs, fruit and vegetables were organized by temperature ranges, which allowed get new conclusions (see Fig. 124). As a result, and taking into account that the space in a refrigerator is limited, it was finally decided to divide fresh produce into 2 main groups, which would use different temperature settings ranged between 0-2 ºC and 8-10 ºC. This solution will provide better storage conditions in spite of those of a current refrigerator.

Regarding ***humidity***, the vast majority of foods require high humidity conditions, ranging from 90-95% RH (Fig.125). Some foods, instead, require lower humidity levels because moisture can damage them. As a result, it has been decided to use high RH in all areas of new 'crisper drawers' ranging from 90-95%. For those products that require less humid conditions, it is suggested to store them out of the 'crisper drawers' (f.i. roots).

Regarding ***ethylene*** activity, results show that a large part of all the fruit and vegetable produce substantial amounts of ethylene gas, while another, denotes sensitivity to it (see Fig. 124). For this reason, as different food organizations suggest, it has been decided to separate ethylene-emitting products from those ethylene-sensitive, in terms of avoiding injuries. As a result, from each previous group (based on their temperature settings) were created another 2 subgroups, by separating ethylene producers from the rest of produce (see again Fig.124). Anyways, the use of ethylene inhibitors is required in each compartment of the new 'crisper drawers'. In compartments with climacteric fruit, the reason for using these inhibitors is obvious, as it should reduce the excess of ethylene gas as these foods emit large amounts of it. Using these inhibitors in other compartments is not mandatory, even though is recommended, as it could prevent its concentrations in case of product misuse (user fault). So, preventing this from happening is a great idea, also because many fruits in these compartments are ethylene-sensitive, and its concentrations could lead to injuries.

RECOMMENDED STORAGE CONDITIONS FOR FRESH FRUIT

FRUITS	TEMPERATURE RANGE (°C)		RELATIVE HUMIDITY (%)		STORAGE TIME (Weeks)	
	Min.	Max.	Min.	Max.	Min.	Max.
Apple* (**)	-1	4,5	90	95	4	32
Apricot**	-0,5	0	85	95	1	3
Avocado, green* (**)	0	2	90	95	1	1
Avocado, ripe* (**)	4,5	13	85	95	2	4
Banana, ripe* (**)	13,5	15	85	95	1	1
Banana, green* (**)	12,5	21	85	95	1	3
Blueberry	-0,5	0	90	100	2	2
Boysenberry	0	0	90	100	0	0
Carambola	10	15	90	90	5	5
Cherry	0	0	90	95	0	1
Cherry	-1	0	85	95	2	4
Chico, (sapodilla)	15	15	85	95	2	2
Coconut	0	2	80	95	4	8
Cranberry	2	4,5	90	100	12	16
Custard apple**	10	20	85	90	2	3
Currant	-0,5	0	90	95	1	2
Duku	10	10	85	90	2	2
Durian	10	10	90	90	1	1
Feijoa	0	4	-	-	4	5
Fig**	-1	0	85	95	1	3
Gooseberry	-0,5	0	90	95	1	4
Grapefruit	10	16	85	90	4	10
Grapes*	-1	0	85	95	12	24
Guava	7	10	90	90	2	3
Kiwifruit* (**)	-0,5	0	90	95	8	16
Langsat	11	14	85	90	2	2
Lemon, coloured*	0	5	85	90	2	3
Lemon, green*	14,5	15,5	85	90	4	24
Lime*	7	10	85	90	4	10
Loganberry	-0,5	0	90	100	2	3
Loquat	1	1	-	-	1	2
Lychee	0	2	90	100	3	8
Mandarin	5	7	85	90	2	8
Mango* (**)	10	13	85	90	2	3
Mangosteen	4	5,5	85	90	1	1
Nectarine**	-0,5	0	85	90	1	6
Olive	5	10	85	90	4	6
Orange	0	9	85	90	3	16
Pawpaw**	7	13	85	90	1	3
Passionfruit**	7	7	90	95	2	5
Peach* (**)	-0,5	0	85	95	2	6
Pear* (**)	-2	0	90	95	8	28
Persimmon, ripe	13	13	90	95	2	2
Persimmon, green	-1	0	90	95	12	16
Pineapple, ripe	5	7	85	90	2	4
Pineapple, green	10	20	85	90	2	4
Plum**	-0,5	0	85	90	1	7
Prune	-0,5	0	90	95	2	4
Pomegranate	0	5	85	90	8	16
Pomelo	7	9	85	90	12	12
Quince	-0,5	0	85	90	8	12
Rambutan	10	10	100	100	2	2
Raspberry	-0,5	0	90	100	0	0
Strawberry	-0,5	0	85	90	1	2
Tamarillo	3,5	10	85	95	1	2
Tangelo	3	3	85	90	2	4
Tangerine	0	3,5	85	90	2	4

* denotes ethylene-sensitive commodities, ** denotes commodities known to produce substantial amounts of ethylene

Fig.122 Recommended storage conditions for fresh fruits. Source: Agriculture and Food. Government of Western Australia.

RECOMMENDED STORAGE CONDITIONS FOR FRESH VEGETABLES

VEGETABLES	TEMPERATURE RANGE (°C)		RELATIVE HUMIDITY (%)		STORAGE TIME (Weeks)	
	Min.	Max.	Min.	Max.	Min.	Max.
Artichoke**	0	0	90	100	3	4
Asparagus*	0	2,5	85	100	2	4
Bean*	4	10	85	100	1	3
Beetroot	0	0	95	95	1	2
Broccoli*	0	0	90	100	1	2
Brussels sprout*	0	0	90	100	2	5
Cabbage*	0	0	90	100	3	6
Capsicum	7	10	90	95	2	3
Carrot*	0	0	90	100	4	6
Cauliflower*	0	0	90	100	2	4
Celeriac	0	0	90	95	12	16
Celery*	-0,5	0	90	100	4	16
Choko	10,5	10,5	90	95	10	12
Collard*	0	0	90	95	1	2
Corn, sweet*	-0,5	0	85	100	1	2
Cucumber*	7	12	85	100	1	2
Eggplant*	7	10	90	95	1	2
Endive*	0	0	90	100	3	3
Garlic, dry	0	0	65	75	24	28
Ginger	13	13	65	65	24	24
Greens, leafy*	0	0	90	100	1	2
Horseradish	-1	0	90	100	40	48
Kale	0	0	90	95	2	2
Kohlrabi	0	0	90	100	2	4
Leek, green	0	0	90	100	4	12
Lettuce*	0	0	90	100	1	2
Marrow	10	12	75	75	6	12
Melon, rock (cantaloupe)* (**)	0	7	85	90	1	2
Melon, honeydew* (**)	7	10	85	90	3	4
Mushroom	0	0	85	100	1	2
Okra*	7	10	90	95	1	2
Onion, dry*	0	0	65	75	4	32
Parsley*	0	0	90	100	4	8
Parsnip	0	1	90	100	8	24
Pea, green	-0,5	0	85	100	1	3
Pepper, chilli*	0	10	60	70	24	24
Pepper, sweet*	7	10	85	90	8	21
Potato*	7	12	85	100	8	32
Potato, sweet*	12	15,5	85	90	16	24
Pumpkin	10	13	70	90	8	24
Radish	0	0	90	95	4	16
Rhubarb*	0	0	90	100	2	4
Rutabaga	0	0	90	95	8	16
Salsify	0	0	90	95	8	16
Shallot*	0	0	90	100	1	2
Silverbeet*	0	0	95	100	1	2
Spinach	0	0	90	100	1	2
Squash*	10	13	70	90	4	16
Tomato, mature green**	12	16	85	95	1	3
Tomato, firm ripe**	6	8	85	95	1	1
Turnip	0	0	90	95	16	20
Turnip greens	0	0	90	95	1	2
Watercress	0	2	90	95	1	1
Watermelon*	2	10	80	90	2	3
Zucchini*	7	7	95	95	1	2

Fig.123 Recommended storage conditions for fresh vegetables. Source: Agriculture and Food. Government of Western Australia.

RECOMMENDED TEMPERATURE RANGES TO STORAGE FRUIT & VEGETABLES

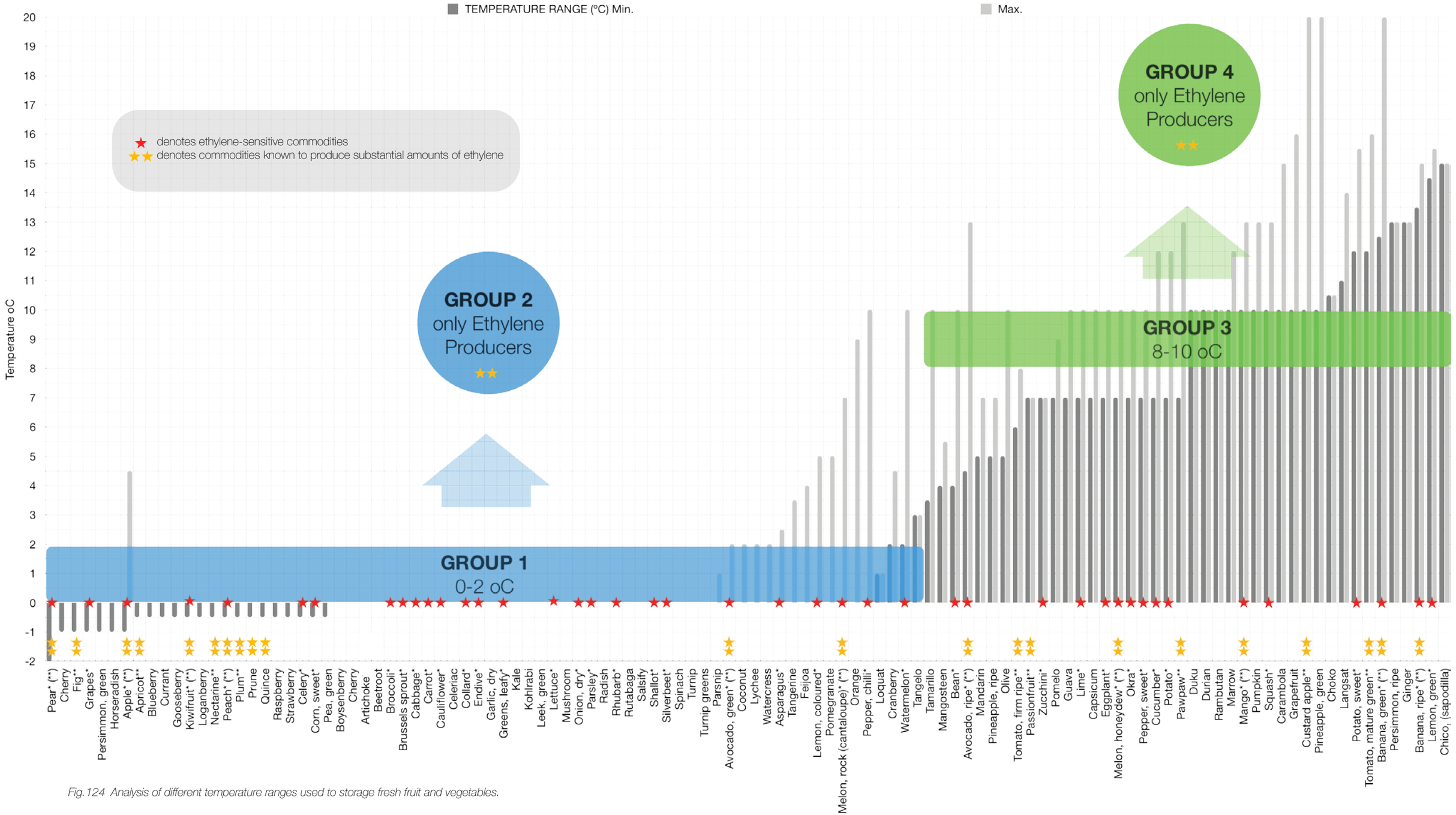


Fig.124 Analysis of different temperature ranges used to storage fresh fruit and vegetables.

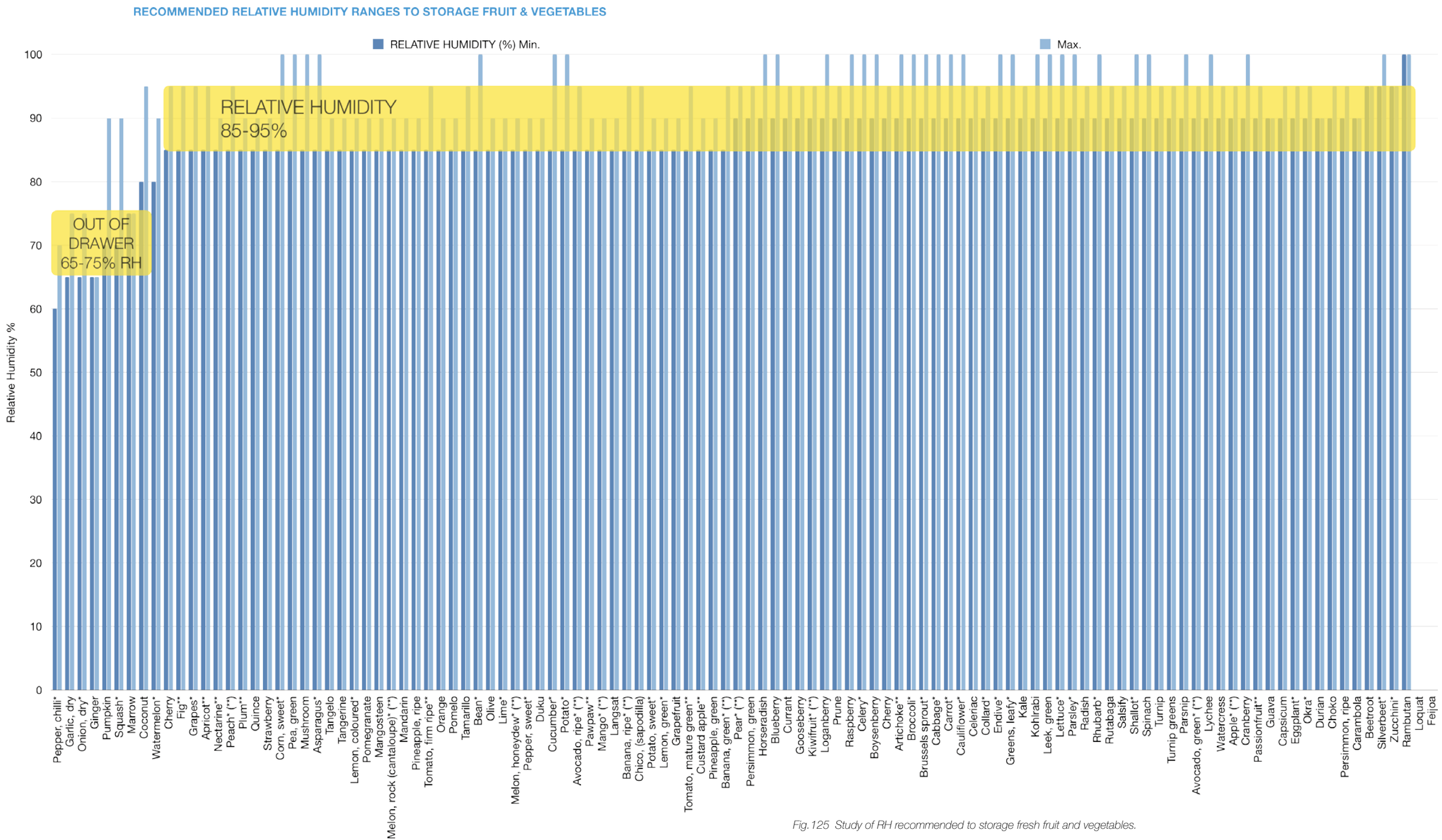
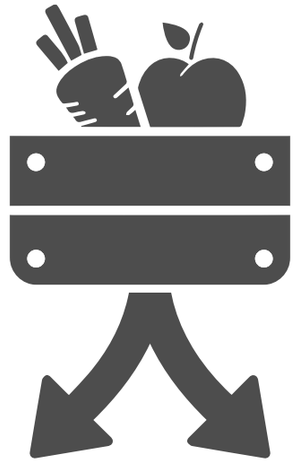


Fig.125 Study of RH recommended to storage fresh fruit and vegetables.

As a result, after a long and deep analysis,
these are the four food groups settings,
defined to storage fresh fruit and vegetables at home.



Group 01
common and ethylene-sensitive
90-95% RH
0-2 °C

Berries (Blueberry, Cranberry, Gooseberry, Loganberry, Raspberry, Strawberry);

Cruciferous vegetables (Broccoli, Brussels sprout, Cabbage, Cauliflower);

Leafy vegetables (Celeriac, Celery, Collard, Endive, Kale, Lettuce, Parsley, Silverbeet, Spinach, Watercress);

Root vegetables (Beetroot, Carrot, Parsnip, Rutabaga, Radish, Turnip);

Temperate fruits (Cherry, Grapes, Watermelon);

Others (Artichoke, Asparagus, Coconut, Corn, Hohlrabi, Leek, Lychee, Mushroom, Pea, Pomegranate).

Group 02
ethylene producers
90-95% RH
0-2 °C

Temperate fruits (Apple, Apricot, Cantaloupe, Fig, Nectarine, Peach, Pear, Plum, Prune, Quince);

Subtropical fruits (Avocado (green), Kiwifruit).

Group 03
common and ethylene-sensitive
90-95% RH
8-10 °C

Citrus fruits (Lemon, Lime, Clementine, Grapefruit, Mandarin, Pomelo, Orange, Tangerine, Tangelo);

Subtropical and Tropical fruits (Carambola (Star fruit), Duku (Langsat), Durian, Guava, Langsat, Mangosteen, Persimmon, Pineapple, Rambutan, Sapodilla,);

Others (Bean, Capsicum, Cucumber, Eggplant, Marrow, Okra, Olive, Pepper (sweet), Potato, Pumpkin, Squash, Zucchini)

Group 04
ethylene producers
90-95% RH
8-10 °C

Subtropical and Tropical fruits (Avocado (ripe), Banana, Mango, Papaya, Passionfruit);

Others (Custard apple, Melon (honeydew), Pawpaw, Tomato).

Fig.126 Advanced food group settings designed exclusively for **SmartFresh**^{PRO} *to storage fresh fruit and vegetables in a home refrigerator.*

USER RESEARCH

Learning more about user needs, wants and behaviors. Identifying main problems and providing solutions related to the refrigerator and its use.

3.3 USER RESEARCH

3.3.1 User Interviews

User research consists a fundamental part of the development of a product. Thanks to the users it is possible to find out what are the personal motivations to use a product, the problems or frustrations while using it, but above all, it serves to find solutions to the existing problems and improve a product in some of its aspects.

The first phase of user research consisted of user interviews, carried out with deliberately selected users. As a result, it was possible to get the answers to the questions raised regarding the refrigerator and its use and then get some conclusions (see page 223).

First of all, at generic levels, users are satisfied with their refrigerators, since it easily meets their needs. It allows conserving food in a simple, fast and efficient way, without requiring by the user any specific knowledge about conservation. Its use is constant, since it is used several times a day, during the whole year. A refrigerator can be defined as a low-complexity universal product, as it is capable of storing almost all kinds of food very easily and effectively, despite the origin or state of these foods (fresh/cooked/processed). It can be used anywhere in the world, by any sex (male/female) and by almost any age, including children, adults and the elderly.

Secondly, what regards to consumption, it has been found that a large percentage of the users analyzed are more aware of the benefits of a healthy diet. This has increased the consumption of fresh foods such as meat, fish, fruit, and vegetables, and therefore, slightly changed their diet. However, despite an increase in the consumption of fresh fruits and vegetables in the last decade, a large part of the users are unaware of their real benefits, although they do recognize that they are beneficial to health. Only 10% of the people interviewed knew the meaning of ‘climacteric fruit’, and how they should be stored regarding other types of fruits and vegetables.

Third, when it comes to food preservation, users commented that they usually store a wide variety of foods in the refrigerator, mostly those that require low temperatures for proper preservation. To identify what types of food should be stored in a refrigerator, they tend to follow the conservation rules as what their parents did. Sometimes these users also look at how these foods are normally stored in supermarkets (here the supermarket's refrigerated food, once at home, would go in the refrigerator also). However, in some cases, they just follow their own criteria on how to preserve most part of them. What refers to fruit and vegetables, most people behave in the same way, as they acknowledge they have never read anything related to how to preserve fresh produce. They just keep it in a refrigerator, because that's how they've done it since they were children. And although their refrigerators always incorporate 'crisper drawers' designed to store these products, many users just ignore these indicators (icons on crisper drawers) and store fruit and vegetables in any area of the refrigerator. The main issue is that 'fridge' manufacturers do not explain that different areas of the refrigerator have been designed for different purpose. These areas provide different storage conditions, but most users just ignore this fact. The only evidence of it are the 'icons' used on these crisper drawers, which suggest the proper space for them. However, often they are very confusing for many reasons. As a result, this leads to incorrect preservation, compromising the quality of fresh produce and shortening its shelf life.

Fourth, concerning the 'crisper drawers', users commented that according to their criteria, the icons on these drawers indicate that all kinds of fruit and vegetables can be stored there. But due to the lack of information provided on how the refrigerator works and the preservation conditions used in its different areas, users perceive that storing fruit and vegetables in other compartments is also possible and that neither the quality nor the shelf-life of these products will be affected. Users acknowledged that they usually store fruit and vegetables together, since this is what their refrigerator suggests. In some cases, consumers pointed out to separate them, but none was conscious about ethylene, nor of its consequences. In addition, the current humidity control systems (sliders) of the crisper drawers, are usually forgotten by users after the first or second use. Their relevance is not properly understood, neither how this factor could affect the preservation.

Fifth, people tend to perceive that they waste very small amounts of food at home, which doesn't correspond to the data provided in the previous chapter. We usually don't perceive how much food we waste at home and why (see page 84), therefore, we don't see how serious this problem is. On the other hand, as it was expected, the foods that most often end up in the trash are fresh foods such as meat, fish, fruit and vegetables, since they are the most perishable and require specific storage conditions for their correct preservation. Any small change could compromise the proper storage conditions and reduce their shelf-life, while increasing the amounts of waste. Once the impacts of food waste and the magnitude of the problem are understood, people wil become more committed to reduce it and learn more about how to improve the preservation of fresh produce.

USER INTERVIEWS

QUESTIONS ASKED

ABOUT REFRIGERATOR

What do you use your refrigerator for?
How often do you use it?
Do you find it easy to use a refrigerator?
Do you need specific knowledge to use a refrigerator?
According to your criteria, does the refrigerator meet your daily needs?
What problems or frustrations have you had with your refrigerator?

ABOUT FOOD CONSUMPTION

What foods prevail in your diet?
Do you usually consume fresh, processed or frozen foods?
How much fruit and vegetables do you consume?
What do you know about climacteric fruit?

ABOUT FOOD PRESERVATION

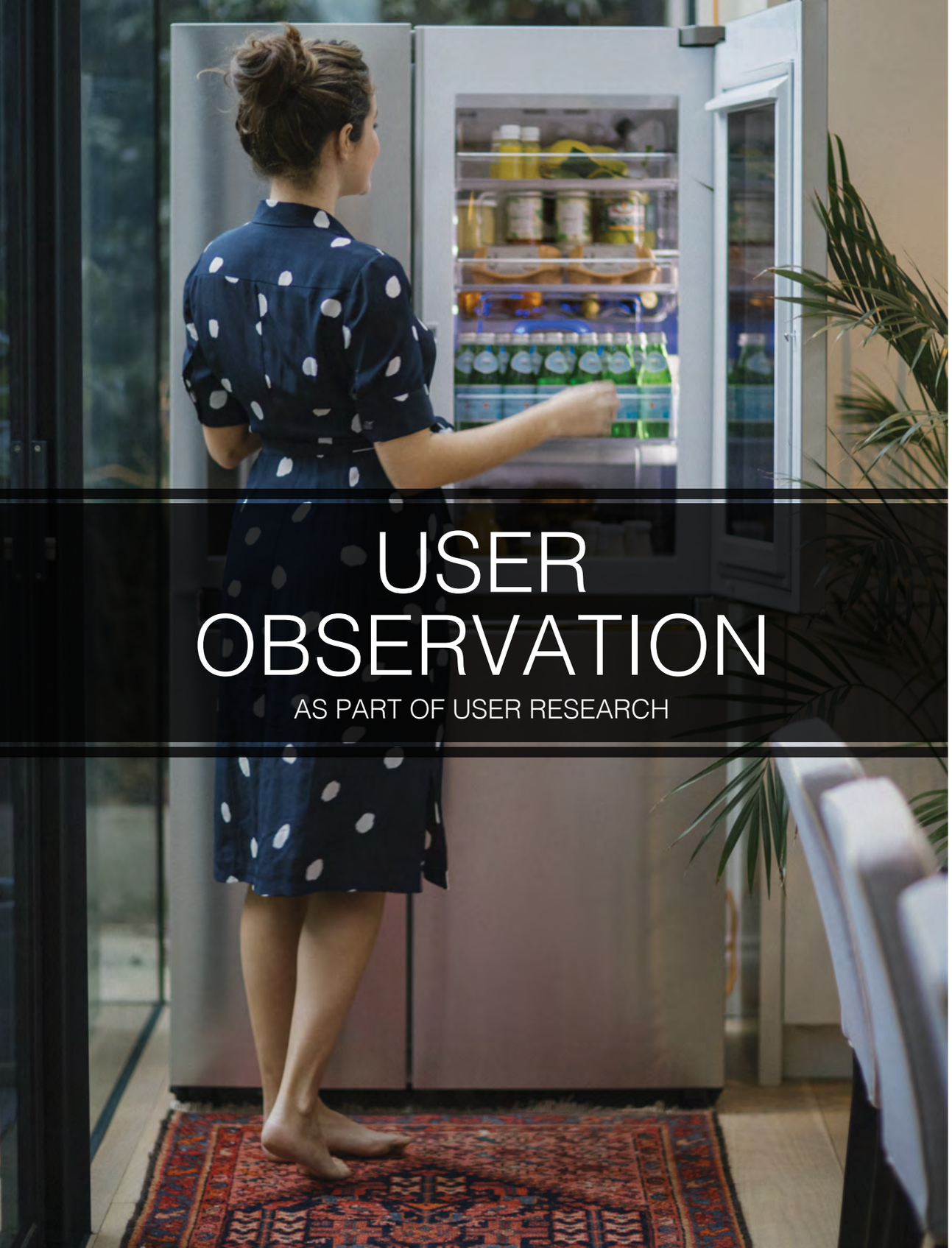
What kind of food do you store in a refrigerator?
How do you identify what foods should be stored in a refrigerator?
Do you usually read food labels to understand how to preserve foods?
Where did you learn how to preserve food?
Have you ever read how to preserve fruit and vegetables properly?
How do you usually preserve fruit and vegetables? Why?
Does your refrigerator somehow help guide the user to preserve food?

ABOUT CRISPER DRAWERS

Do you find it easy to know what each refrigerator compartment is for?
How many drawers for fruit and vegetables does your refrigerator have?
Do you know if storage conditions of these drawers differ in any way?
Do you usually store fruits and vegetables together?
Do you usually store fruits and vegetables inside the crisper drawer?
How many times have you changed the humidity of the crisper drawer?

ABOUT FOOD WASTE

How much food do you waste at home?
What type of foods are the most waster at your home?
In your opinion, what are the main issues that lead to this waste?
Would you be interested in reducing this food waste?



USER OBSERVATION

AS PART OF USER RESEARCH

3.3.2 User Observation

Different methodologies available in 'user research' phases have a special value for the subsequent development of the product. But although all methods are important as they provide relevant data about a product and how it is used, 'user interviews' usually provide limited information. This is because the questions made by the interviewer are usually generic and don't apply to most specific cases. Most time it is supposed that we all behave the same or similar way.

Besides, customer's feedback may differ from a real feeling as people are too polite to tell you the unvarnished truth. Furthermore, probably these people don't know or can't articulate the 'true' answer you expect as they may like to eat, but they are probably not 'food critics'.

User observation, instead, allows obtaining much more reliable information on how the product works, since they are taken from observing the behaviors of real users using a real product.

According to ***IDEO's design principles***, their second step of the design process consists in "*observing real people in real-life situations to find out what makes them tick: what confuses them, what they like, what they hate, where they have latent needs not addressed by current products and services.*"[104] They aren't big fans of focus groups and they don't much care for traditional market research either. The main factor of their design approach is that all IDEO-designed products were inspired by watching real people in real life.

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104 The Art of Innovation. Tom Kelley and Jonathan Littman. Great Britain, 2014. Profile Books LTD. (pp. 6-7, 25-52).

Fig.127 One of the examples of how some users storage fruit and vegetables inside their refrigerator.

User observation works well and it is one of the best methods to find real answers. It allows to observe people interact with the product and try to understand not only the nuances of human behaviors but also strive to infer motivations and emotions. Time-by-time you should ask yourself a question "why?" to get to the underlying psycology of a person's interactions with a product. You should try to get under people's skin to figure out what they think and do, as well as why. Look out for 'crazy' users who do things differently, as they are people who might teach you something you didn't know. Create empathy because outrageous new products and ideas recognize that people are human.[105]

Observing how some users use their refrigerators has been an effective way to get deeper into the user-product interactions and get answers to questions that most time even users would not be able to answer. After several months of study analyzing how different families storage their food in the refrigerator, interesting data was obtained. Summing up all these cases it was observed that, most time users didn't storage their food correctly. Regardless of the refrigerator different families had at their home, users tended to store part of fresh produce outside the crisper drawers (see example on Fig 127).

First of all this was because the drawers used to store fruit and vegetable were usually full, and therefore users had to use those provided for meat and fish or even to use the main compartment of the refrigerator to store these products. As we already know by now, the storage conditions of other refrigerator compartments differ from those recommended for preserving fruit and vegetables (even the crisper drawers of many refrigerators are far from these recommended conditions), so storing fresh produces here goes to shorten their useful life. The conclusion that can be drawn here is that the drawers for fruit and vegetables in today's refrigerators are too small and offer limited space to store these products. In the previous chapter it was already mentioned that 1/5 of our diet is made up of fruit and vegetables (see again Fig. 55). So why 20% of the refrigerator is not set up to take care of these foods?

Secondly, users repeatedly stored fresh fruit and vegetables outside these drawers, even in cases when there was still free space. And this makes us raise another question. Why? Fridge manufacturers are constantly innovating their products and the recent Bosch and Samsung product advertisements affirm that their new crisper drawers use high humidity levels (RH 95%) to preserve fresh fruit and vegetables up to 3x times longer (see pages 163-175).

Surprisingly, analyzing the images that different brands use in their advertising campaigns, a rather contradictory reality is observed. Brands like Samsung and Electrolux, although also many others, promote their new refrigerators using a non-sense random storage of fresh produce, placing them also outside of these crisper drawers (Fig. 128 and Fig. 129, red circles). Why is there so much contradiction in the pictures they use on their advertising campaigns? This is confusing in many ways, but most of all it confuses users on how to store food properly in a refrigerator. So, in the end, users don't follow rules and store fruit and vegetables according to their own criteria. They don't mind about leaving them out of crisper drawers since even the manufacturers do so.

105 *idem*

Fig.128 An example of Samsung advertisement promoting their new refrigerator. However, an interesting point is that they store some fresh produce outside the 'crisper drawers'.

Fig. 129 An example of Beko advertisement taken from their official website. Even here it can be observed that some manufacturers intentionally store different fresh produce outside the 'crisper drawers'.

USER OBSERVATION

AND POSSIBLE SOLUTIONS TO REDUCE

FOOD WASTE

USER ISSUES

- People are human, don't expect them to act as you think they should,
- Users normally don't follow the rules (they tend to behave according to their own rules),
- Users normally don't know how to storage fresh produce properly (nobody teached them to do so),
- When people do not know what to do or how to proceed, they tend to notice what others are doing (they storage food according to how others storage them).

REFRIGERATOR PRODUCERS ISSUES

- Compartments for fresh produce are still too small in refrigerators (these drawers are filled up easily).
- Not clear data about food storage (refrigerator producers advocate they keep improving their crisper drawers to preserve fresh produce better and for longer while keep storing them anywhere),
- No commitment by fridge manufacturers (according to the food industry, they aren't equally committed to preserving these foods properly),
- Not reliable icons (they aren't clear as they promote to mix all fruit and vegetables together despite of recommendations),
- No alternatives (in over a century the fridge doesn't seem to have changed much, and there aren't many other alternatives for fresh produce at home).

POSSIBLE SOLUTIONS

Redesign today's refrigerator:

- Enhance storage conditions of refrigerators at home (even if people buy too much food, or do not consume them on time, this is the most effective solution to reduce food waste),
- Make crisper drawers bigger (we consume more fruit and vegetables that crisper drawers can store today),
- Design things to avoid misuse (f.i. crisper drawers, icons on them, etc.),
- Help users to use a new refrigerator properly through the UI/UX design (users must be guided on how to store food, reduce food waste, etc.),
- Increase the commitment of brands and users (raise customer awareness about food waste and why we must reduce it, explain how this product helps to reduce it, and how we can contribute to it as users).

Despite that, even if fruit and vegetables could be stored in any area of the refrigerator, without suffering any impact on their quality and shelf-life, which has been shown not to be true. What is the reason it's being done by the manufacturers? Besides, there are icons of fruit and vegetables on every crisper drawer, which suggests the type of products that should go there. But, why to use these icons when even these manufacturers are not able to follow their own rules? Why is there so much controversy?

Another big problem detected during user observation is that users mostly ignore storage recommendations for fruit and vegetables. It was already mentioned that the fridge manufacturers could improve the way their crisper drawers work, but above all, inform users that climacteric fruit should be stored separately from the rest of the produce (when ethylene filters are not provided). Most brands just ignore it, as these drawers always use a mixed storage. As a result, this reduces their shelf-life and makes them spoil faster. Hence, food that could have been consumed, is often thrown away because of inefficient storage techniques used at home.

3.3.3 Defining Problems and Providing Solutions

After user interviews and user observation it has been observed that there are different problems that can influence the preservation of fresh foods such as fruits and vegetables. Caused by 2 main factors (those that depend on the users, and those that depend on the producers of refrigerators), these problems involve losses of these foods causing an increase in the food that is wasted in our homes.

Food losses at home are extensive (over 20% of fruit and vegetables) and they depend on many factors. As designers, we should remember that "people are human", and we can't expect them to act as we think they should. Instead, we can design objects in a way to avoid their misuse. Reducing this waste is possible and necessary. But it requires making some changes regarding the functioning of the refrigerator, but also change user behaviors regarding food consumption and preservation.

First, it is necessary to understand the scale of the food waste problem and focus on reducing it globally.

Secondly, we must create a commitment both by home appliance brands and by the users. These brands should approach the food waste problem seriously and responsibly, improving their refrigerators by providing the best conditions for the preservation of perishable foods at home (according to those recommended), aiming to reduce this waste. On the other hand, users must commit to change their behavior regarding consumption and the preservation of fresh produce. Be aware of their value, their health benefits but also the impacts (economic, environmental and social) that their waste produces. Hence, it is required to re-educate users, teach them how to properly store fruit and vegetables at home, while focusing on making these tasks simple and easy to follow.

TECHNOLOGY EXPLORATION

AS PART OF THE DESIGN PROCESS

3.4 TECHNOLOGY EXPLORATION

3.4.1 Cooling System (Temperature Settings)

Regarding the technological needs of the new refrigerator concept, in this section we will proceed to a more detailed analysis of the different technologies already mentioned in the previous chapter. Focused on both its advantages and disadvantages, we will be able to check its capabilities and find out the limits of design.

First, the analysis will focus on the temperature settings. Its operation consists of absorbing the heat from the refrigerator and expelling it to the outside (Fig. 130). To achieve this, a coolant is circulated through a closed system. When this liquid passes through the expansion device, its pressure and temperature decrease, which causes the liquid to evaporate (it turns into gas). This allows the heat to be absorbed by evaporator coils inside the refrigerator. Subsequently, this gas passes through the compressor, which increases its pressure.

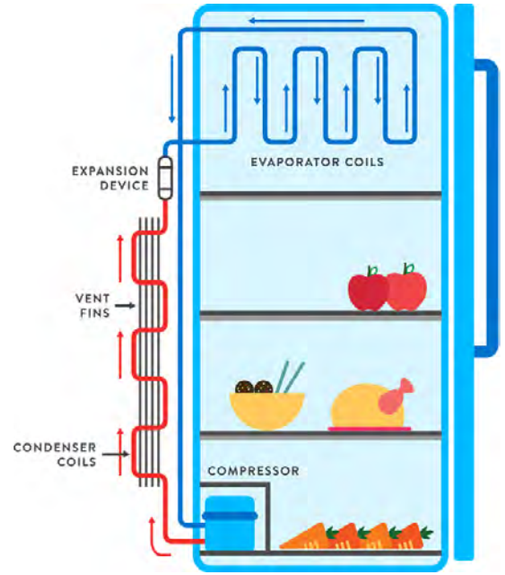


Fig.130 Refrigerator's Cooling System.

Fig.131 Samsung Twin Cooling System, two independent coolers for each compartment (freezer and fridge).

Thanks to this pressure, the refrigerant gas becomes liquid again, and as it passes through the condenser coils, it emits the heat into the room. This cycle is constantly repeated until the thermostat orders the compressor to stop, at which point the refrigerator will have reached the desired temperature and the liquid will stop flowing through the system.

The current refrigerator has a refrigeration system, capable of providing two different temperature ranges: 0-2ºC (fridge), -18ºC (freezer). Certain more recent models incorporate independent cooling systems, which prevents odors and humidity from each compartment from mixing. Samsung Twin Cooling Plus is an example of it, which also allows to have better temperature control in each section, reduce energy consumption and extend the useful life of the product.

However, as it has been seen in section 3.3.2, the new refrigerator concept requires an extra temperature range between 8-10ºC. This temperature will be focused on preserving those agricultural foods that are usually grown in warmer environments. This means that the new concept has to integrate 3 different refrigeration systems, each one capable of cooling the different modules of the refrigerator independently. In any case, this cooling technology (based on coolant) is cheap, efficient and works great, so there is no need to look for any substitute technology.

3.4.2 Humidification System (Relative Humidity Settings)

This system is necessary to increase the relative humidity levels in the crisper drawer to those recommended (RH 90-95%). It was already possible to verify that the refrigerators analyzed in the previous chapter could not reach these levels. On the one hand, the main issue with this system is that it obtains the humidity from the water released by fruit and vegetables. This creates a great problem of water-loss, which leads to losses in quality and also reduces the shelf-life of these products. On the other hand, these humidity levels in the drawers are never constant, since it depends on the volume of water that is capable of expelling fresh produce through the condensation process. So when the produce in the drawer is fresh (higher water content) and the drawers are full, these RH levels will be higher. But, once these products aren't so fresh and the drawers are almost empty, RH levels will be much lower.

To provide an optimal conditions of humidity to preserve the fresh produce in these drawers, the use of a humidification system is required. There are different humidification systems that can meet these requirements, but it is necessary to find out which of them is the one that best suits our product. Let's proceed.

Vaporization

In this process, the water is heated to the boiling point, thus transformed from a liquid to a vapor state. The great advantage of this process is that steam is sterile and free of germs (see Fig. 132). Moreover, vaporization is a humidification process that can be controlled most accurately, which is of central importance for various applications.

However, even if this process is very accurate and provide a clean water (free of germs

Fig. 132 Working process of a hot steam vaporizator.

and bacteria), it doesn't suit our refrigerator concept, as it creates a hot steam due to the boiling process, and should be cooled before its use in a refrigerator. Moreover, water tank should filled with water, which is not an easy task when implementing into a refrigerator. This could be improved by using a direct water inlet and some valves. Another problem, is that the water usually contains different salts and minerals, which will be depositing in different parts (water tank, components, etc.) and will require maintenance, such as cleaning or repairs. The best solution would be to use a distilled water (for a water tank) or a reverse osmosis, in case of a direct water inlet.

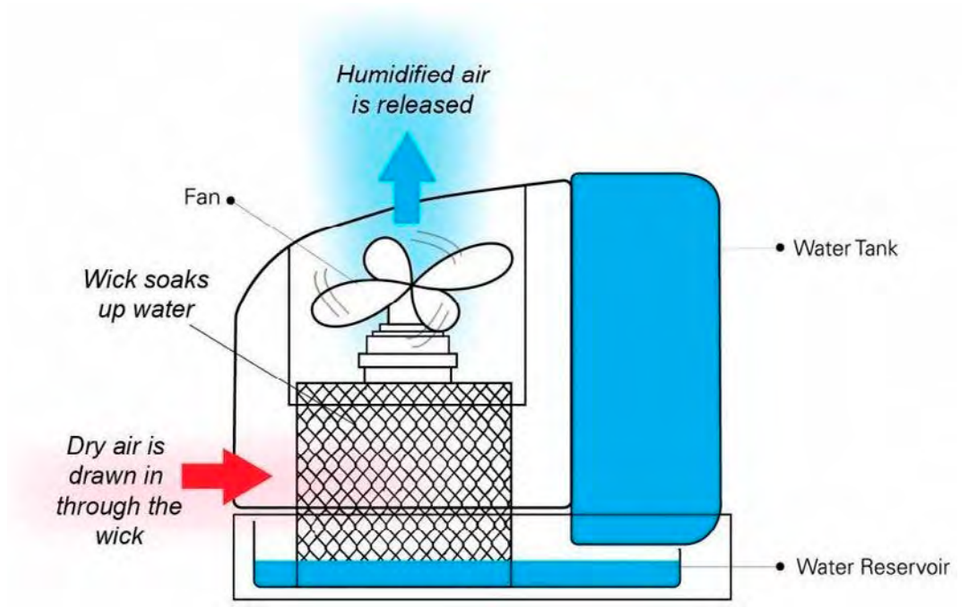


Fig. 133 Working process of an evaporation humidifier.

Evaporation

For evaporation, moisture is achieved through a process of evaporation. Water is conveyed over evaporator mats, so the air that simultaneously flows past these mats evaporate it and gets enriched with moisture (see Fig. 133).

This principle is simple, cheap and functional, but the main issue is that it requires bigger space. This is due to the fact that the water evaporates thanks to the flow of the air that passes near the humid surface of these mats. As a consequence, this surface must be large enough to be able to provide the required humidity levels, and this does not seem the best option to incorporate in a refrigerator. Moreover, this system also requires frequent maintenance as the salts in the water (when not distilled) will be depositing inside the products system and even in the room, creating a fine layer of so defined white dust. This sistem doesn't kill bacteria but this is not a problem as they could be killed once inside the crisper drawer. Another advantage of this system is that it provides de cool steam which could be directly implemented into a refrigerator.

Atomization

This process releases fine water droplets to the surrounding air, using mechanical atomizers (nozzles) or acoustic flat plate atomizers (ultrasonic vibration).

In case of **nozzles**, the process is very simple. A pump pumps the water at a certain pressure that later comes out through this nozzle. Since

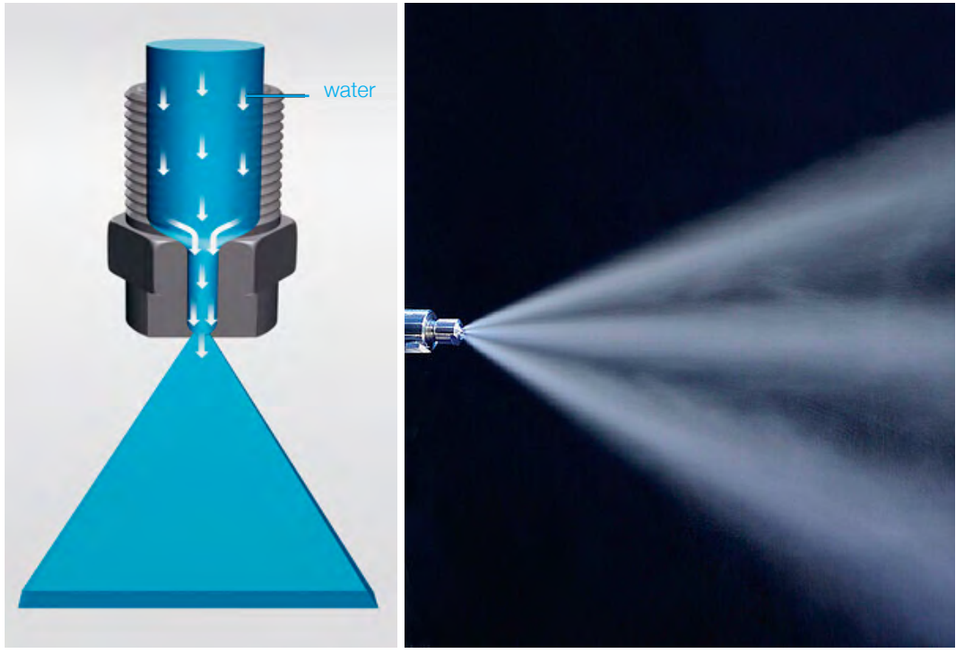


Fig. 134 A mechanical atomizer (nozzle).

the diameter of the nozzle hole is much smaller than that of the pipe through which the water flows, this makes increase the flow speed when passing through this nozzle, allowing to spray the water into thousands of small water droplets (Fig. 134).

This system is one of the most widely used at an industrial level, with the purpose of increasing and maintaining precise humidity control in different environments and market sectors. This type of system is somewhat more complex than it may seem at first glance. An example of a nozzle system provided here is a Humidification Fog Systems by MicroCool®[106] (Fig. 135).

This product is composed of different mechanisms and components that make it a complete humidification system. As it is designed to cover large areas, it's dimensions are also big. The process of this humidification system starts with a pump, which creates a constant pressure and water flow in the system. From here, the water flows through the reverse osmosis cylinders. They are capable of capturing impurities in the water such as salts and minerals, which with the passage

106 *Cold Storage Humidification by MicroCool®. (https://www.microcool.com).(https://www.microcool.com/industrial-humidification/cold-storage-humidification/)*

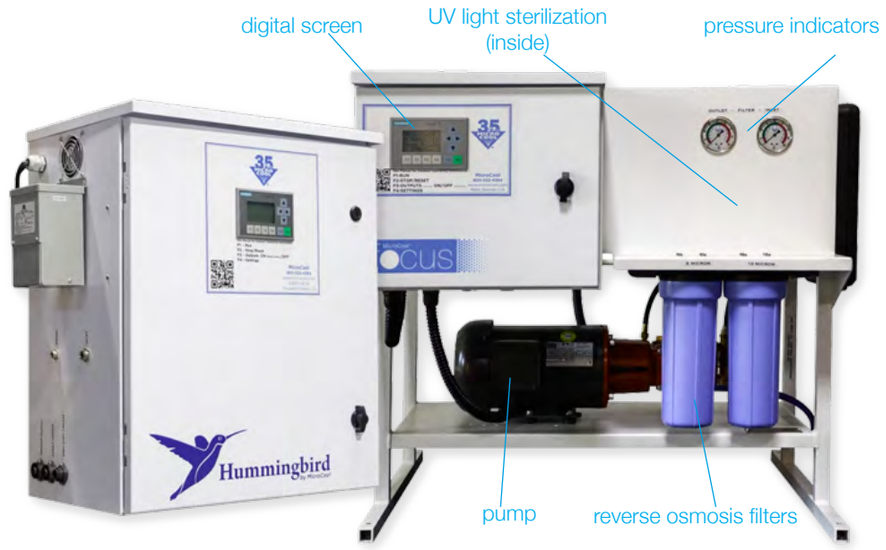


Fig. 135 Commercial & Industrial Humidification Fog Systems by MicroCool®.

of time would be deposited within different components of the system. By using reverse osmosis, it is possible to avoid a frequent cleaning process due to these salts deposition, and it also reduces the replacement costs of certain parts of the product that are prone to clogging by these minerals. The water pressure in these pipes is monitored both before and after these osmosis filters. This allows to control the obstruction level of these filters and to know exactly when they are needed to be replaced. The next step is an ultraviolet (UV) light treatment. This system makes the water flow through the UVC light frequencies tunnel which will kill most part of bacteria in the water. As a final part, the water flow is taken to the nozzles, which atomize the water into water droplets and increase the humidity of the environment to the required levels. The whole process is controlled through a digital screen.

What refers to **Ultrasonic Vibration**, it is commonly being used for humidifiers and other applications. In these atomizers, an electrical signal is converted to mechanical oscillation using a piezoelectric material immersed in a reservoir of water. The ultrasonic waves created by the mechanical vibration of the plate are directed towards the water surface creating a mist of water droplets (Fig. 136). These atomizers are normally available in a high frequency range of 1.65–3 MHz which are capable of producing droplets within the range of 1–5 µm in diameter using 2 up to 30 W of power. The flow rate varies within the range of 5–400 mL/h. They are in contact with water and the water level on their top affects their performance and should be taken into account for the optimum performance of the device. They are available in various plate area dimensions and thicknesses.[107]

107 *Ahmed M. Al-Jumaily, Ata Meshkinzar, "On the Development of Focused Ultrasound Liquid Atomizers", Advances in Acoustics and Vibration, vol. 2017, Article ID 7861726, 10 pages, 2017. https://doi.org/10.1155/2017/7861726*

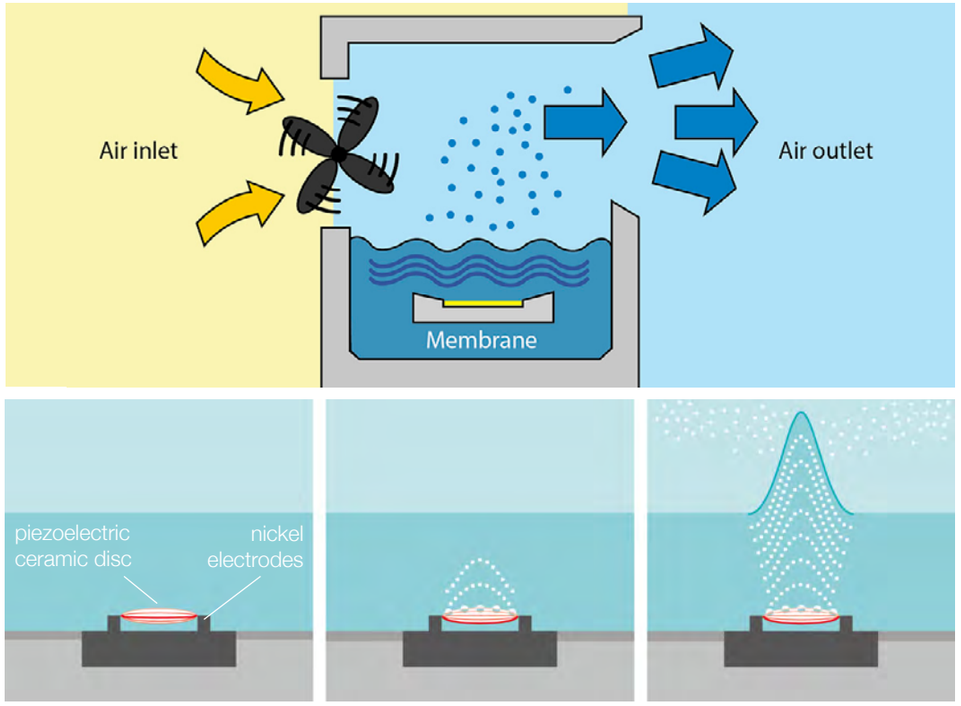


Fig.136 Acoustic flat plate atomizer system (a), ultrasonic plate vibration (b).

As in the previous case, this technology is used at industrial levels and allows controlling humidity levels on a large scale. The following image shows an industrial ultrasonic humidifier created by FrigoBlock[108] (see Fig. 137). And although in our case we do not need an object of these capacities since the volume of our product is much smaller (crisper drawers), it is necessary to analyze this object and understand how it works. At first glance, the dimensions are smaller than those of the nozzle system, and this is mainly due to the fact that this system does not require a water pump. After the water is turned into cold steam, this moisture is distributed in the room by an internal fan. The produced cold mist does not affect the efficiency of the refrigeration system. A less than 1 micron sized droplets moves faster because of the air circulation in the room. Due to this there is the same humidity level all over the room. This system provides automatic flushing that is controlled by humidity sensors. It also incorporates automatic water re-filling with water level control and warning system when these levels are too low or high. As a result, the humidity production process in this system is quicker, more efficient and less noisy than the other systems.

108 *FrigoBlock. Ultrasonic Humidifier (http://www.frigoblock.com.tr/eng/ultrasonic-humidifier.php)*

KAPASİTE TABLOSU / CAPACITY TABLE

Model Adı / Model Name		Kapasite / Capacity	Oda Hacmi / Room Volume	Çektiği Güç / Power Consumption		Nem Oranı / Humidity Level
				NUH	NUH ATM	
NUH 3000	NUH ATM – 3000	2-3 lt/h	0 - 599 m^3	140 Watt	340 Watt	%80-%98
NUH 6000	NUH ATM – 6000	4-6 lt/h	600 - 899 m^3	260 Watt	460 Watt	%80-%98
NUH 9000	NUH ATM – 9000	6-9 lt/h	900 - 1.199 m^3	380 Watt	580 Watt	%80-%98

Fig.137 Industrial ultrasonic humidifier by FrigoBlock, and its capacity table characteristics.

The productive capacities of this humidifier are very high, capable of maintaining high levels of humidity (80-98%) on surfaces between 0-599 m^3, at a speed of 2-3 lt/h (see NUH 3000 model). However, these capacities are much higher than those required, since our product (crisper drawers) would have a total volume of approximately 1m^3. This makes possible to reduce its dimensions considerably for its later incorporation in a refrigerator. In this way, ultrasonic technology seems to be among the most interesting due to its productive capacities, efficiency, low noise levels (no pumps) and above all because of the dimensions.

On the other hand, it is necessary to take into account that UV light is not necessary to kill the bacteria in the water, since this feature will be available inside the drawers, allowing this process to be carried out later. What does require a more in-depth study are the water filtering systems. They allow reducing different particles in the water, as well as dissolved salts and minerals (and also bacteria). This reduces the deposition of these salts in different parts of the humidification system (including crisper drawers), thus reducing maintenance (cleaning and repairs), and increasing the useful life of the product and its components.

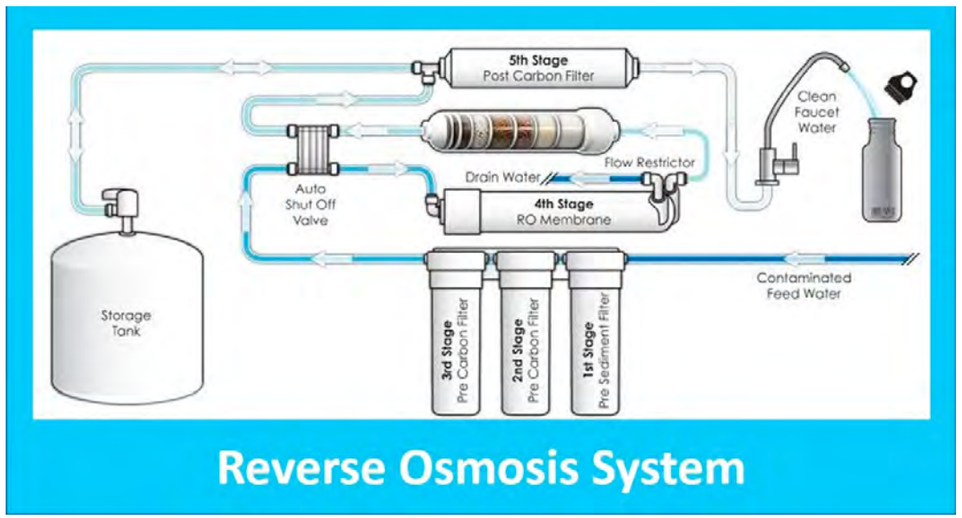


Fig.138 Example of a 10-head ultrasonic mist maker, and its capabilities.

3.4.3 Water Treatment

A prerequisite for long-term, failure-free and hygienic operation of a humidification system is the quality of the water used. Consequently, it is important that the water treatment works perfectly in line with the humidification system. There are a wide range of water softeners, desalination systems and systems for complete water purification through reverse osmosis.

Among different systems, reverse osmosis (RO) is one of the most efficient methods of water purification and is used in many households as well to get clean and safe drinking water. Before getting into reverse osmosis, it is important to understand what osmosis is and how it works? Osmosis is a naturally occurring phenomenon. It is a process wherein a diluted solution will tend to flow into a strong saline solution. In other words, it is the flow of fluid from a higher concentration to a lower concentration area.

Unlike osmosis, reverse osmosis requires external pressure to work as it acts against gravity, which is from lower to higher concentration area. This external pressure is applied to a highly soluble fluid that enables it to pass through a selectively permeable membrane to a lower concentrate fluid. The membrane allows water to flow through while blocking larger molecules like contaminants. The RO process leaves the solvent (fresh water) on one side and higher concentrations of solute on the other side.[109]

In summary, Reverse Osmosis water treatment system should be considered to implement into the new concept of the refrigerator, which will allow the humidification system to function correctly, with low maintenance required. In addition, the water filtered by this process can be also used in a fridge water dispenser, when this option is provided.

109 *A brief discussion on reverse osmosis system. Cannon Water Technology Inc. (https://cannonwater.com/blog/discussion-on-reverse-osmosis-ro-system/)*

3.4.4 Antimicrobial Treatments

The main focus of antimicrobial treatments on fresh produce is to reduce the biological loads, which accelerate the rotting and senescence processes of the produce. Many companies have been looking for solutions to reduce these microorganisms activity, including vegetative bacteria, bacterial spores, virus, yeasts, and molds. Among these solutions, we can find different sanitizers and disinfectants that are being used by food industry, and these are chlorine, chlorine dioxide (ClO_2), organic acids, ozone, hydrogen peroxide, electrolyzed water and trisodium phosphate (TSP) and others. However, on the following pages we will proceed with the analysis of the most relevant methods for this project. So let's take a look at some of them.

Chlorine Treatment

Chloring and associated compounds are the most routinely used by the food industry. The antimicrobial effect of chlorine is attributed to the breaking of chemical bonds in molecules such as enzymes and proteins. This method has been used for sanitation purposes for several decades, but it is not the most effective one. It has been attested the inability of chlorine to effectively act on foodborne pathogens.[110]

According to Dr. Keevil, "*the problem with fresh produce is that many people eat it fresh, so it misses the cooking step which would kill most pathogens, one reason why companies have relied on chlorine washing before sale.*"[111]

110 *Ijabadeniyi OA, Minnaar A, Buys EM (2011) Effect of attach- ment time followed by chlorine washing on the survival of inoculated Listeria monocytogenes on tomatoes and spinach. J Food Qual 34(2):133–141. doi:10.1111/j.1745-4557.2011. 00375.x*

111 *Viable-but-Nonculturable Listeria monocytogenes and Salmonella enterica Serovar Thompson Induced by Chlorine Stress Remain Infectious. Callum J. Highmore, Jennifer C. Warner, Steve D. Rothwell, Sandra A. Wilks, C. William Keevil. mBio Apr 2018, 9 (2) e00540-18; DOI: 10.1128/mBio.00540-18*

Institution	Health standards
Food and Drug Administration (FDA)	Requires a concentration limit exposure of 0.05 ppm during 8 h
Occupational Safety and Health Administration (OSHA)	Requires a concentration limit exposure of 0.10 ppm during 8 h
National Institute of Occupational Safety and Health (NIOSH)	Recommends an upper limit of 0.10 ppm, not to be exceeded at any time
Environmental Protection Agency (EPA)	Requires a concentration limit exposure of 0.08 ppm during 8 h

Fig. 139 Reference exposure levels of ozone.

Although the potential of chlorine to inhibit microorganisms has been reported, its interaction with some components, such as organic matter, leads to the formation of carcinogenic chlorinated by-products. As a result, some European countries have forbidden its use.[112] Safety concerns of these compounds and their impact on human and environmental raise to explore alternatives of chlorine.

However, even if this method is not the most effective of all, it still keeps killing a part of certain bacteria, which helps reducing their activity. In any case, this system is not suitable for a new fridge concept, as it requires a large infrastructure for washing these foods, and then recycling dirty waters.

Ozone Treatment

Gaseous ozone is a strong sanitation and fumigation agent and can be used to sanitize foods in storage room and during shipping, to prevent bacteria, mold, and yeasts on produce. It can eliminate undesirable flavor produced by bacteria and chemically remove ethylene gas to slow down the ripening process. Unlike chlorine, ozone is environmentally friendly, as, in water, it quickly degrades to oxygen, leaving no toxic waste (Fig. 141).

Although ozone is very effective treating produce, it has some drawbacks. In low concentrations ozone is not an extremely toxic gas, but at high concentrations ozone can cause severe detrimental health effects and can even be fatal. For these reasons, several federal agencies have established health standards or recommendations to limit human exposure to ozone (see Fig. 139).

According to different studies, treatment with this gas normally uses concentrations that in many cases exceed these limits (red lines on Fig. 140), which is why protective equipment is required in terms to avoid such harmful effects on human health.[113] Furthermore, the treatment conditions should be specifically determined for all types of products for the effective and safe use of ozone. This means that the same ozone treatment conditions may affect differently on different produce, increasing the shelf life of the first one and reducing it in the other case.

The same research study mentioned above exposes other very important data that should be taken into account. Ozone treatment can lead to a safer product with an extensive shelf life, but in some cases it can also affect the overall quality of the final product. In different cases of this study it was found that, due to

112 *Betts G, Everis L (2005) Alternatives to hypochlorite washing systems for the decontamination of fresh fruit and vegetables. In: Jongen W (ed) Improving the safety of fresh fruit and vegetables. CRC Press, Wageningen.*

113 *A Review on Ozone-Based Treatments for Fruit and Vegetables Preservation. Fátima A. Miller, Cristina L. M. Silva, Teresa R. S. Brandao. Food Eng Rev (2013) 5:77–106DOI 10.1007/s12393-013-9064-5*

Produce	Treatment conditions	Quality/safety characteristics	Results
Apples	Exposure to 450 ppb ozone for 48 h and storage for 12 days at 20 °C with 95–97 % relative humidity (RH)	*Botrytis cinerea* Color Chlorophyll fluorescence Texture	Lesion size was reduced on treated apples Ozone treatment had no significant effect on color or on chlorophyll fluorescence
Banana	Ozone exposure at a flow rate of 8 mL/s for 0, 10, 20, and 30 min	Total phenol and total flavonoid content Vitamin C Antioxidant activity	Results showed that ozone treatment for up to 20 min would be useful in enhancing the nutritional properties
Blackberries	Storage for 12 days at 2 °C in an atmosphere with 0.0, 0.1, and 0.3 ppm of ozone	Fungal decay Anthocyanins Color POD activity	Ozone storage suppressed fungal development for 12 days, while 20 % of control fruits showed decay No impact on anthocyanin content Color was better retained in ozonated samples
Plums	Exposure to 0.1 µmol/mol ozone and maintenance at 13 °C under 95 % RH during 13 days	*B. cinerea*	Ozone treatment suppressed spore production by as much as 20 % in comparison with 'control' fruit Ozone treatment resulted in no effects on lesion development
Strawberries	Exposure to 40 ppm ozone for 1, 5, 30, 60, or 120 min	Biothiol content	At 40 ppm, ozone treatment for 30 min was found to be optimal for disinfection purposes, maintaining beneficial biothiols levels
Asparagus	Exposure to 40 ppm ozone for 1 h	Biothiol content Total bacteria counts	Ozone exerted minimal effect on biothiol concentrations 0.75 log reductions were observed
Broccoli	Broccoli treated with 1-methylcyclopropene was stored in an atmosphere with 0, 200 and 700 nL/L ozone at 12 °C with 95–97 % RH for up to 12 days	Color Weigh loss Respiration and ethylene rates Chlorophyll fluorescence Decay Volatile compounds	Application of 200 nL/L ozone showed no significant impact on color, weight loss, respiration and ethylene production and chlorophyll fluorescence, while 700 nL/L ozone treatments were injurious Both ozone concentrations caused reduction or elimination of decay
Carrots	Intermittent flush of ozone (0, 7.5, 15, 30, or 60 mL/L) into chambers for 8 h daily during 28 days at storage temperatures of 2, 8 and 16 °C	*B. cinérea* *S. sclerotiorum* Weight loss Color	Results suggested that an ozone supply of 15 mL/L for 8 h a day at 2 °C could provide some disease protection with a minimum of physical and physiological damage
Cucumber	Exposure to 40 ppm ozone for 1 h	Biothiol content Total bacteria counts	1.04 log reductions on bacterial counts were observed
Green bean	Exposure to 40 ppm ozone for 1 h	Biothiol content Total bacteria counts	Ozone did not decrease the level of biothiols 0.38 log reductions were observed

Fig. 140 Overview of the impact of gaseous ozone treatments on quality and safety characteristics of fresh produce.

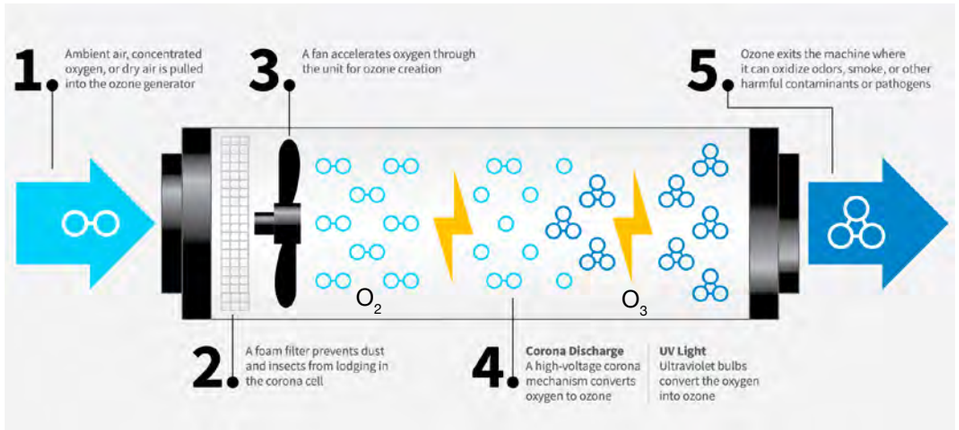


Fig.141 A scheme of an ozone generator

the strong oxidizing activity of ozone, produce can suffer a variety of damages when high concentrations of this gas are used. Among them is the color change, the firmness decrease attributed to the tissue injury, the loss of antioxidant compounds, decrease in vitamin C, oxidative spoilage, and others.

So although it is a very efficient antibacterial method, it requires certain security measures for its use. In high concentrations this gas can be lethal. Therefore, due to a system failure, this gas could even cause serious health damage or even the death of users. This situation suggests that the best option is that its use continues to be carried out in safe environments suitable for this purpose, and not in a home. In addition, it has been found that the ozone treatment is effective only if it is applied with specific conditions for each product. As a result, this makes it impossible for these conditions to be applied to all fresh produce equally, without certain products suffering any damage on quality or their shelf life. Therefore, the use of ozone is not considered suitable for use in the new refrigerator concept.

UV-C Irradiation

Food irradiation is a completely safe process of sterilizing food with UV lamps, which are designed to emit wavelengths within 200-280 nm (Fig. 142). The energy these waves produce is absorbed from bacteria cells, which damages microbial DNA and prevents microbial cell replication, which means these cells die. The UV-C light treatment is used as a surface decontamination, as it can't penetrate to the inner tissues. Thus, to avoid shaded areas (areas where the light can't get), produce is usually passed through UV-C light tunnels (Fig. 143) or placed in UV-C light chambers (Fig. 144), able to decontaminate them from different angles.

UV-C light is used in many food industry applications, and it is becoming a common alternative to sanitizing both fruit and vegetables. It is used to prevent produce diseases and enhance their shelf life and quality. UV lamps can effectively eliminate viruses like E. Coli and Salmonella as well as many other microbes which cause food to spoil. Germicidal UVC lamps are proven to eliminate many viruses

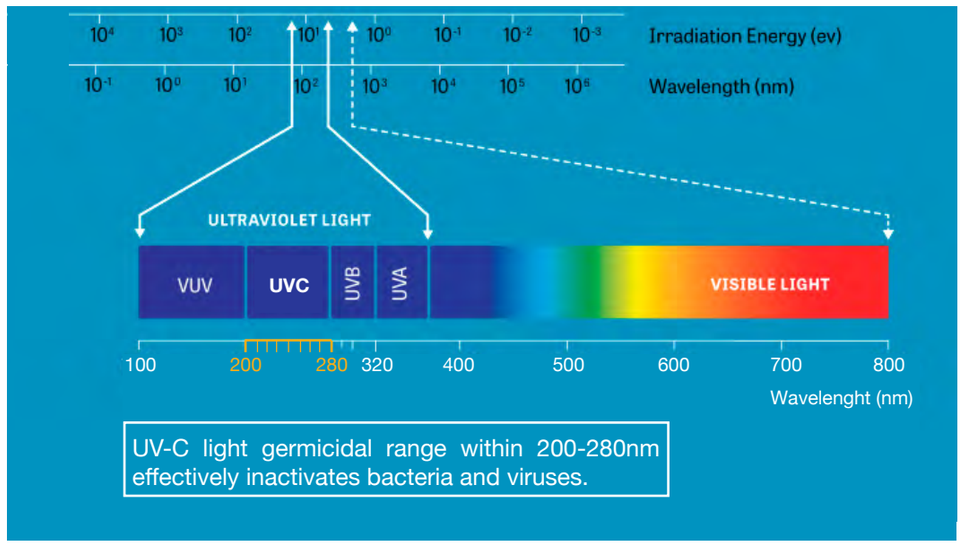


Fig.142 UV-C light germicidal ranges used for food sanitizing.

and bacteria, molds and spores as well as fungi and yeasts. How effective the treatment is depends on exposure time, level of irradiation, and the technology used.

Research shows that by using UV-C light to sanitize fruits and vegetables helps to delay microbial growth without altering the quality of the produce. UV-C light can be more effective in reducing microbial growth than the commonly used chlorine, hydrogen peroxide or ozone, which can leave residue and ultimately reduce quality. Furthermore, this technology is safe, easy to use, low maintenance, and does not require extensive safety equipment to be implemented.[114]

A recent research analyzed the impact of the UV-C light treatment on a wide range of fresh fruit and vegetables. The conclusion was that the UV-C treatment on produce surface has to be as gentle as possible for keeping the integrity and the freshness of fruits and vegetables. Results showed up that fruits treated with 0.25 kJ/m^2 light conditions, had a slower rate of senescence. Instead, a dose of UV-C of 1.0 kJ/m^2 (or higher), produced several damages to the fruits (see data on Fig. 144).[115]

It has been shown that the peak efficiency of UV-C treatment against microorganisms is around a wavelength of 253nm. For this reason, for decades it has been the

114 *The Benefits of UV Light Application on Fresh Produce. Alpha-Purify. 2018. https://www.alpha-purify.com/news/the-benefits-of-uv-light-application-on-fresh-produce*

115 *Ultraviolet light treatment of fresh fruits and vegetables surface: A review. Journal of Agroalimentary Processes and Technologies 2013, 19(3), 325-337. https://www.journal-of-agroalimentary.ro/admin/articole/22340L53_Vol_19_3__2013_325-337.pdf*

Fig.143 UV-C light tunnel used for industrial food sanitizing. Source: Youtube.

wavelength approved by the US Food and Drug Administration (FDA), and the most commonly used for these purposes.

However, one of the biggest issues of UV-C light is that its wavelenghts are quite dangerous for humans. A 253nm wavelenghts penetrate human tissue, and a short exposure to this light will cause pain and redness (sunburn), while exposure over long periods of time can lead to skin cancer, accelerated skin aging, and cataracts (eyes). For this reason, safety protocols and equipment must be in place to protect workers operating on or near UV light sources. To prevent this risk, UV sterilization throughout the food industry is always used in closed objects that avoid this light to get out. Most common examples of food decontamination are UV light tunnels that kills bacteria and pathogens as the food moves through the continuous production line (Fig. 143), or a UV germicidal chambers, as shown on the image on the right (Fig. 144).

Recent research from the laboratory of Dr. David Brenner, overcomes the safety concern of UV-C treatment. Brenner's research has explored the use of UV light at 222nm wavelengths (also known as "Far-UVC" light) instead of the industry standard of 253.7nm. He and his team have found that 222nm light can kill bacteria just as easily as conventional UV lamps, but without harming human skin or eyes. However, far-UV light faces the same penetration limitations as traditional germicidal lamps and is therefore best suited for the decontamination of surfaces, rather than food products themselves.[116]

116 *Research Efforts Lower the Safety Risk of Germicidal Ultraviolet Lights. Global Food Safety Resource. https://globalfoodsafetyresource.com/germicidal-ultraviolet-lights/#*

Fig.144 BioShift UV Germicidal Chamber used for food decontamination.

Far-UV Sterilray is currently the only company licenced to sell 222 nm lamps. According to its president, Jogh Neister, 222nm lamps outperform traditional germicidal UV lights because, "*Far-UV wavelengths do not pose the same risk to human exposure while they are still effective at killing pathogens. The lamps contain no mercury or electrodes, have very long lamp-life, and produce no ozone. Also, this light will not damage rubber or plastics*."

After this extensive analysis of antibacterial treatment technologies, a conclusion has been reached. Chlorine and Ozone treatments are technologies that work quite well at an industrial level, but at a domestic level they would be difficult to integrate for several reasons. Regarding UV-C treatment, its use is mainly focused on surfaces, since the areas where this light does not reach (shaded areas) can not be decontaminated. Despite this, although fresh produce in crisper drawers would only be partially decontaminated, it is much better than not having any system, and this makes it the best option to integrate into the new concept of the refrigerator. It is a silent, compact technology, and hardly requires maintenance. Once integrated, the decontamination process should be carried out when the crisper drawers are closed, which does not imply any risk for users. However, in order to avoid possible damage to users and the product itself (rubber and plastics), it has been decided that Far-UV-C light technology should be implemented into the new concept of refrigerator that is being developed in this project.

Fruit (Cultivar)	**UV light conditions**	**Results**
Apple (*Malus domestica*, cv. Red Delicious)	UV-C λ = 253.7 nm 1.5-24 mW/cm^2	– Reduction of *E. coli* O157:H7 with 3.30-log CFU/cm^2
Bluberry fruit (*Vaccinium corymbosum* L. cvs. Collins, Bluecrop)	UV-C 0-4 kJ/m^2 Storage 7 d at 5°C plus 2 d at 20°C	– Weight loss and firmness were not affected by light treatment – Decay incidence from ripe rot (*Colletotrichum acutatum*, syn. *C. gloeosporioides*) on fruit was decreased by 10% with 1-4 kJ/m^2 UV-C light – Antioxidants (measured by total anthocyanin), total phenolics, and ferric reducing antioxidant power (FRAP) increased with treatment intensity
Grapes (*Vitis vinifera* L. cv. Italia)	UV-C λ = 254 nm 0.125-4 kJ/m^2	– Grapes irradiated 24-48 hours before inoculating with *Botrytis cinerea* showed a lower disease incidence than those inoculated immediately before irradiation. – Doses above 1.0 kJ/m^2 resulted in skin discolouration. – Treatment within the optimum range did not significantly reduce the numbers of epiphytic yeasts that showed antagonism towards pathogenic moulds.
Peach (*Prunus persica*, cv. Elberta)	UV-C, λ = 254 nm 0.4-40 kJ/m^2	– Exposure to UV delayed ripening, suppressed ethylene production and increased phenylalanine ammonia-lyase (PAL) activity – inactivation of *Monilinia fructicola* inoculated after UV treatment – Doses of 40 kJ/m^2 increased susceptibility to brown rot
Pear (*Pyrus communis* L.) Fresh-cut pear – slices with peel	UV-C λ = 253.7 nm Time = 0–20 min Dose = 0–87 kJ/m^2	– Reductions with 1.8-2.5-log of cocktail strains of: *Listeria*, *L. innocua* ATCC 33090, *L. innocua* CIP 8011, *L. welshimeri* BE 313/01, *L. monocytogenes* (ATCC 19114, ATCC 33090), and yeasts: *Z. bailli* NRRL 7256, *Z. rouxii* ATCC 52519, *D. hansenii* NRRL 7268
Persimmom fruit (*Diospyros kaki* Thunb. cv. Karaj)	UV-C 1.5 and 3 kJ/m2 Storage 0-4 month at 1°C	– UV-C reduced the postharvest disease incidence without important effect on fruit attributes (firmness, ethylene production and skin colour)
Strawberries (*Fragraria ananassa*, *Duch.* cv Kurdistan)	UV-C λ = 254 nm 0.25 and 0.5 J/cm^2 Stored up to 7 d at 1...5°C	– All UV-C doses decreased growth of yeast – Fruits treated with the highest doses (0.5 J/m^2) are significantly firmer on day 7 and this dose improved the sensory quality of the product

Fig.145 Short summary of the study results related to postharvest UV treatment of fruits surface.

Vegetable (cultivar)	UV light conditions	Results	References
Asparagus, white (*Asparagus officinalis* L.)	UV-C, λ = 254 nm 1 kJ/m^2, 8 min Aqueous ozone Combined treatments	– Slight reduction of respiration in white asparagus spears, but increase in spear tissue toughness – Total cell wall compounds were only tendentiously reduced after 4 d of shelf-life at 20°C by application of aqueous ozone and UV-C	Huyskens-Keil *et al*., 2011
Bell peppers (*Capsicum annuum* L.), whole	UV-C 2.27kJ/m^2 21 d at °C	– Reduced decay caused by *Botrytis cinerea*	Artés *et al*., 2006
Broccoli heads (*Brassica oleracea* cv. Italica Group)	UV-C 4–14 kJ/m^2	– Delayed yellowing and chlorophyll degradation at 20°C – Displayed lower respiration rate – Increased total phenols and flavonoids, along with higher antioxidant capacity	Costa et al., 2006
Leaf lettuce	UV-C λ = 253.7 nm 1.5 – 24 mW/cm^2	– *Salmonella* spp. 2.65 log – *E. coli* O157:H7 2.79-log	Yaun et al., 2004
Lettuce (*Lactuca sativa* L. cv. 'Red Oak Leaf') - fresh cut	UV-C, λ = 254 nm 0.4, 0.81, 2.44, 4.07 and 8.14 kJ/m^2 MAP (2-10 kPa O_2 and 5-12 kPa CO2) Storage 10 d, 5°C	– Combination of UV-C radiation and MAP was effective for reducing psychrotrophic bacteria, coliform, and yeast growth. – Sensory quality of lettuce was not adversely affected	Allende and Artés, 2003b
Spinach (*SPinacia oleracea* L.)	UV-C 2.4, 7.2, 12.0 and 24.9 kJ/m2 13 and 14 d at 5°C	– All UV-C doses were effective in reducing bacterial growth (pathogens *L. monocatogenes* and *S. enterica*; spoilage bacteria *Pseudomonas marginalis*)	Escalona et al., 2010
Tomatoes (*Lycopersicon esculentum* L.) for fresh cut	UV-C 4 kJ/m^2 pretreatment + Storage under 5 kPa O_2 + 1 kPa CO_2 at 12°C for 21 d	– Retarded ripening – Maintained better firmness and sensory attributes than air storage	Robles et al., 2007
Zucchini squash (*Cucurbita pepo* L., cv. Tigress) slices	UV-C 10 and 20 min 5 or 10°C	– Significant reduced microbial activity and deterioration during subsequent storage at 5 or 10°C – Higher respiration rates – No consistent effect of UV-C on sugar or malic acid concentrations	Erkan et al., 2001

Fig.146 Short summary of the study results related to postharvest UV treatment of vegetables surface.

3.4.5 Ethylene Management

Ethylene is a gaseous plant hormone that is responsible for fruit and vegetables development, ripening and senescence. Ethylene accumulation is, thus, extremely detrimental in produce storage, especially in mixed loading where high ethylene producing commodities are stored close to highly ethylene sensitive commodities. Reducing ethylene concentrations from 100 ppb to < 5 ppb in many fresh produce handling areas increased shelf life by up to 60 % (Wills et al. 1999). As a result, controlling and reducing ethylene concentrations inside storage area is quite important.

There are different techniques for ethylene removal, which include air ventilation, use of different absorbers and oxidizers, ozone, and catalytic oxidation (see Fig. 147). Different techniques are used according to the product, type and volume of the storage space.

Absorbing Packages (f.i. activated carbons, clay, zeolite) or **Oxidizers** (f.i. potassium permanganate) are suitable in small storages. However, these materials may get rapidly saturated, which require their frequent replacement and it makes them not the ideal option for long term storage, or large storage areas. After use, these materials also pose additional problem of waste disposal, which also should be solved.

Air Ventilation is cheap and effective technique for ethylene removal that can be used in small to large storage areas. However, in some cases this technique can not be used as in case of controlled atmosphere storage, as this would disturb the set air conditions.

Ozone treatment for ethylene removing is effective in controlled atmosphere storage and in large closed storage spaces. However, ozone is harmful to human health and its high concentrations could be injurious to fresh produce too (Smilanick, 2003).

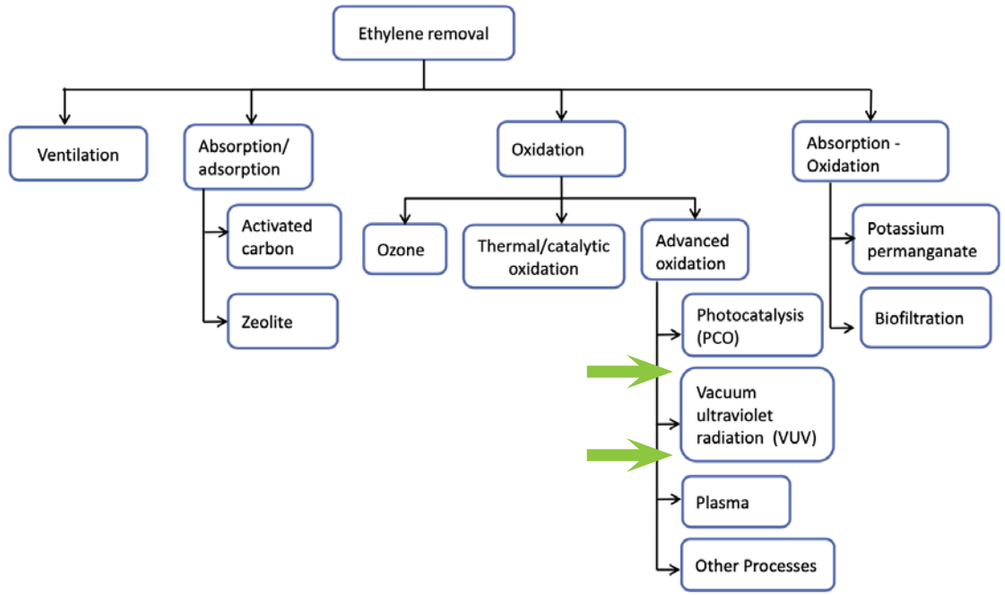


Fig.147 Different processes for ethylene removal.

Thermal/Catalytic Oxidation systems, on the other hand, can oxidize ethylene at high temperatures (over 100°C). They operate in a continuous mode in large storage volumes, but this process is energy intensive and require higher costs.

Due to the limitations of previously mentioned ethylene removing techniques, a research of alternative techniques was proposed. According to a recent research published on *Postharvest Biology and Technology*, Photocatalysis (PCO) and Vacuum Ultraviolet Radiation (VUV) Photolisis techniques have certain advantages over the conventional methods used by food industry as an ethylene removing systems.[117]

There is a limited scientific evidence to determine the effectiveness of these technologies to eliminate or reduce ethylene concentration along the postharvest supply chain of fresh produce. However, the above mentioned research on "Efficacy of photocatalysis and photolysis systems for the removal of ethylene under different storage conditions", carried out different tests under realistic fruit storage conditions, in terms to determine PCO and VUV potential and efficacy. So let's analyze the most relevant data exposed in this paper.

In first place, PCO and VUV are more sustainable, safe and cost-effective ethylene removing techniques, than any of previously mentioned above. They are based on the

117 *Namrata Pathak, Oluwafemi J. Caleb, Cornelia Rauh, Pramod V. Mahajan. Efficacy of photocatalysis and photolysis systems for the removal of ethylene under different storage conditions. Postharvest Biology and Technology. Volume 147, 2019. Pages 68-77. ISSN 0925-5214. https://www.sciencedirect.com/science/article/abs/pii/S0925521418304472*

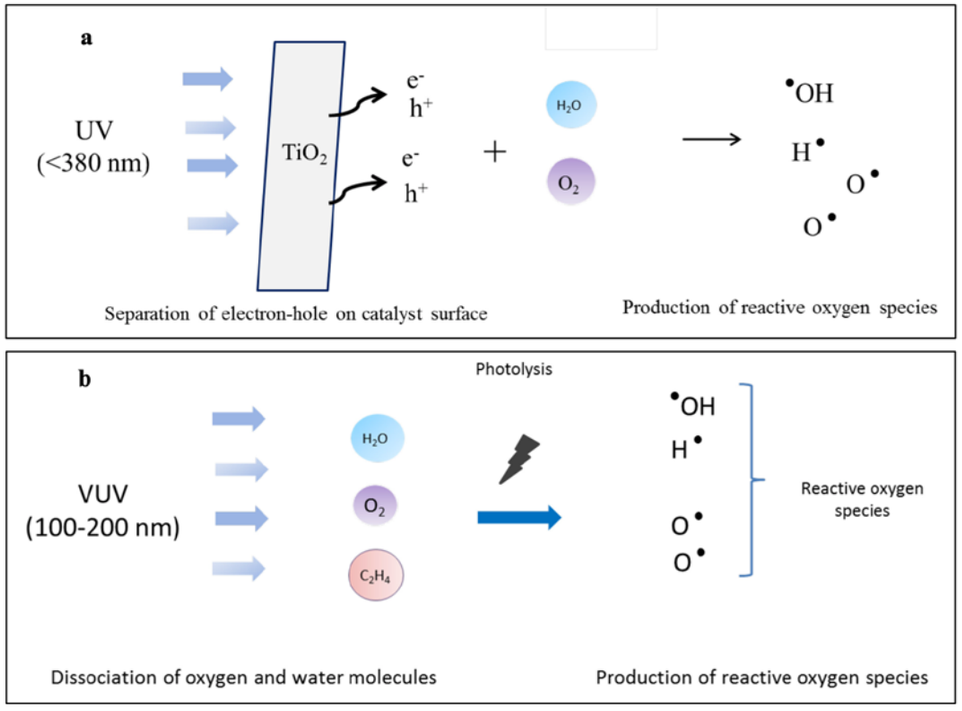


Fig.148 Generation of reactive oxygen species (ROS) in: a) photocatalysis (PCO), b) VUV photolysis.

use of ultraviolet light, which do not generate any solid waste, hence, no aditional cost for waste disposal is required. They can operate continuously without frequent replacement of parts and they do not require high temperatures for operation.

Photocatalysis (PCO) is a surface technology, based on the use of ultraviolet light ($UV_{254\ nm}$) and catalysts, such as titanium dioxide (TiO_2) or others. Here, the surface of the catalyst semiconductor is irradiated by ultraviolet wavelenghts, producing an electron-hole pair generation that react with surface absorbed oxygen and water molecules to produce reactive oxygen species (Fig. 148a).

In **VUV Photolysis**, instead, oxygen and water molecules in gaseous state are dissociated under VUV irradiation ($UV_{185+254\ nm}$) to produce similar reactive oxygen species (Fig. 148b).

Both techniques are based on the same working principle, generating *Reactive Oxygen Species* (ROS). The oxydizing ability of these reactive species can oxidize different gaseous impurities (such as ethylene) and can break down various substances such as organic acids, microbes and some inorganic molecules. As a result, PCO photocatalysis and VUV photolysis can be used as ethylene removing technique but also as antimicrobial treatment of fresh produce.

Class	(µL C_2H_4/kg^{-h} at 20°C)	Commodities
Very low	<0.1	Artichoke, asparagus, cauliflower, leafy vegetables, root vegetables, potato, cherry, citrus, grape, jujube, strawberry, pomegranate.
Low	0.1-1.0	Cucumber, eggplant, okra, watermelon, chili, bell pepper, pumpkin, olive, pineapple, blueberry, raspberry.
Moderate	1.0-10.0	Tomato, banana, fig, guava, honeydew, melon, mango, plantain.
High	10.0-100.0	Apple, apricot, avocado, cantaloupe, kiwifruit, nectarine, papaya, peach, pear, plum.
Very high	>100.0	Sapota, mammee apple, passion fruit, cherimoya.

Fig.149 Classification of Horticultural Commodities According to Ethylene Production Rates.

Before proceeding with the research, it is important to analyze the following data. Ethylene production rates in fresh produce varies greatly and may range from ***very high*** (>100 µL kg^{-1} h^{-1}) in passion fruit; ***high*** (10–100 µL kg^{-1} h^{-1}) in apples, pear, avocado; ***moderate*** (1–10 µL kg^{-1} h^{-1}) in bananas, fig, tomato; ***low*** (0.1-1 µL kg^{-1} h^{-1}) in blueberries to ***very low*** (<0.1 µL kg^{-1} h^{-1}) in carrots and citrus fruits (Blanke, 2014, Fig. 149). Thus, ethylene accumulation inside a closed storage chamber may vary depending on the type and amount of product, storage conditions and on the dimensions of the storage room.

Another research suggests that, in general, ethylene could induce physiological responses in fresh produce even at concentrations ***below 0.001 µL L^{-1}***.[118] However, the threshold for its physiological effects on fruit and vegetables may vary widely. To compare these data, a summary of detrimental effects of ethylene on fresh produce is provided on the Fig. 150.

However, ethylene is also present in ambient air due to hydrocarbon combustion (cities with dense traffic and industries), and others (f.i. sun UV irradiation), hence, high levels of this gas may accumulate along the fresh produce supply chain. Ethylene concentration in ambient air of cities is generally from low to moderate, ranged between ***1-5 µL L^{-1}***.[119]

Next research investigated the ethylene concentrations at various points in the fruit and vegetables supply chain, including retail areas, depots, shop stores, pack-houses and storage facilities.[120] The lowest ethylene concentrations (<0.05 µL L^{-1}) were found in retail areas and shop store rooms, indicating that good ventilation prevented accumulation of ethylene in those areas. On the other hand, highest ethylene concentrations (up to 3.6 µL L^{-1}) were found in storage facilities.

118 *Wills, R. B. (2015). Low ethylene technology in non-optimal storage temperatures. In R. B. H. Wills & J. Golding (Eds.), Advances in postharvest fruit and vegetable technology (pp. 167–190). Boca Raton: CRC Press.*

119 *F.B. Abeles, P.W. Morgan, Mikal Saltveit. Ethylene in Plant Biology: Second Edition. ResearchGate. January 2012. https://www.researchgate.net/publication/288562081_Ethylene_in_Plant_Biology_Second_Edition*

120 *Rees, D., Hipps, N., Colgan, R., & Thurston, K. (2011). Ethylene and microbial hotspots in the fresh produce supply chain [final report]. Waste Resources Action Programme (WRAP), Banbury, Oxfordshire, UK. https://link.springer.com/article/10.1007/s11947-017-1889-0#Tab1*

Ethylene effect	Specific effect	Ethylene exposure level	Commodity	Storage condition and duration	Reference
Abscission	Basal leaf abscission	–	Cauliflower	–	Rees et al. (2011)
Colour	Yellowing	0.1 µL L^{-1} and <0.005 µL L^{-1}	Broccoli, Parsley, Chives	5, 20 °C	Wills et al. (1999)
		1 µL L^{-1}	Broccoli	10 °C for 12 days	Fan and Mattheis (2000b)
		<0.005–10 µL L^{-1}	Chinese cabbage	0, 20 °C	Wills et al. (1999)
	Degreening	10 µL L^{-1}	Cucumber	15 °C for 12 days	Hurr et al. (2009)
	Leaf tip browning	<0.005–1 µL L^{-1}	Lettuce	0 , 20 °C	Wills et al. (1999)
	Mesocarp discolouration Pulp browning	50 µL L^{-1} 12–48 h 4 µL L^{-1}	Avocado	5 °C for 3 weeks	Pesis et al. (2002)
	Increase in hue angle (greenness), reduction in lightness	1 µL L^{-1}	Kiwifruit	17 weeks	Pranamornkith et al. (2012)
Physiological disorders	Chilling injury	50 µL L^{-1} 12–48 h; 4 µL L^{-1} <0.005–10 µL L^{-1}	Avocado Orange	5 °C for 3 weeks 5 °C for 56–129 days	Pesis et al. (2002) Wills et al. (1999)
	Russet spotting	126 µmol m^{-3}	Lettuce	6 °C for 9 days	Fan and Mattheis (2000b)
	Superficial scald Internal browning	0, 1, 5 or 10 µL L^{-1}	Pear	2 °C for 3 months	Bower et al. (2003)
	Rotting and senescence	<0.005–1 µL L^{-1}	Strawberry	0, 20 °C for 8 h–10 days	Wills and Kim (1995)
	Epidermal sloughing, water soaking	1 µL L^{-1}	Cucumbers	15 °C for 12 days	Hurr et al. (2009)
	Water soaking injury	1 µL L^{-1}	Kiwifruit	17 weeks	Pranamornkith et al. (2012)
Senescence	Chlorophyll degradation and decline in protein content	10 µL L^{-1}	Coriander leaves	20 °C for 8 days	Jiang et al. (2002)
Softening	Loss of firmness Softening	0.01, 0.1 and 1 µL L^{-1} 0.1–100 µL L^{-1} <0.005–10 µL L^{-1}	Kiwifruit Peach Mango, peach, custard apple, Banana, kiwifruit	0 °C, 4 weeks – 0, 20 °C	Jabbar and East (2016) Hayama et al. (2006) Wills et al. (2001)
Sprouting	Increased sprouting	<0.005–10 µL L^{-1}	Potato	20 °C for over 35 days	Wills et al. (2004)
Taste and flavour	*Bitterness*	42 µmol m^{-3}	Carrot	10 °C for 4 days	Fan and Mattheis (2000b)
	Bitterness, earthy flavours, green flavours, terpene flavour, aftertaste	1 µL L^{-1}	Carrots	15 °C for 3 weeks	Seljåsen et al. (2001)
Toughness	Lignification	1 µL L^{-1}	Asparagus	22 °C in air with 80–90 % RH for 5 days in the dark	Liu and Jiang (2006)

Fig.150 Summary of detrimental effects of ethylene on fruit and vegetables. Data from "Photocatalysis and Photochemical Oxidation of Ethylene: Potential for Storage of Fresh Produce - a Review.

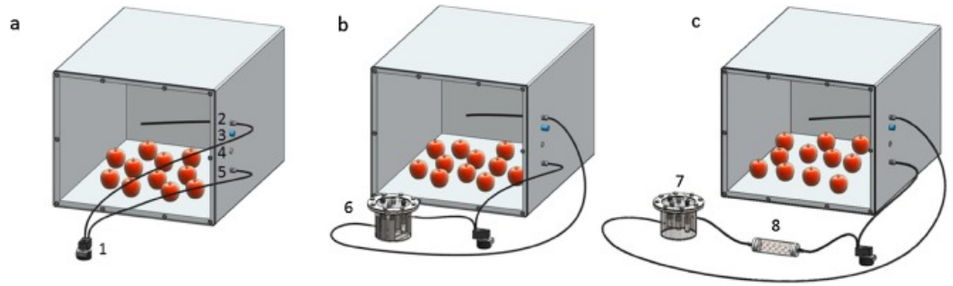


Fig.151 Experimental setup for fruit storage. a) Control chamber, b) Photocatalytic oxidation (PCO) chamber, c) Vacuum ultraviolet light (VUV) photolysis chamber. 1 - pump, 2 - inlet, 3 - temperature/humidity sensors, 4 - rubber septum, 5 - outlet, 6 - PCO reactor, 7 - VUV reactor, 8 - ozone filter.

Often, fruit and vegetables are stored in mixed loading due to space constraints. This can be highly detrimental, as ethylene-producing and ethylene-sensitive comodities are placed together, which can rise ethylene concentrations and damage all produce. Some data recordered that in mixed fruit cargo, ethylene levels (produced from apples) can easily get up to 50 µL L^{-1}. However, decreasing ethylene concentrations from 10 to 0.001 µL L^{-1} in mixed storage (climacteric and non-climacteric fruit), can increase postharvest life.[121]

PCO and VUV test outcomes

The study by Pathack (2019) analyzed the effectiveness of PCO and VUV ethylene removal systems. For this, real conditions were recreated, using 6kg of apples for each container (Fig. 151), for 8 days. Each of these tests were carried out using different humidity and temperature settings to find out the behavior of these technologies under different storage conditions. And this is what was obtained.

Apple storage (Fig. 151a) revealed that the ethylene concentration increased to 70 µL L^{-1} in 8 days at 1 °C. The initial maximum ethylene concentrations of 35 µL L^{-1} in PCO chamber, could be reduced to <0.04 µL L^{-1} within 50 minutes. Meanwhile, the initial maximum ethylene concentrations of 32 µL L^{-1} in VUV chamber, could be reduced to <0.04 µL L^{-1} in just 7 minutes (see data on Fig. 152).

Ethylene removal in VUV photolysis was much faster than PCO. This was due to the fact that VUV technique relies on ethylene oxidation in the gaseous phase whereas, meanwhile PCO is a surface phenomenon, which mainly occurs at the irradiated surface of the photocatalyst (higher TiO_2-coated surface area means faster ethylene oxidation). Higher O_2 concentration in the reactor favored both ethylene removal processes. However, high relative humidity impeded PCO and enhanced VUV photolysis efficacy of ethylene oxidation. Lowering the temperature from 21°C to 1°C showed no consistent trend of temperature effects on ethylene removal in the PCO process, whereas

121 *Pranamornkith, T., East, A., & Heyes, J. (2012). Influence of exogenous ethylene during refrigerated storage on storability and quality of Actinidia chinensis (cv. Hort16A). Postharvest Biology and Technology, 64(1), 1–8.*

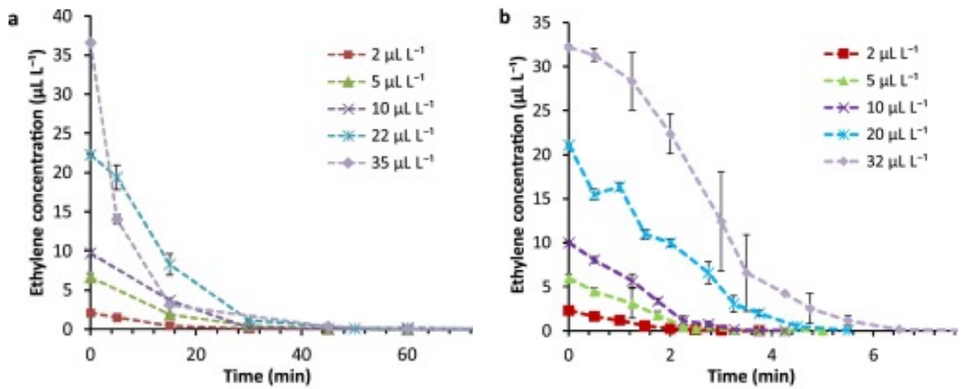


Fig.152 Ethylene concentration as a function of irradiation time a) Photocatalytic oxidation (PCO) and b) Vacuum ultraviolet photolysis (VUV). The legends denote different initial ethylene concentration. All experiments were carried out at 10% relative humidity, and 21°C.

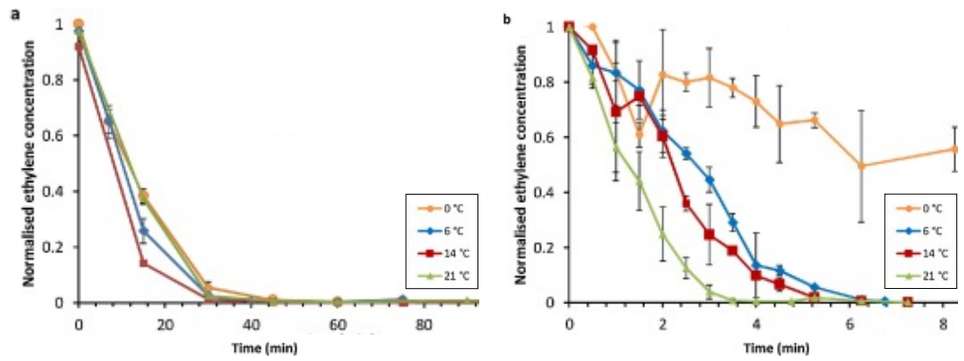


Fig.153 Effect of temperature on ethylene removal in a) Photocatalytic oxidation (PCO) b) Vacuum ultraviolet photolysis (VUV). All experiments were carried out at 10% relative humidity, and 21% O2. Error bars indicate standard deviation from mean values (n = 3). Statistical analysis on the effect and interaction is presented for percentage ethylene removal.

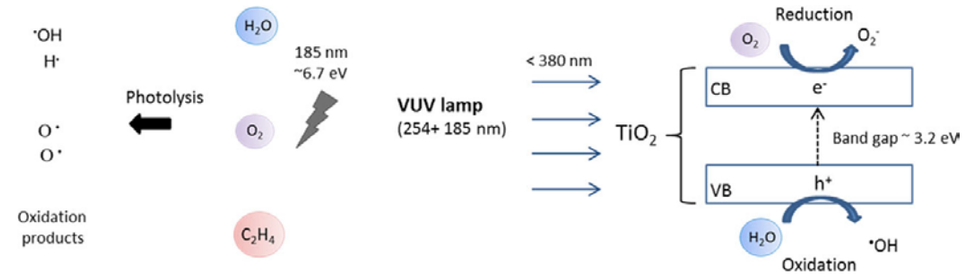


Fig.154 Schematic of production of reactive oxygen species in ethylene oxidation by combined photochemical and photocatalytic oxidation process (VUV-PCO). CB conduction band, VB valence band, PCO photocatalytic oxidation, VUV vacuum ultraviolet light.

in VUV photolysis, reducing the temperature decreased ethylene removal significantly (data on Fig. 153b). As a result, due to its reduced efficiency at low temperature, VUV photolysis may not be as advantageous in cold storages as in higher temperatures storage (>13 °C) of tropical fruits.

Both techniques (PCO and VUV) are highly dependent on initial ethylene concentration. At low ethylene concentrations their removal efficiency is lower. Overall VUV photolysis showed higher ethylene removal efficiency than PCO. The drawback of VUV technique is that its wavelenghts produce ozone, which should be removed using additional ozone filter, as its high concentrations could damage fresh produce and it is also dangerous for humans. Unlike VUV, PCO technique does not involve ozone generation, therefore, does not require any additional filtration mechanism. Nonetheless, the ozone produced in VUV process ($UV_{185+254}$) can be decomposed using additional catalysts, such as MnO_2, paladium, cobalt. As a result, studies based on combined action of VUV and ozone-assisted catalysis are being done.[122, 123]

Hybrid VUV-PCO Oxidation

Photocatalytic and photolysis oxidation present good potential for ethylene removal, but individually they both have certain drawbacks. PCO suffers from catalyst deactivation and lower efficiency under high humidity conditions, meanwhile VUV technique produces toxic ozone gas (O_3) in the process, and furthermore its efficiency at low temperatures is limited. Hybrid VUV-PCO technique could improve the ethylene removing process, and counteract these inefficiencies.

122 *Huang, H., Lu, H., Huang, H., Wang, L., Zhang, J., & Leung, D. Y. (2016a). Recent development of VUV-based processes for air pol- lutant degradation. Frontiers in Environmental Science, 4, 17.*

123 *Huang, H., Lu, H., Zhan, Y., Liu, G., Feng, Q., Huang, H., ... & Ye, X. (2016b). VUV photo-oxidation of gaseous benzene combined with ozone-assisted catalytic oxidation: effect on transition metal catalyst. Applied Surface Science.*

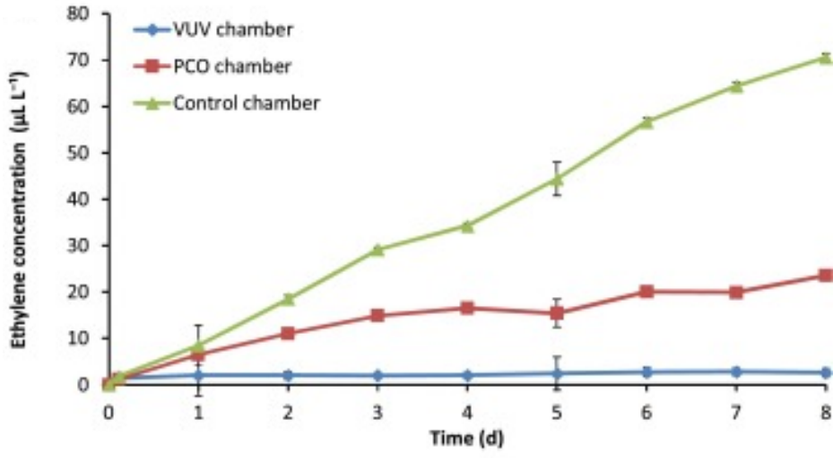


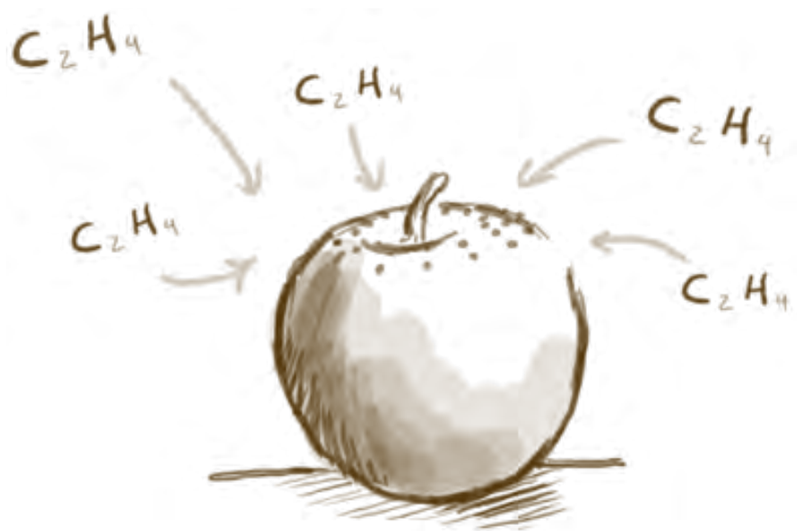
Fig. 155 Ethylene concentration in different apple storage chambers stored at 1°C, 97% RH, during 8 days.

The hybrid VUV-PCO system can be obtained by coupling of VUV (185 nm) and PCO (UV/TiO_2) simply by replacing the UV lamp in the PCO process with a $UV_{254 + 185}$ lamp (Fig. 154). This system shows better results at high RH conditions, due to the VUV efficiency in high humidity environment. VUV is also effective against photocatalyst deactivation, as its irradiation can eliminate the formation of non-volatile by-products from the photocatalyst surface. Meanwhile, PCO catalyst surface can easily decompose O_3 generated from VUV light and improve the efficiency of ethylene removal system at low temperature, conditions in which the VUV technique presents some issues.

However, studies on ethylene removal by VUV-PCO are very limited, and practical application of this hybrid system for ethylene removal in produce storage has not been reported. Hence, its possible impact on quality remains unknown. Until now, the main focus of VUV-PCO studies has been on removal of air pollutants such as toluene, formaldehyde and benzene. This VUV-PCO hybrid technique has been reported to be more efficient in volatile organic compounds removal (VOC) than VUV or PCO alone.[124]

Its higher efficiency is produced due to the combined effect of photochemical oxidation in gas phase (VUV light 185 nm) and PCO on the surface of catalyst (UV at 254 nm/TiO_2). Thus, the hybrid VUV-PCO system could have a high potential for ethylene removal in postharvest storage than VUV or PCO alone.

124 *Chang, K. L., Sekiguchi, K., Wang, Q., & Zhao, F. (2013). Removal of ethylene and secondary organic aerosols using UV-C254 with TiO2 catalyst. Aerosol and Air Quality Research, 13, 618–626.*



Conclusions

As ethylene can be harmful on fresh produce, the implementation of suitable ethylene control technologies can effectively minimize ecological and economical losses due to unnecessary waste of fresh produce. And this also applies to the storage of fruit and vegetables at home. Among different technologies analyzed on previous pages, VUV ethylene removing technique would be the most recommended for its use in the concept of the refrigerator that is being developed here. It provides many advantages and it is the most recommended technique for high RH conditions (those required for fresh produce). Notwithstanding it was observed that at low temperatures its efficiency gets reduced, this difference is not so big. According to the previous study, VUV photolysis kept the ethylene concentrations at the lowest levels even at low temperatures (1°C, 97% RH, see Fig. 155).

Furthermore, this concept aims to improve the storage of fresh produce at home by extending its shelf-life, thus reducing food waste. In any case, this doesn't require keeping it in a fridge for months, as none of us need it. But, as far as possible, the best storage conditions able to be integrated into the new refrigerator should be provided. As a result, there is no need to completely eliminate ethylene, but keep it as low as possible. Additionally, crisper drawers will be opened by the user several times a day, which will improve the air ventilation and further ethylene reduction.

What refers to hybrid VUV-PCO technique, to understand its advantages and measure its impact, further studies and tests in real storage conditions of postharvest produce are required.

Fig. 156 Highly sensitive ethylene (C2H4) sensor by Membrapor.

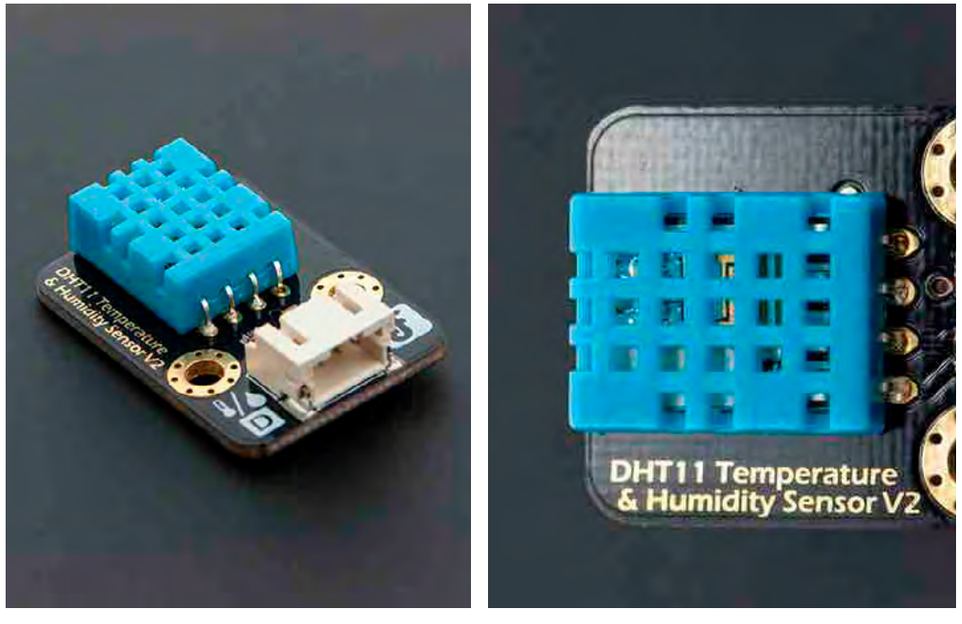


Fig. 157 DHT11 Temperature and humidity sensor.

3.4.6 Main Sensors

Apart from all the systems and technologies discussed above, sensors also form an important part of a product as a whole, in this case the refrigerator. They are necessary to analyze the conditions of different storage areas of the products. When these recommended conditions change, an action is necessary to restore the previous conditions again. The new concept of the refrigerator will need a meticulous control of temperature, humidity and ethylene levels, which will allow to fulfill these tasks. Often humidity and temperature can be monitored at the same time, as in the case of the DHT11 **hygrometer sensor** (Fig. 157).

On the other hand, **ethylene sensor** should be used to detect changes in ethylene concentrations produced by climacteric fruits. As a result, Membrapor C_2H_4/C-10 sensor is a highly sensitive ethylene sensor capable of operating at high levels of humidity (10%-95% RH), and a wide range of temperatures (-20ºC +50ºC) (Fig. 156).[125]

In the case of the humidity sensor, for example, it can provide the relevant data on RH levels within a fridge compartment (f.i. crisper drawer). These data are periodically analyzed, and the results are sent to a central system (computer). Here these data are analyzed and compared with those of the pre-established conditions that each compartment should have. If the results differ and the humidity levels are lower than those recommended, then a command is sent to the humidification system to activate it and restore RH levels again. Meanwhile the humidity is being raised, the sensor will continue to measure and transmit the RH level data to the computer. Once these levels have reached those recommended, the humidification system will stop working. This checking process is repeated from time to time, and is activated again when these conditions change. In the case of ethylene, the process is very similar.

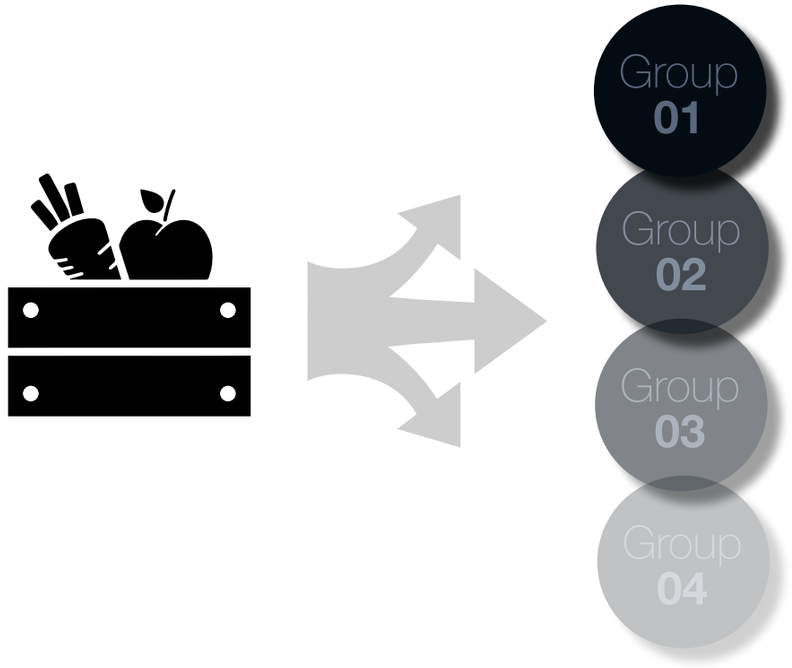
125 *Ethylene Gas Sensor C2H4/C-10. Specification Sheet. Membrapor.* http://www.membrapor.ch/sheet/Ethene-Gas-Sensor-C2H4-C-10.pdf

3.4.7 Updated Fruit and Vegetables Classification

The analysis of the technologies in the previous pages has created a great dilemma about the classification of the fruit and vegetables made in chapter 3.2.2. On the one hand, countless studies suggest that climacteric fruit should be stored separately from the non-climacteric fruit, due to the damage that these last can suffer in the presence of ethylene. For this reason, previously it was proposed the distribution of fruit and vegetables in 4 main groups, grouping them according to their shared storage conditions (Fig. 126).

On the other hand, the analysis of technologies has shown more than acceptable results. Regarding the control of ethylene gas concentrations, the VUV technique has shown to be able to keep low ethylene in a chamber with apples (high ethylene producing fruit) for an extended period of time (for more than 8 days) (see again Fig. 155). Besides, the constant use of the refrigerator as the opening and closing of its doors and drawers, would improve the air ventilation of these compartments and balance the concentration of certain gases such as ethylene, oxygen, and carbon dioxide.

Therefore, this raises the question whether the 4 fruit and vegetable groups created above are really necessary (Fig. 124). If it is possible to control ethylene concentrations and keep them at low levels, then the most advisable thing would be to use mixed crisper drawers, both for climacteric and non-climacteric products. Although some climacteric fruit can emit large concentrations of ethylene, the VUV system would be able to detect the excess of this gas at pre-established levels and activate the ethylene removal process, which in few minutes would be controlled again.



As a result, the ethylene factor would no longer be an obstacle for the definition of the fruit and vegetable groups. Neither is humidity since practically all produce requires high levels of RH (90-95%). The same happens with the antimicrobial treatment (UV-C light), which would be applied uniformly over the surface of these foods. Although, the great disadvantage of this technology is that it is only effective in areas irradiated by these wavelengths. The areas where this light cannot reach are defined as “shaded areas” since their antibacterial properties do not apply there. It is quite evident that in drawers with lots of fruit, there would be many areas like that. However, this is not a problem since the oxidizing capacity of ethylene removing VUV technique, can effectively oxidize ethylene, but also prevent fresh produce from bacteria, mold, and yeasts in these “shaded areas”.

In this case, the only relevant factor to take into account would be the temperature settings. According to the analyzes carried out in chapter 3.2.2., it would be recommended to use the two previously established temperature ranges, set between 0-2ºC and 8-10ºC (Fig. 124). The biggest advantage now, is that mostly all fruit and vegetables would be now possible to divide into just 2 large groups (Fig. 158). This means that the new refrigerator concept will only need two compartments, which allows to simplify this product and make it quite less complex.

UPDATED FRUIT AND VEGETABLES CLASSIFICATION

After reviewing the technologies, it was decided to update the food storage settings, defined for fresh produce at home.

Group 01
common and ethylene-sensitive
90-95% RH
0-2 °C

Berries (Blueberry, Cranberry, Raspberry, Strawberry);
Cruciferous vegetables (Broccoli, Cabbage, Cauliflower);
Leafy vegetables (Celeriac, Celery, Collard, Endive, Kale, Lettuce, Parsley, Silverbeet, Spinach, Watercress);
Root vegetables (Beetroot, Carrot, Parsnip, Radish, Turnip);
Temperate fruits (Cherry, Grapes, Watermelon);
Others (Artichoke, Asparagus, Coconut, Corn, Hohlrabi, Leek, Lychee, Mushroom, Pea, Pomegranate).

Group 02
ethylene producers
90-95% RH
0-2 °C

Temperate fruits (Apple, Apricot, Cantaloupe, Fig, Nectarine, Peach, Pear, Plum, Prune, Quince);
Subtropical fruits (Avocado (green), Kiwifruit).

Group 03
common and ethylene-sensitive
90-95% RH
8-10 °C

Citrus fruits (Lemon, Lime, Clementine, Grapefruit, Mandarin, Pomelo, Orange, Tangerine, Tangelo);
Subtropical and Tropical fruits (Carambola (Star fruit), Duku (Langsat), Durian, Guava, Langsat, Mangosteen, Persimmon, Pineapple, Rambutan, Sapodilla,);
Others (Bean, Capsicum, Cucumber, Eggplant, Marrow, Okra, Olive, Pepper (sweet), Potato, Pumpkin, Squash, Zucchini)

Group 04
ethylene producers
90-95% RH
8-10 °C

Subtropical and Tropical fruits (Avocado (ripe), Banana, Mango, Papaya, Passionfruit);
Others (Custard apple, Melon (honeydew), Pawpaw, Tomato).

Group 01
Berries, Cruciferous veg., Leafy veg., Temperate fruits and Others
90-95% RH
0-2 °C

- ✓ mixed fruit and vegetables storage
- ✓ high relative humidity (90-95% RH)
- ✓ low temperature storage (0-2 °C)
- ✓ advanced ethylene management
- ✓ latest antimicrobial treatments

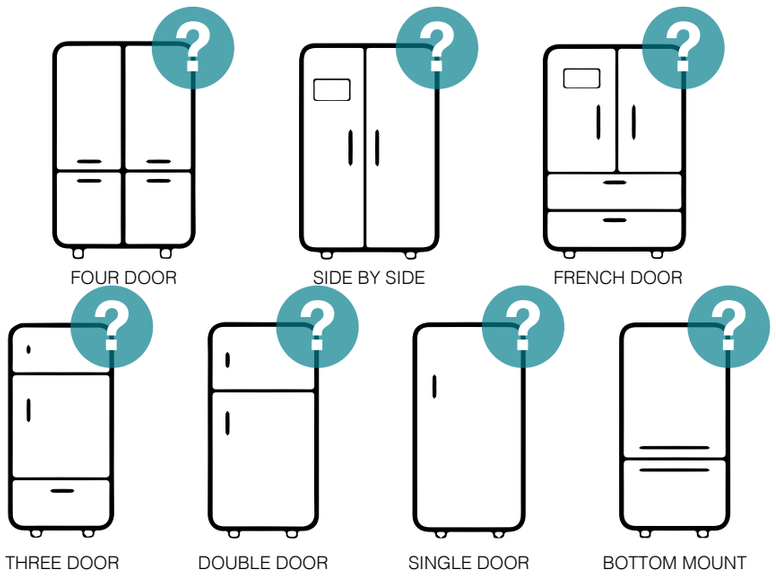
Group 02
Citrus, Subtropical, Tropical and other fruits
90-95% RH
8-10 °C

- ✓ mixed fruit and vegetables storage
- ✓ high relative humidity (90-95% RH)
- ✓ mid temperature storage (8-10 °C)
- ✓ advanced ethylene management
- ✓ latest antimicrobial treatments

Fig.158 Updated fruit and vegetables classification according to new product settings

CONCEPT LAYOUT

Next step, select a refrigerator on the market as a design reference and then focus on redesigning it, in terms of enhancing its preserving techniques to store fresh produce.



3.5 CONCEPT LAYOUT

3.5.1 Design Reference

The modern refrigerator, as we know it, works correctly and fulfills its purpose of preserving a great variety of foods we consume. But, throughout history, society has been evolving and with it our diet. In response to this, the refrigerator has had to adapt to these changes, innovating and improving some internal aspects with the passage of time. So there is no doubt that the current refrigerator works properly and preserves food well, but it is questioned whether the current conservation techniques could not be improved to some extent.

Development of a product that improves the conditions of preservation of fresh fruit and vegetables at home is a need and an urgency. Large quantities of fresh fruit and vegetables are being wasted, and not only produce huge impacts on our planet, but also on our society and on our pockets.

There are many reasons why these wastes are generated. But the most outstanding of all, without exception, is the way we store these foods. On the one hand, there is the consumer factor, which due to the lack of information or ignorance, ends up wasting large quantities of these foods. On the other hand, there is the factor of the manufacturer, which is directly related to the product. It is assumed that this product works well and that it fulfills its function correctly. However, not all refrigerators have been designed following the same guidelines and meeting the same objectives. As already noted in the previous chapter, many manufacturers on the current market address the issue of food waste in different ways. Some do it better than others, but what is clear, is that there are still some aspects that could be improved, and this is the main purpose in this project.

Fig.159 Samsung Family Hub™ 4-French Door Refrigerator, with 21.5" Touch Screen

At this point, I have decided to use ***Samsung Family Hub™*** refrigerator as the main project reference and ***Fresh by Design™*** by ***Bosch*** refrigerator as a tech reference (regarding crisper drawers), since these are the most advanced refrigerators on the market today. As already mentioned in the previous chapter, Samsung Family Hub is the only one fridge that actually integrates a giant touch screen, which will be very useful to proceed with the development of this project and provide further information about fruits and vegetables and also about their proper storage. What stays for preserving fruit and vegetables, the previous case study showed that the conditions used by Samsung refrigerator were good, but not optimum. Hence, as my field of research only deals with these foods, my purpose on the next pages will be only focused on redesigning crisper drawers, as there is no need to consider improving other areas of the refrigerator.

The type of product chosen to work on is a '*french door*' model, as the trend toward this type of refrigerator is growing. However, to bear in mind that the solution suggested on the following pages, would also be possible to apply to any other type of refrigerator.

According to the data obtained on previous pages, fruit and vegetables can be divided into 2 main groups in terms of improving their storage conditions.

As a result, it has been proposed to redesign these 'crisper drawers', creating 2 bigger drawers (as we already consume around 20% of fresh produce). In this way it would be possible to provide 2 different storage conditions to preserve fruit and vegetables properly at home.

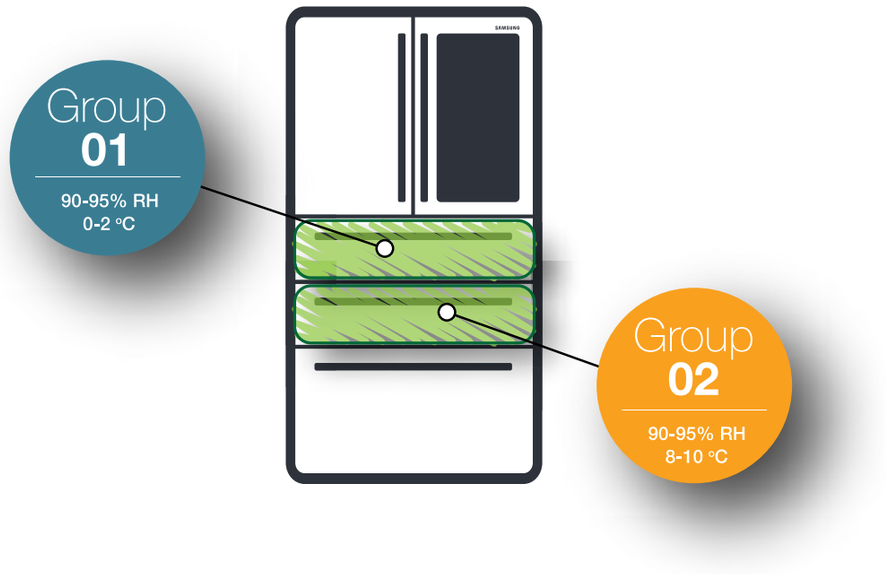
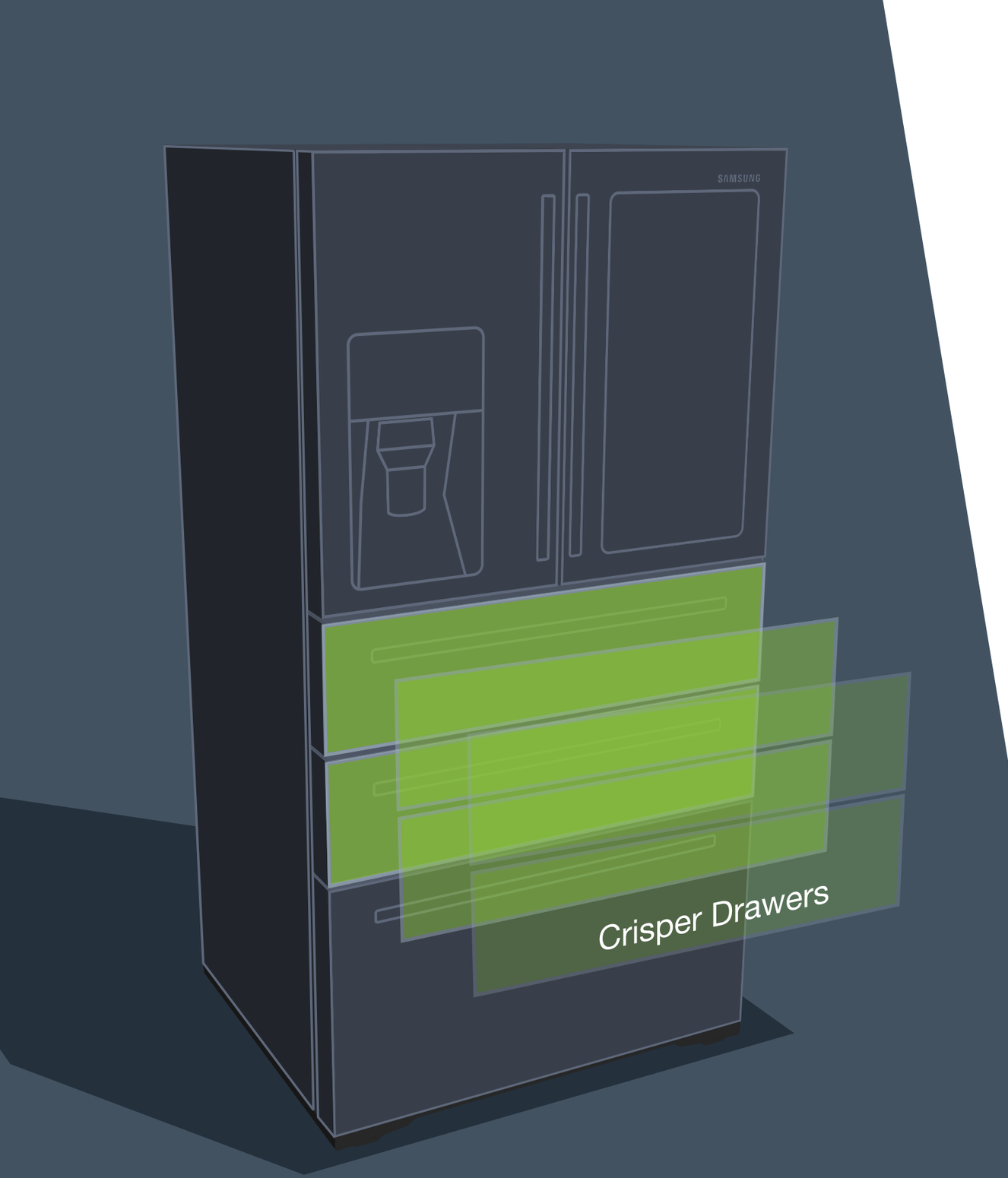


Fig.160 New product layout according to previous data on storage conditions requirements.



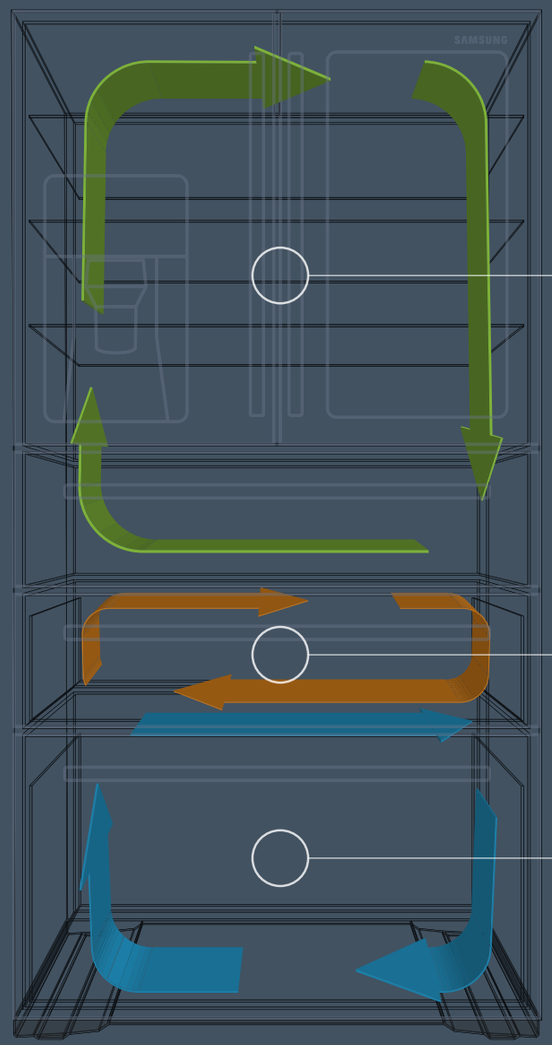
3.5.2 How Does It Work?

MAIN FEATURES

Controlling conditions of:

- Temperature
- Relative Humidity
- Ethylene
- Bacteria

1 Temperature Management



Firstly, the new **SmartFresh**^{PRO} concept implements 3 separate Cooling Systems that provide ideal temperature control in each of its compartments.

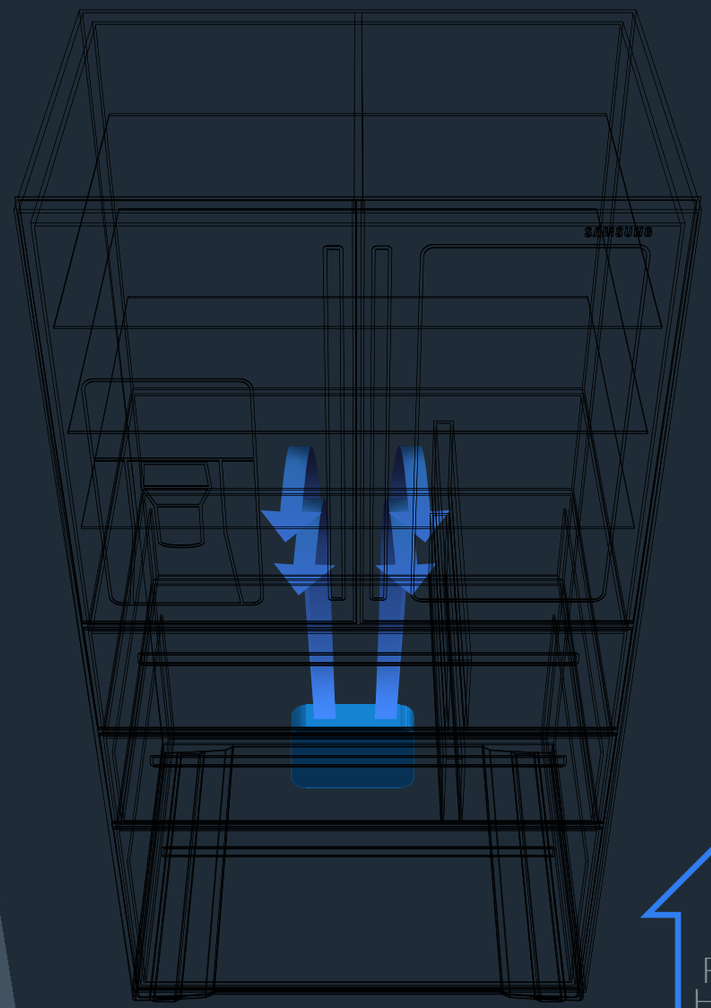
Multiple sensors allow to monitor temperature ranges and minimize their variations during the product use.

Cooling System 1
0-2 ºC

Cooling System
8-10 ºC

Freezing System
-18 ºC

2 Relative Humidity Control



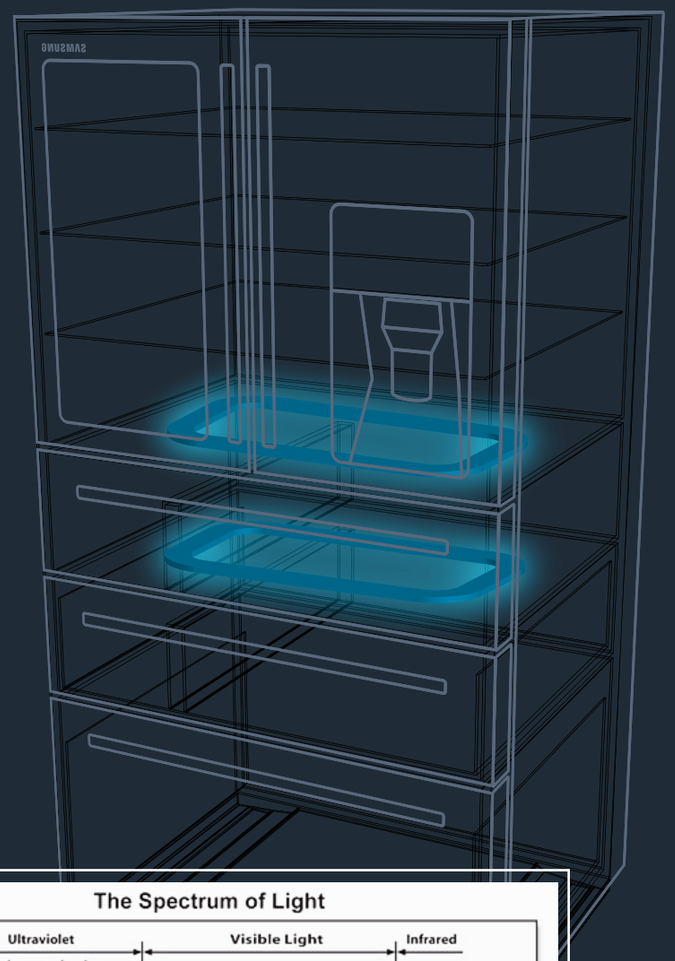
Secondly, and unlike current refrigerators do, SmartFresh^{PRO} provides an external humidity system that really allows to reach high humidity levels (RH 95%) in the compartments for fruit and vegetables.

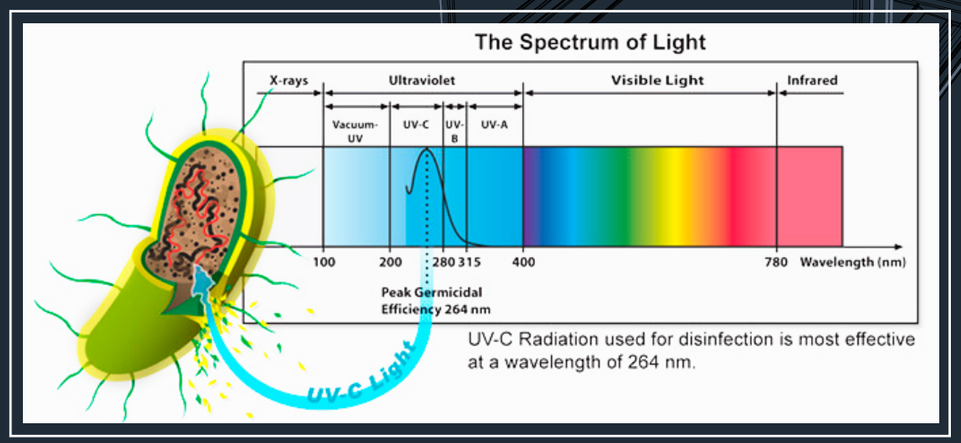
Based on **ultrasonic technology**, cold steam is generated and sent directly to the crisper drawers, while avoiding temperature changes. To provide adequate RH control, the drawers incorporate hygrometer sensors that monitor their levels and activate the mechanism only when necessary, thus avoiding excessive energy consumption.

UP TO
95%
Relative Humidity

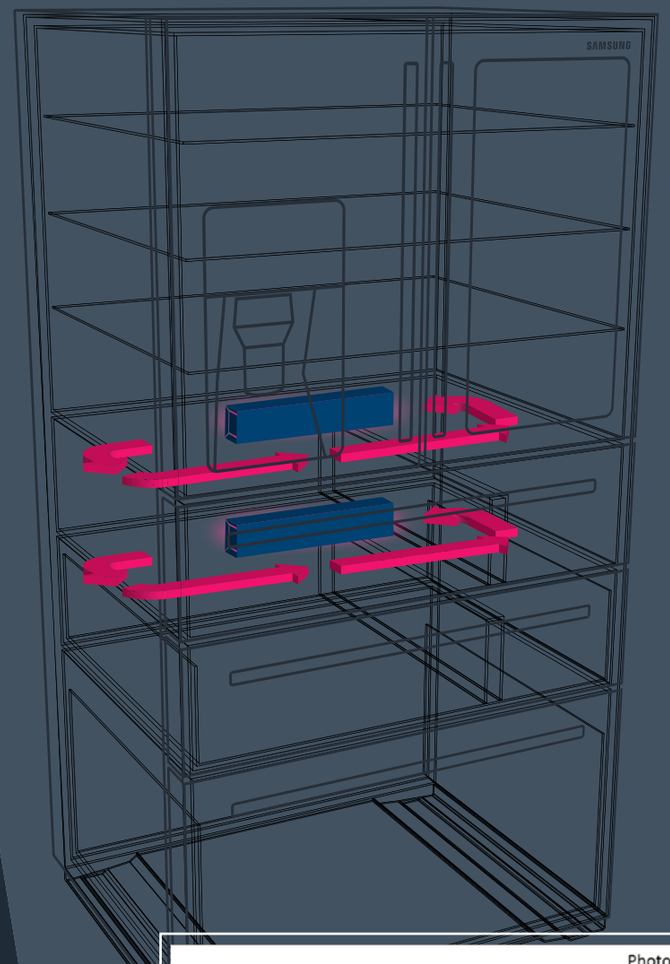
3 Bacteria Treatment

Thirdly, to disinfect fruit and vegetables inside the crisper drawers, this product incorporates UV-C light, capable of killing most bacteria and pesticides. Used by the food industry, this technology is safe and the most effective against bacterial growth.



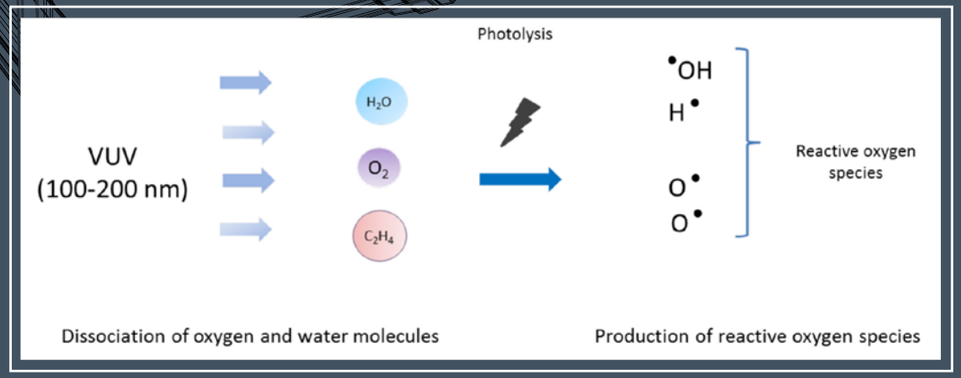


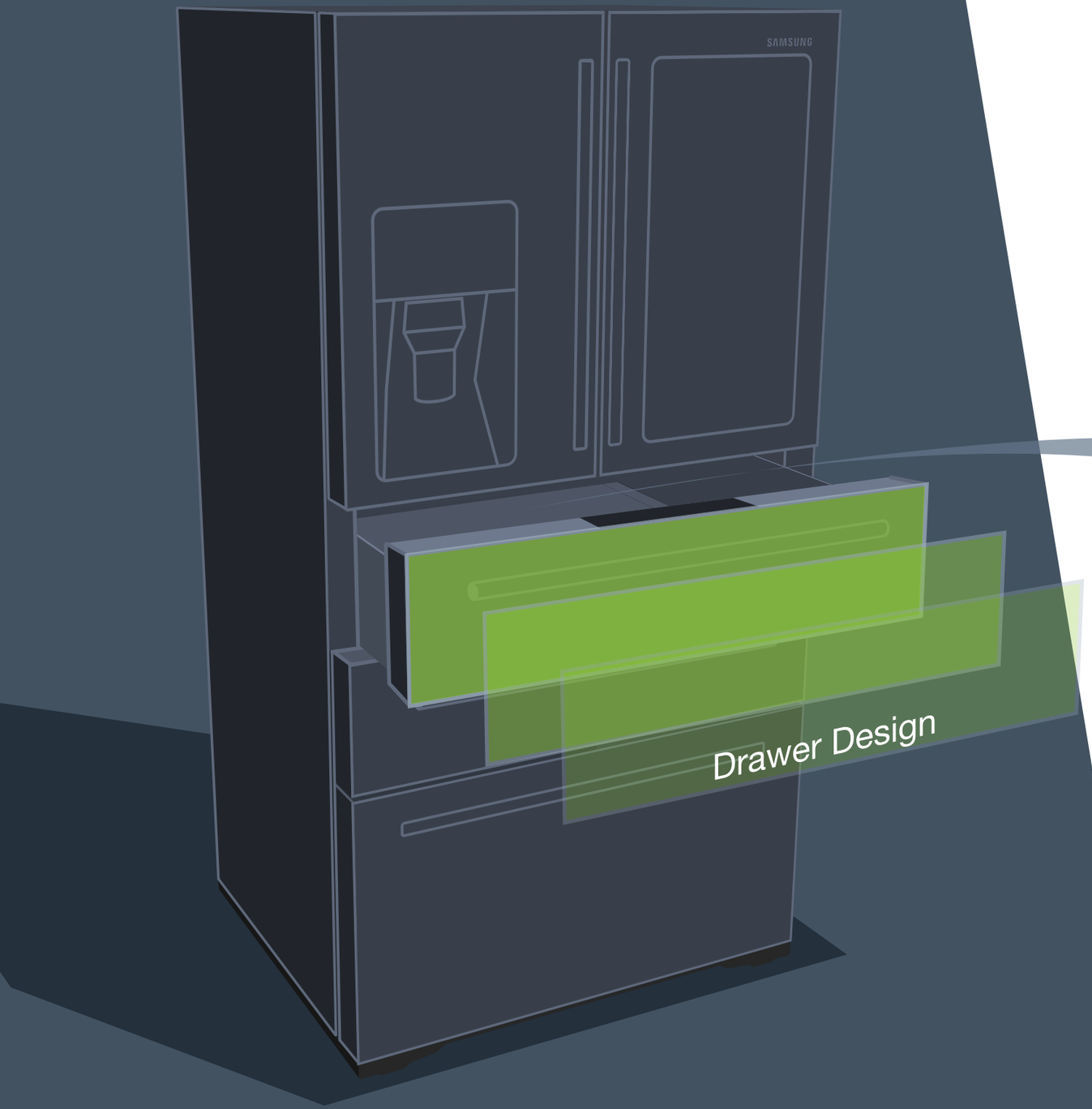
4 Ethylene Treatment



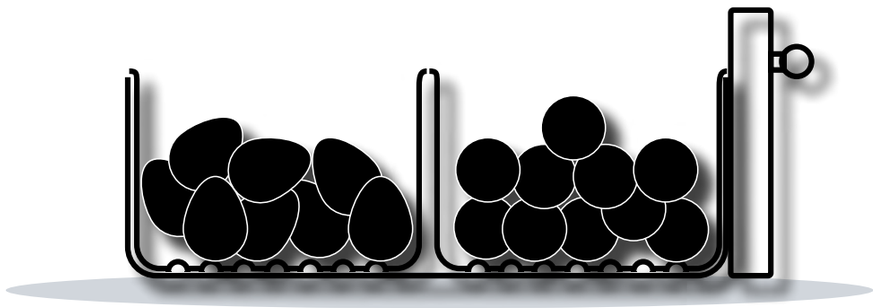
Fourthly, in terms of avoiding injuries produced by ethylene gas, each crisper drawer incorporates an ethylene removing system.

Based on *Vacuum Ultraviolet Light (VUV) Photolysis* technology, this becomes a perfect solution for ethylene treatment in high RH areas such as crisper drawers. It is energy efficient, long-lasting product that leaves no toxic residues. When ethylene sensors detect that ethylene levels rise, the VUV technique is activated. It creates an airflow inside the drawer which makes the air flow through this system and oxidize the ethylene. Due to the high oxidizing capacity of ROC created during this process, they are also able to oxidize different bacteria, molds and pesticides, hence, increasing an overall antimicrobial efficiency of the product.





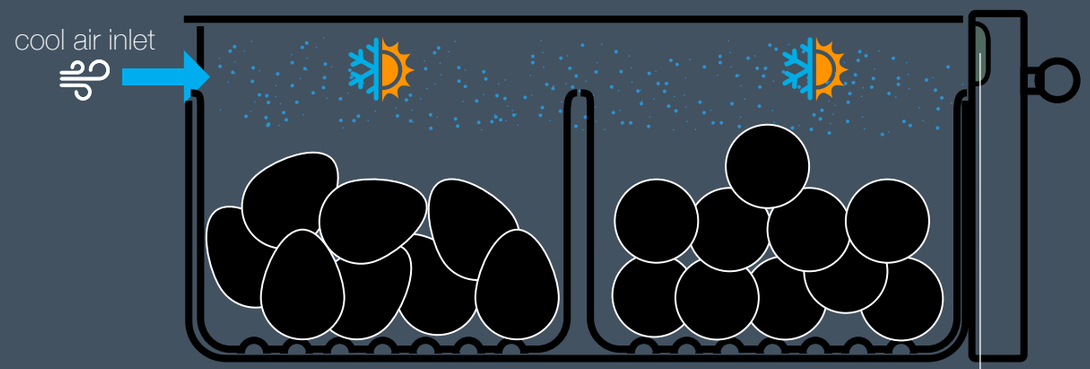
3.5.3 Inside the Crisper Drawer



Drawer Design

This ‘insulated drawer’ consists of an **external body** and several **internal compartments** that allow to keep your crisper drawers clean and organized.

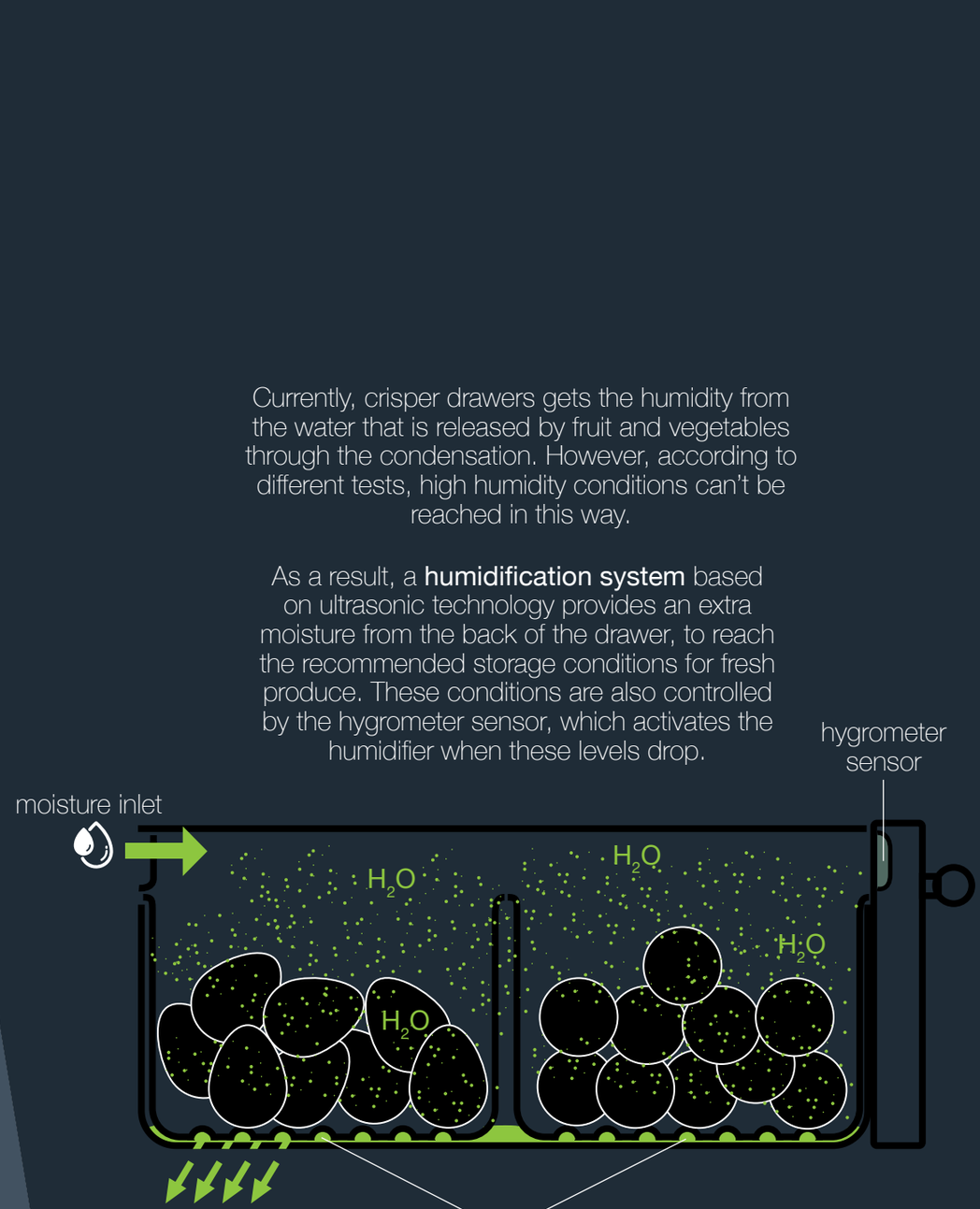
The **cooling system** provides the drawers with two different temperature settings, among 0-2 ºC and 8-10 ºC. These storage conditions are continuously measured by the hygrometer sensor (it measures the temperature and humidity), integrated in the drawer’s door. Once the required temperature is reached, the system turns off and will be only used again when these levels would rise (hotter air in the kitchen gets in when users open the fridge).



To ensure that the recommended preservation conditions for these foods are maintained, the ***hygrometer*** **sensor** is incorporated into the front part of the drawer.

Currently, crisper drawers gets the humidity from the water that is released by fruit and vegetables through the condensation. However, according to different tests, high humidity conditions can’t be reached in this way.

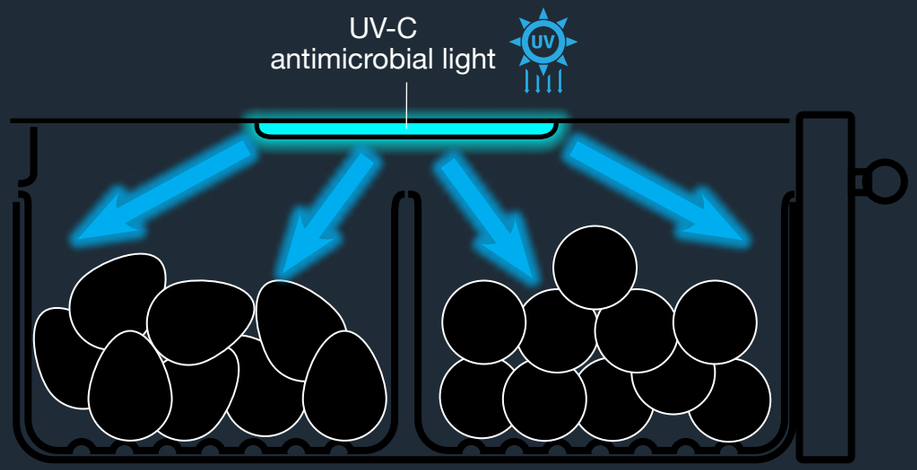
As a result, a **humidification system** based on ultrasonic technology provides an extra moisture from the back of the drawer, to reach the recommended storage conditions for fresh produce. These conditions are also controlled by the hygrometer sensor, which activates the humidifier when these levels drop.



Because the high humidity conditions (90-95% RH), part of the water would be condensed and accumulated on the bottom of the drawers. Thus, the design of the lower part of these drawers avoids the produce to be in direct contact with the water, meanwhile the excess water is drained out of the drawer.

Due to high humidity conditions that promote bacteria and molds growth, it was implemented an **UV-C antimicrobial system** to reduce their activity. It is an efficient, non-polluting method that eliminates different bacteria, molds, pesticides from the surface of fruit and vegetables.

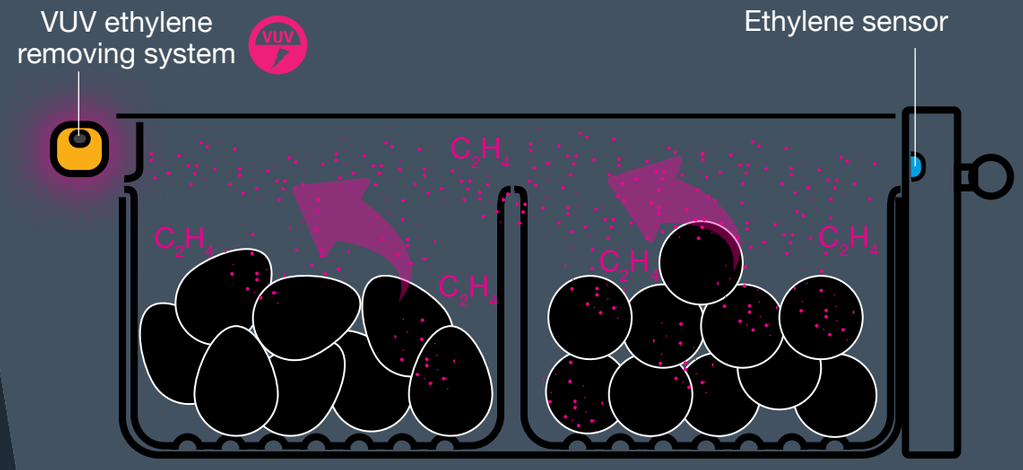
UV-C light lamps are placed on the top of the drawer, allowing better distribution of UV wavelenghts along the compartment. Its exposure usually requires just several minutes to effectively kill most of the microorganism loads.



To avoid the harmful effects of UV-C light on human health, it was decided to use Far-UVC light (222 nm wavelengths), which doesn't harm human skin or eyes, and it is perfect for its use in a home refrigerator.

Vacuum Ultraviolet Light (VUV) Photolysis technique is an efficient ethylene removing system that is placed on the back of the refrigerator. When the ethylene concentrations rise (detected by sensors), this system turnes on and makes the air from the drawer pass through VUV system. At this point, ethylene gas is oxidized reducing its concentration to the safest levels.

The reactive oxidizing components (ROC) produced during this process, can additionally oxidize different bacteria, molds and pesticides in those 'shaded areas' where UV-C light cannot reach.



To ensure that ethylene concentrations are always kept low, an ***ethylene sensor*** was implemented inside the front part of the drawer, which measures the storage condition related to this gas. Besides, it can also be used to detect rotting produce and warn the user about it.

3.6 THE PRODUCT

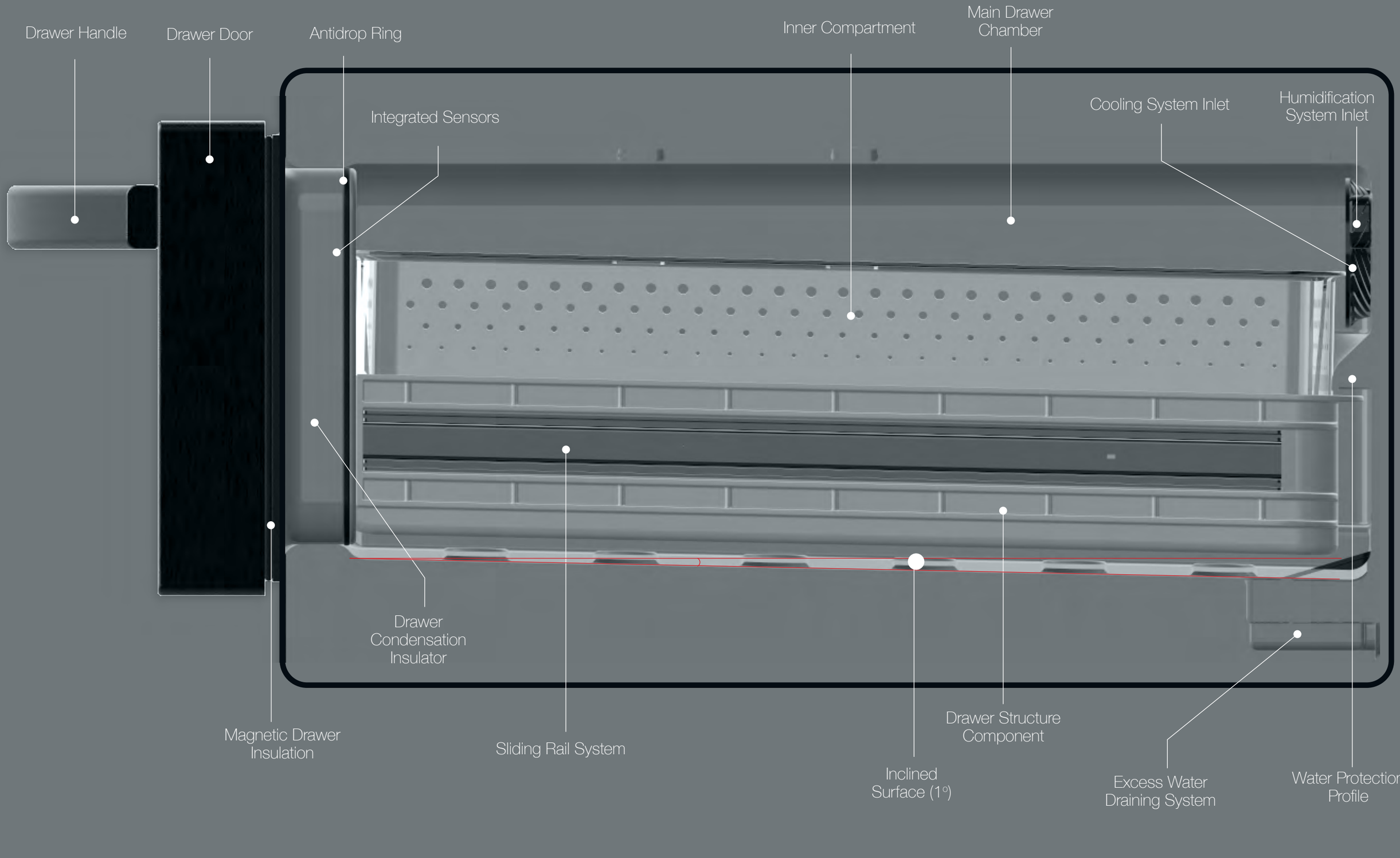
Smart Fresh PRO is an advanced preservation system for fresh produce, designed for the household use. Its main benefits are improving the food quality, extending their shelf-life, reducing amounts of food waste, thus saving user's money. Furthermore, it aims to guide the user to preserve fresh fruit and vegetables properly at home.

This concept focuses on managing the factors that mostly impact on fresh produce preservation, providing the proper storage conditions for a wide range of fruit and vegetables. As a consequence, these conditions increased the complexity of the concept, even though, the final design was simplified through the use of different sensors and latest technologies that made its use suitable even for a child.

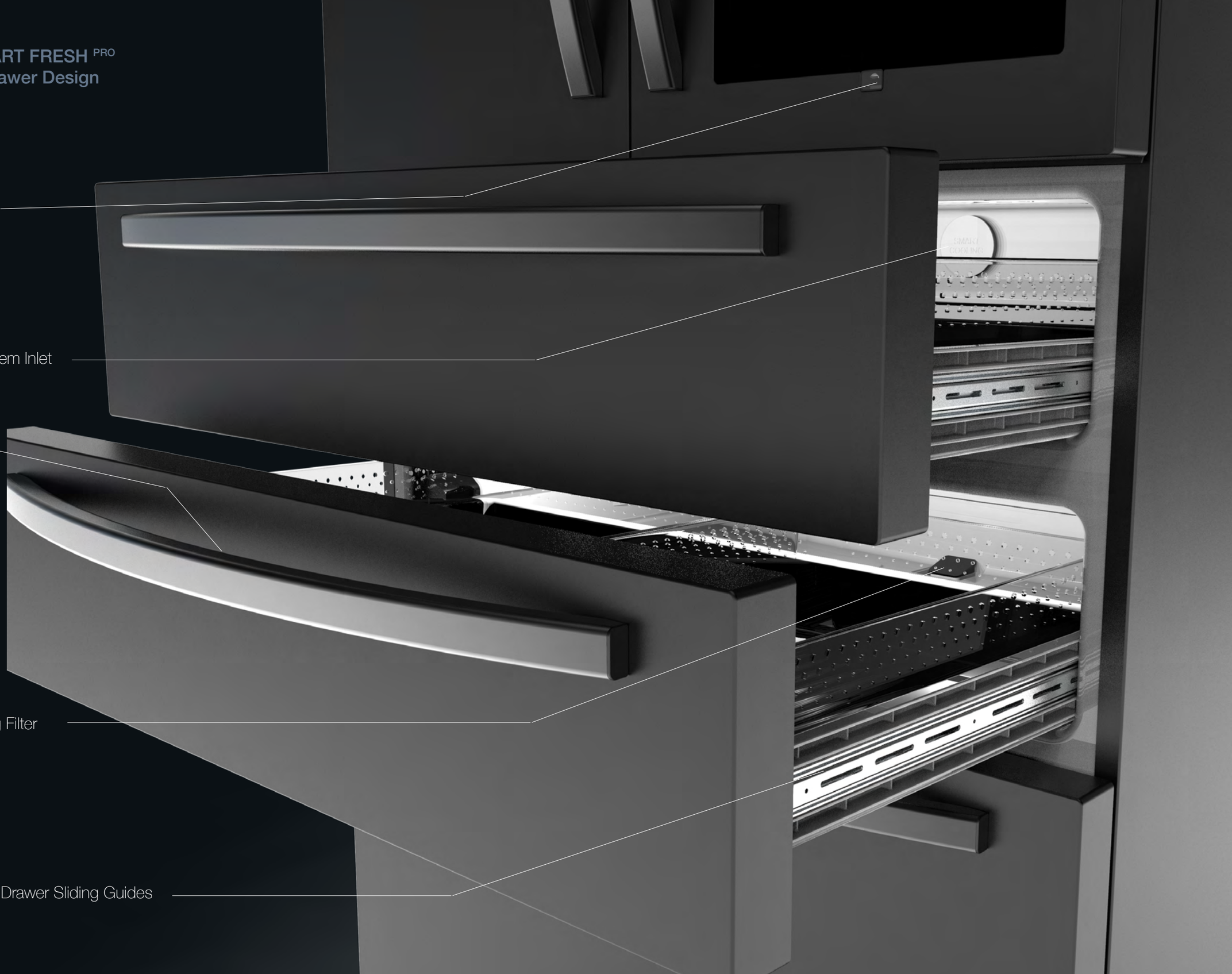
The Smart Fresh PRO system is composed of two insulated "crisper drawers" which focus on maintaining high humidity levels, reducing ethylene gas concentrations, and inactivating bacterial activity inside of them. The main difference between their functioning is the use of different temperature settings. This condition is required because some foods are grown in warmer areas (such as tropical and subtropical fruits), and they can't be stored at low temperatures (around 0ºC), as this could lead to freezing injuries.

Both compartments are connected to an external ultrasonic humidification system, which allows to reach high relative humidity levels (around 95%), as those recommended. As a result, each compartment is insulated and incorporates a special draining water system due to the water condensation inside of them. The bottom sufrace of each drawer has been inclined 1 degree to improve the extraction of water excess. As well, the main drawer contenitors and the inner contenitors have been designed in terms to avoid water accumulation inside of them, by implementing lots of tiny cuts on the bottom of these parts, facilitating this task.

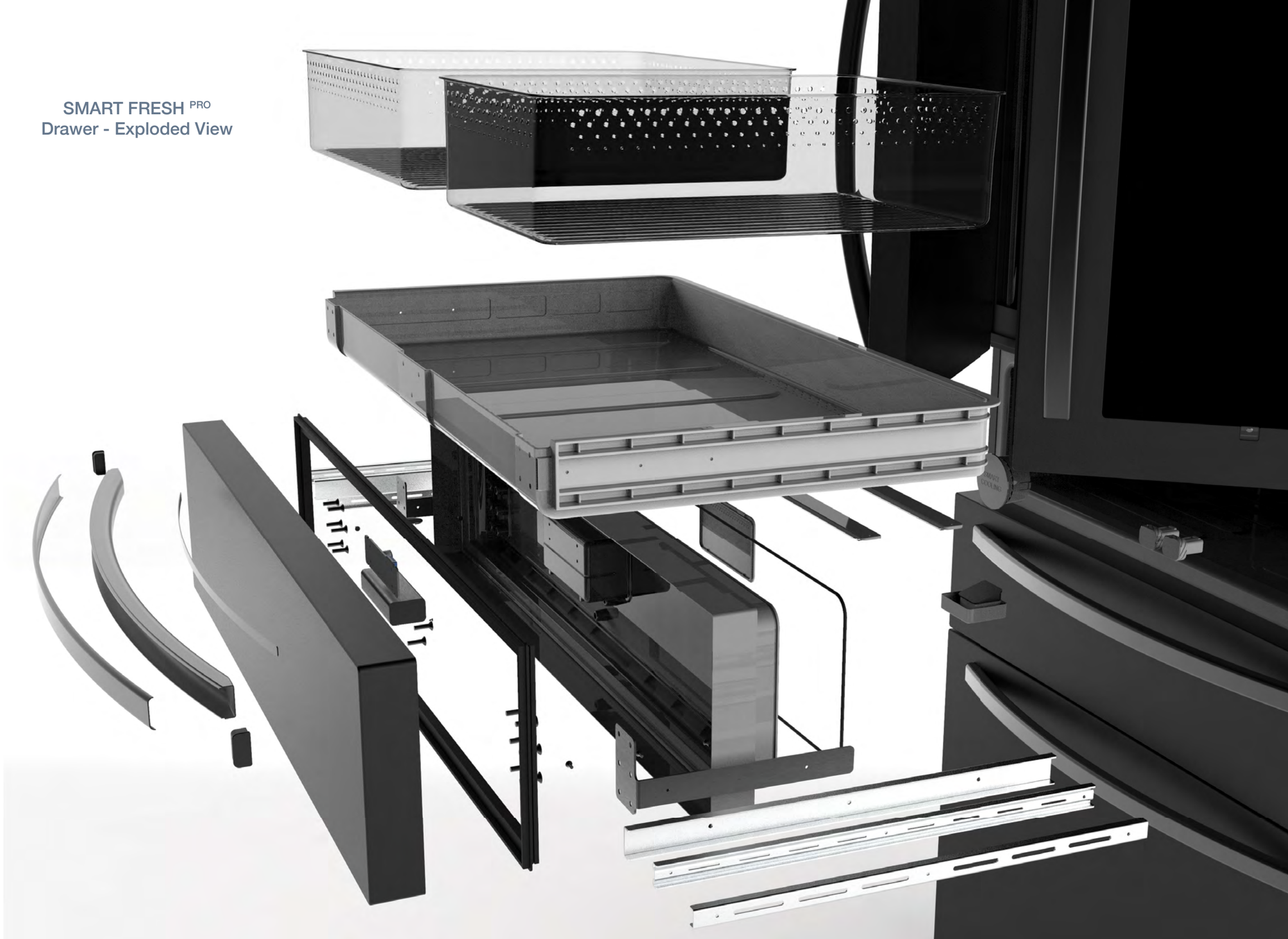
CRISPER DRAWER CONCEPT - SIDE VIEW



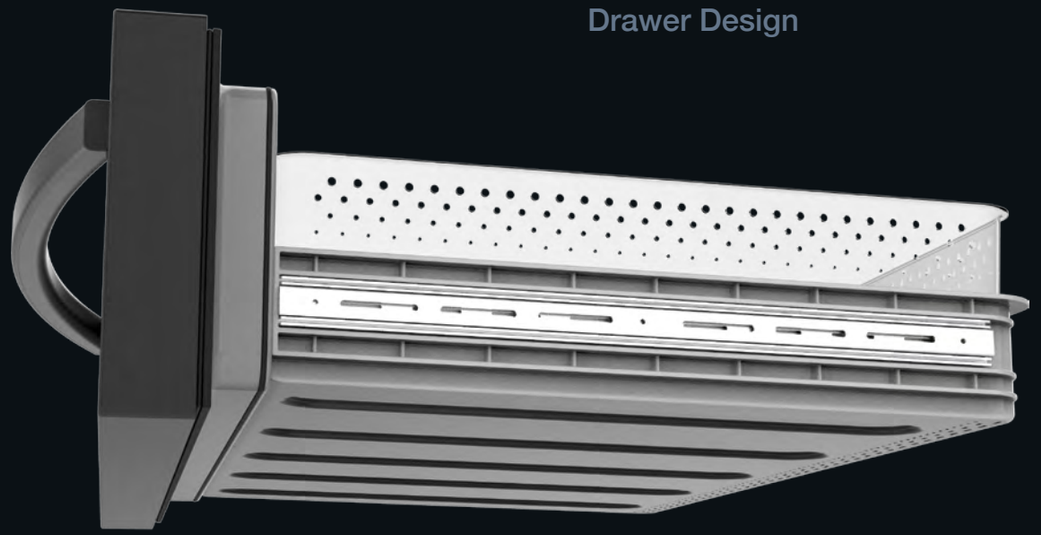
SMART FRESH PRO
Drawer Design



SMART FRESH PRO
Drawer - Exploded View



SMART FRESH PRO
Drawer Design



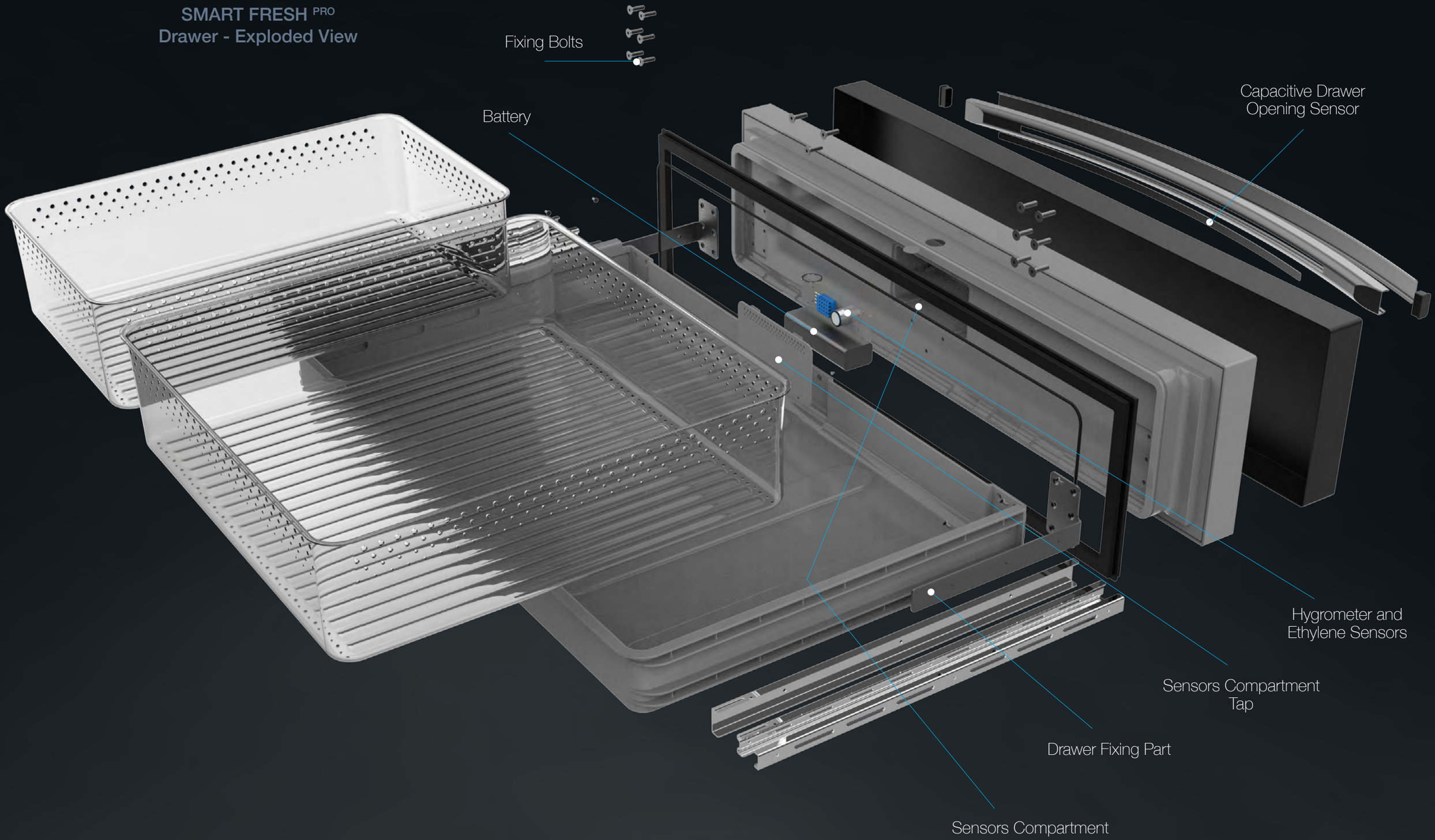
PRODUCT DIMENSIONS

225 mm

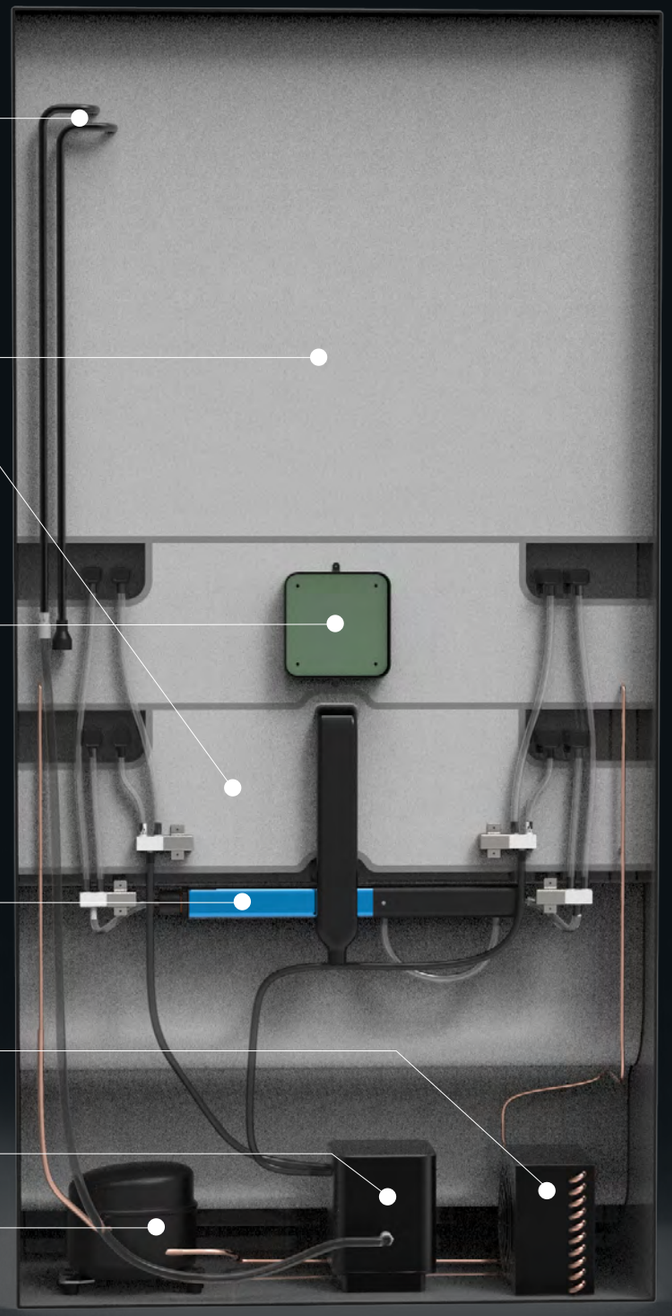
570 mm

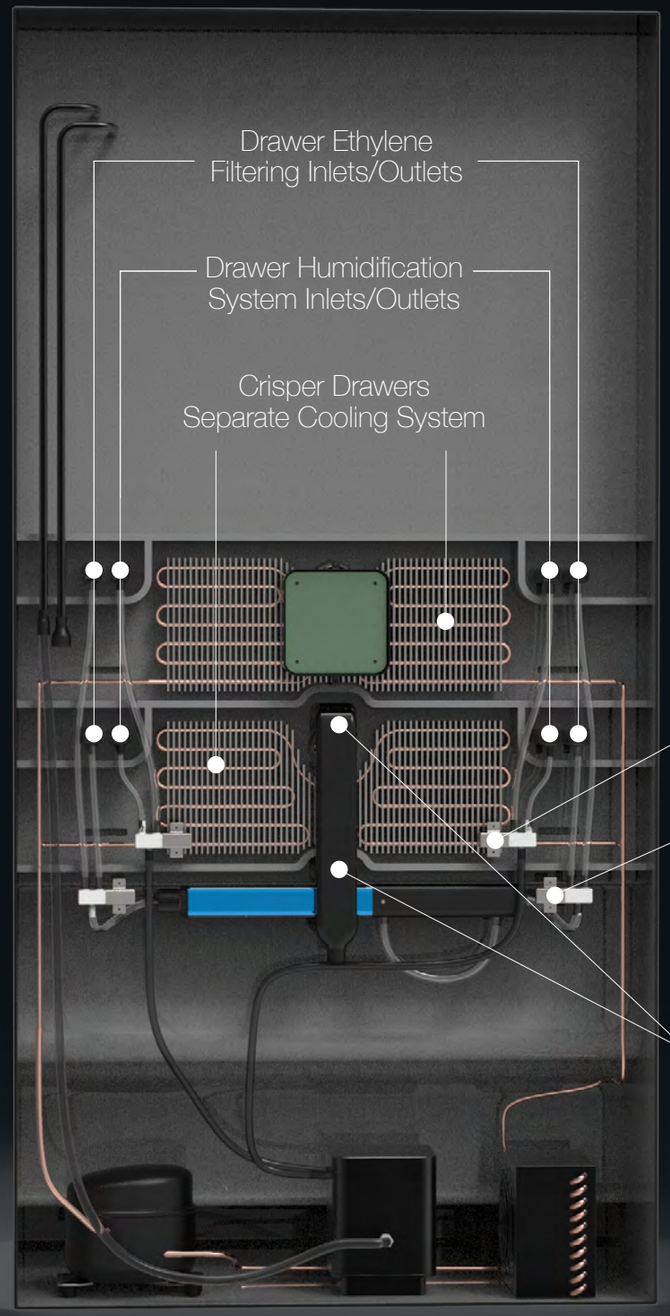
820 mm

SMART FRESH PRO
Drawer - Exploded View



SMART FRESH PRO
- Back View





A GUIDE TO THE PROPER STORAGE OF FRESH FRUIT AND VEGETABLES

Group 01

Berries, Cruciferous veg., Leafy veg., Temperate fruits and Others

90-95% RH
0-2 °C

Berries (Blueberry, Cranberry, Raspberry, Strawberry);

Cruciferous vegetables (Broccoli, Cabbage, Cauliflower);

Leafy vegetables (Celeriac, Celery, Collard, Endive, Kale, Lettuce, Parsley, Silverbeet, Spinach, Watercress);

Root vegetables (Beetroot, Carrot, Parsnip, Radish, Turnip);

Temperate fruits (Cherry, Grapes, Watermelon);

Others (Artichoke, Asparagus, Coconut, Corn, Hohlrabi, Leek, Lychee, Mushroom, Pea, Pomegranate).

Group 02

Citrus, Subtropical, Tropical and other fruits

90-95% RH
8-10 °C

Temperate fruits (Apple, Apricot, Cantaloupe, Fig, Nectarine, Peach, Pear, Plum, Prune, Quince);

Subtropical fruits (Avocado (green), Kiwifruit).

Citrus fruits (Lemon, Lime, Clementine, Grapefruit, Mandarin, Pomelo, Orange, Tangerine, Tangelo);

Subtropical and Tropical fruits (Carambola (Star fruit), Duku (Langsat), Durian, Guava, Langsat, Mangosteen, Persimmon, Pineapple, Rambutan, Sapodilla,);

Others (Bean, Capsicum, Cucumber, Eggplant, Marrow, Okra, Olive, Pepper (sweet), Potato, Pumpkin, Squash, Zucchini)

Subtropical and Tropical fruits (Avocado (ripe), Banana, Mango, Papaya, Passionfruit);

Others (Custard apple, Melon (honeydew), Pawpaw, Tomato).

UI / UX

User Interface (UI) and User Experience (UX) as a part of User Guide. It's aim is to help preserving fresh produce properly at home and to guide users while using a new fridge concept.

3.7 USER INTERFACE AND USER EXPERIENCE

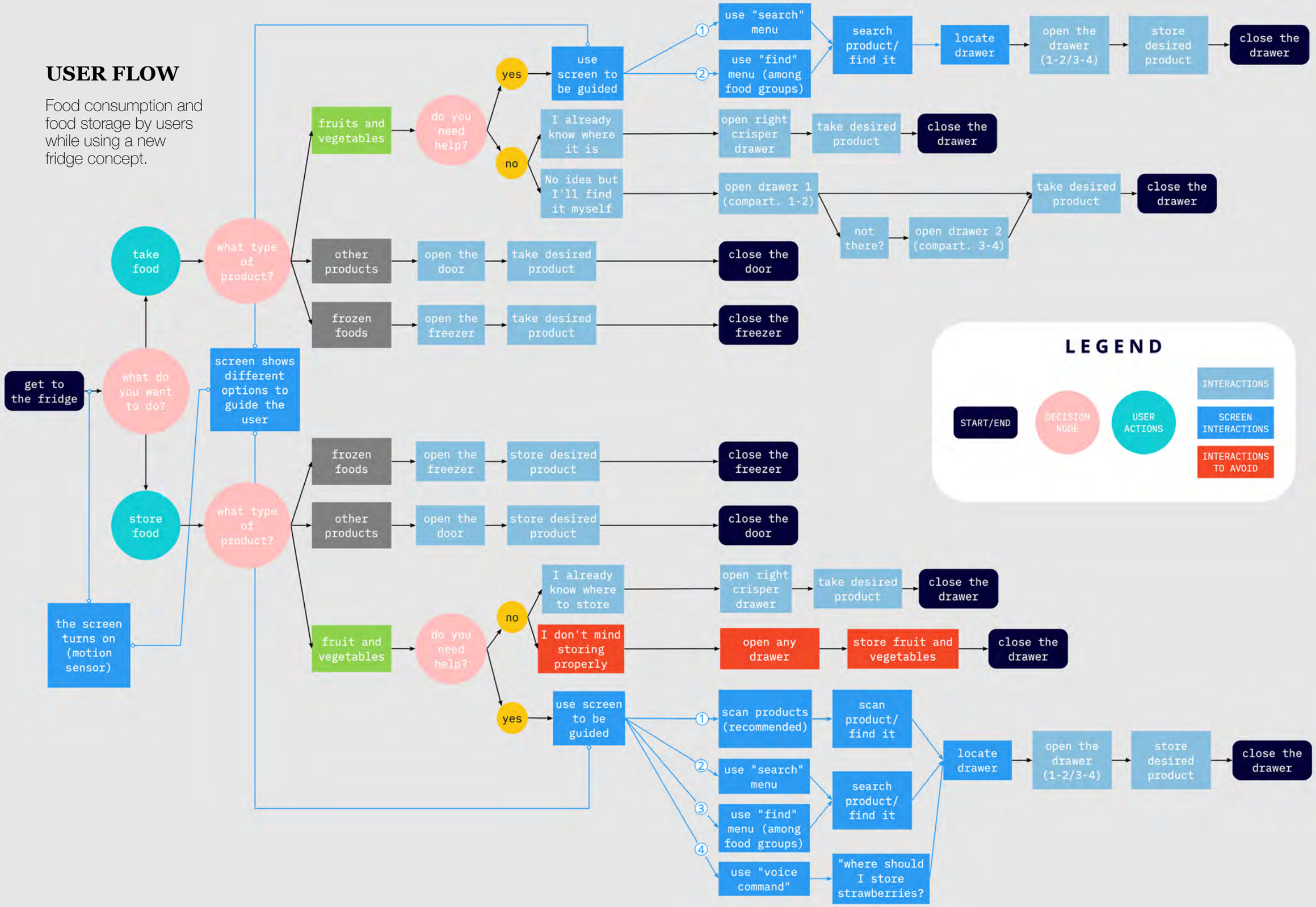
3.7.1 User Flow

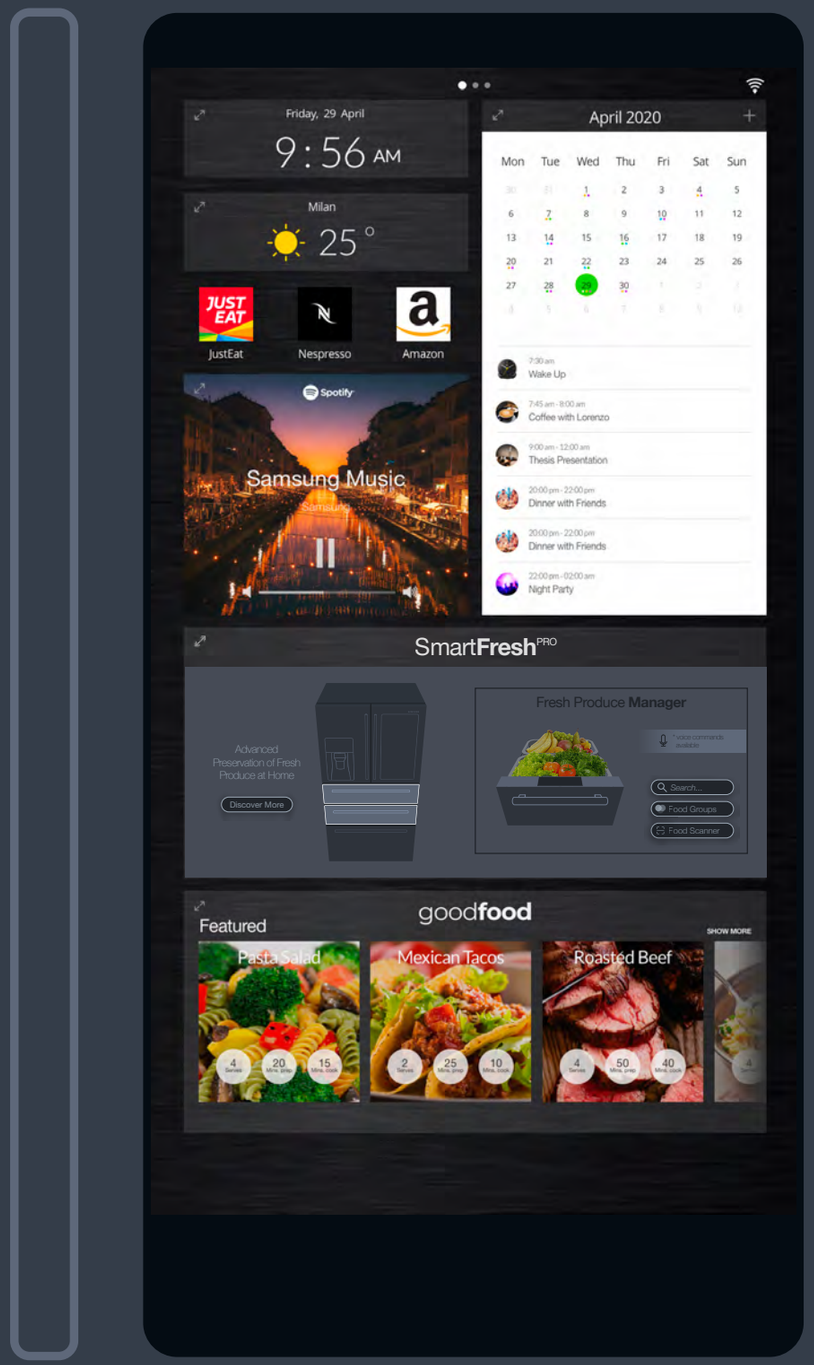
User Interface and User Experience design were requested as part of this project. The need to guide users through different phases of the use of the new fridge concept has lead to study user-product interactions and find out how to make this product easy to use. Since the new concept pretends to preserve all fresh fruit and vegetables in four separate compartments, this concept has finally gained some complexity. As a result, the best way to solve this complexity was through the use of the interactive touch screen integrated on the front part of this refrigerator.

The first part consisted in study "task flows", "user flows" and "mind maps" to find out different touchpoints of the product and how to organize these data for the following phases of design. User flow as shown in the following pages tries to regroup the possible actions of the users through the use of the new refrigerator. In general terms, the operation of this product remains the same. However, due to the complexity of using this product in the storage and consumption phases of fruit and vegetables, it was necessary to design new ways to interact with the product in such situations.

USER FLOW

Food consumption and food storage by users while using a new fridge concept.





3.7.2 Visual Design

Once “site maps” and “user flow” were defined, the design process focused on creating “wireframes” for their subsequent integration in the product’s touch screen. The design of the visual part of the product follows a hierarchical order, which aims to keep the way of interacting with the product simple, offering a wide range of actions, and a large amount of useful information for users about the food they consume. These data are important for several reasons. First of all because fresh products like fruit and vegetables are often bought without clothing. So the useful information that is usually provided in the food labels (expiration date, recommended preservation conditions, nutritional value, macro and micronutrients, etc.) are not present, but they are still quite important for the preservation of these foods as well as for the consumption of a balanced diet. On the other hand, this would also allow to collect data on the foods that are most commonly consumed, add foods to shopping lists, create different eating plans or even share the data of what a specific user consumes with the doctor or dietitian to monitor adherence to people’s diets.

VISUAL STRUCTURE

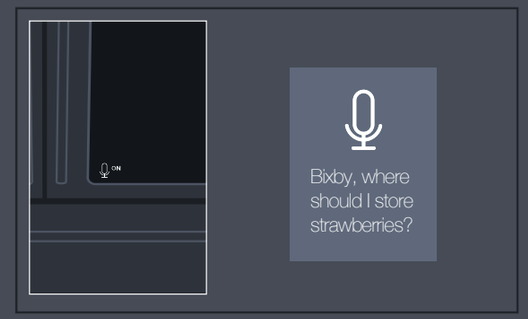
Structure of the screen interactions new concept offers to the user.

Voice commands available

Once voice control has been activated, users can use it as a guide during the use of this product as well as for the preservation of fresh produce.

SmartFresh PRO

Voice Control



SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Fresh Produce **Manager**

* voice commands available

Search...

Food Groups

Food Scanner

Search menu allows to search for fruit and vegetables in fridge database.

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Food Groups

SmartFresh PRO

Provided with 2 big crisper drawers, it offers 4 different areas with ideal conditions to storage your fresh produce.

Fruit and **Vegetables**

To preserve fruit and vegetables properly they were divided into 4 main groups according to their recommended storage conditions.

Group 01 | Group 02 | Group 03 | Group 04

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Temperate fruits: Apple, Apricot, Cantaloupe, Fig, Nectarine, Peach, Pear, Plum, Prune, Quince;

Subtropical fruits: Avocado (green), Kiwifruit.

Drawer Specif.

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Citrus fruits: Lemon, Lime, Clementine, Grapefruit, Mandarin, Pomelo, Orange, Tangerine, Tangelo;

Subtropical and Tropical fruits: Carambola (Star fruit), Duku (Langsat), Durian, Guava, Langsat, Mangosteen, Persimmon, Pineapple, Rambutan, Sapodilla;

Others: Bean, Capsicum, Cucumber, Eggplant, Marrow, Okra, Olive, Pepper (sweet), Potato, Pumpkin, Squash, Zucchini.

Drawer Specif.

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Berries: Blueberry, Cranberry, Gooseberry, Loganberry, Raspberry, Strawberry;

Cruciferous vegetables: Broccoli, Brussels sprout, Cabbage, Cauliflower;

Leafy vegetables: Celeriac, Celery, Collard, Endive, Kale, Lettuce, Parsley, Silverbeet, Spinach, Watercress;

Root vegetables: Beetroot, Carrot, Parsnip, Rutabaga, Radish, Turnip;

Temperate fruits:Cherry, Grapes, Watermelon;

Others: Artichoke, Asparagus, Coconut, Corn, Hohlrabi, Leek, Lychee, Mushroom, Pea, Pomegranate.

Drawer Specif.

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

Subtropical and Tropical fruits: Avocado (ripe), Banana, Mango, Papaya, Passionfruit;

Others: Custard apple, Melon (honeydew), Pawpaw, Tomato.

Drawer Specif.

Food Scanner

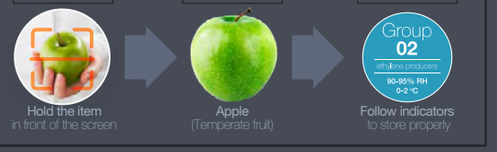
Info Button

SmartFresh PRO

Food Scanner

Integrated on the front part of the fridge, this feature allows to scan fresh fruit and vegetables.

Based on an integrated database, food recognition allows you to quickly identify the type of food and suggest to the user where it should be stored.



SmartFresh PRO

Food Scanner

Integrated on the front part of the fridge, this feature allows to scan fresh fruit and vegetables.

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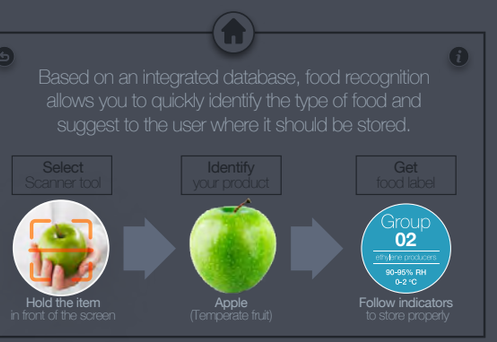

SmartFresh PRO

Advanced Preservation of Fresh Produce at Home

Discover More

BIBLIOGRAPHY

(Books, research papers, and articles from magazines, journals, newspapers, etc.)

Akkasheh (2015). 'Clinical and metabolic response to probiotic administration in patients with major depressive disorder: A randomized, double-blind, placebo-controlled trial', Nutrition, September 25, 2015.
Aladjadjiyan A. (2012). Physical Factors for Plant Growth Stimulation Improve Food Quality. Agricultural University, Plovdiv, Bulgaria.
Allen A. P., Hutch W., Borre Y., Kennedy P. J., Temko A., Boylan G., Murphy E., Clarke G., Cryan J. F. (2015). A psychobiotic that modulates brain activity, the stress response and neurocognitive performance in healthy volunteers. University College Cork. Ireland.
Artés-Hernández F., Martínez-Hernández G.B., Aguayo E., Gómez P.A., (2016). Fresh-Cut Fruit and Vegetables: Emerging Eco-friendly Techniques for Sanitation and Preserving Safety.
Baer David J., Gebauer Sarah K., Novotny Janet A. (2012). Measured energy value of pistachios in the human diet. British Journal of Nutrition. Cambridge University.
Barrett Diane M., Lloyd Beate. Advanced preservation methods and nutrient retention in fruits and vegetables. Journal of the Science of Food and Agriculture, Volume 92, Issue 1. 2012.
Barilla Center for Food and Nutrition. (2012) Food waste: causes, impacts and proposals.
Barilla G., Blanco S., Buchner B., Segrè A., Bloom J., Wang R., Cavallo R., Freegans T. S., Cedroni M., Nierenberg D. (2013). Contro lo spreco, sconfingere il paradosso del food waste. Barilla Center for Food and Nutrition. (pp.8-12).
Bhuvandas Nishi. (2012). Impacts of urbanisation on environment. International Journal of Research in Engineering & Applied Sciences. Volume 2, Issue 2 (February 2012) ISSN: 2249-3905
Brown T., Corry J., James S. J. (2004). Humidification of chilled fruit and vegetables on retail display using an ultrasonic fogging system with water/air ozonation. International Journal of Refrigeration 27(8):862-868.
Carmody Rachel N., Wrangham Richard W.. The energetic significance of cooking. Journal of Human Evolution. Volume 57, Issue 4, October 2009, pages 379-391.
Chauliac M. (2018). Nutri-Score. The front of pack nutrition labelling scheme recommended in France.
Chen Nelson G., Gregory Kalvin, Sun Ye, Golovlev Val. (2011). Transient model of thermal deactivation of enzymes. Biochim Biophys Acta. 2011 Oct; 1814(10): 1318–1324.
Cohen, Barney (2015). "Urbanization, City Growth, and the New United Nations Development Agenda". 3 (2). Cornerstone, The Official Journal of the World Coal Industry. Pp. 4–7.
Czech B, Krausman P.R, Devers P.K. 2000. Economic Associations Among Causes of Species Endangerment in the United States. BioScience 50, 593–601.
Diederichs, Herder C., Robbach S., Roden M., Wudy S.A., Nöthlings U., Alexy U., Buyken A.E. (2017). Carbohydrates from Sources with a Higher Glycemic Index during Adolescence: Is Evening Rather than Morning Intake Relevant for Risk Markers of Type 2 Diabetes in Young Adulthood? US National Library of Medicine. National Institutes of Health.

Emily A. Seward & Steven Kelly. 2016. Dietary nitrogen alters codon bias and genome composition in parasitic microorganisms. Genome Biology 17: 226; doi: 10.1186/s13059-016-1087-9
Enders, Giulia. (2015). "The Brain and the Gut". Gut: the inside story of our body's most under-rated organ. Scribe UK.
Estruch R., Ros E., Salas-Salvadó J., Covas M.I., Corella D., Arós F., Gómez-Gracia E., Ruiz-Gutiérrez V., Fiol M., Lapetra J., Lamuela-Raventos R.M., Serra-Majem L. (2013). Primary Prevention of Cardiovascular Disease with a Mediterranean Diet. The New England Journal of Medicine.
Folley J., Steinmetz G., Richardson J.. Where will we find enough food for 9 billion people? National Geographic Magazine.
Forney Charles F.. Optimizing the Storage Temperature and Humidity for Fresh Cranberries: A Reassessment of Chilling Sensitivity (2008). American Society for Horticulture Science.
Gao-Feng Yuan, Bo Sun, Jing Yuan, Qiao-Mei Wang. (2009). Effects of different cooking methods on health-promoting compounds of broccoli. Journal of Zhejiang University.
Garcia, Elisabeth, Barrett Diane. Preservative Treatments for Fresh-Cut Fruits and Vegetables. University of California.
Gast Karen L. B. (2001). Storage conditions: fruits and vegetables. The University of Maine.
Harris, S.R. Production is only half the battle. A training manual in fresh produce marketing for eastern Caribbean [1988]. FAO, Rome (Italy).
Huston Tom. (2017). How do we feed the planet in 2050? The Guardian.
Hwang I.G., Jee Shin Y., Lee S., Lee J., Mi Yoo S. (2012). Effects of Different Cooking Methods on the Antioxidant Properties of Red Pepper (Capsicum annuum L.). The Korean Society of Food Science and Nutrition
Igwemmar N.C., Kolawole S.A., Imran I.A. (2013). Effect Of Heating On Vitamin C Content Of Some Selected Vegetables. International Journal of Scientific & Technology Research. Volume 2, Issue 11. November 2013. ISSN 2277-8616.
Jacobs David R., Gross Myron D., Tapsell Linda C.; Food synergy: an operational concept for understanding nutrition, The American Journal of Clinical Nutrition, Volume 89, Issue 5, 1 May 2009, Pp. 1543–1548.
Jones, T. W. (2006), Using Contemporary Archaeology and Applied Anthropology to Understand Food Loss in the American Food System, Bureau of Applied Research in Anthropology, University of Arizona.
Kitinoja Lisa and Kader Adel A.. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition). University of California, Davis. Postharvest Technology Research and Information Center.
Koebnick C., Strassner C., Hoffmann I., Leitzmann C. (1999). Consequences of a long-term raw food diet on body weight and menstruation: results of a questionnaire survey. Annals of Nutrition & Metabolism Journal.

Koebnick Corinna, Garcia Ada L., Dagnelie Pieter C., Strassner Carola, Lindemans Jan, Katz Norbert, Leitzmann Claus, Hoffmann Ingrid. Long-Term Consumption of a Raw Food Diet. The Journal of Nutrition, Volume 135, Issue 10, 1 October 2005, Pages 2372–2378.

Krajmalnik-Brown (2015). 'Gut bacteria in children with autism spectrum disorders: challenges and promise of studying how a complex community influences a complex disease', Microbial Ecology in Health and Disease, Vol 26 (2015).

Larry S. Bourne. Urbanization - The Social Impacts of Urbanization.

Link Lilli B., Potter John D.. Raw versus Cooked Vegetables and Cancer Risk. Cancer Epidemiology, Biomarkers & Prevention, Volume 13, Issue 9. September 2004. Pp. 1422-1435.

Lourida Iliana. (2013). Proof that the Mediterranean diet is good for your brain. The Conversation Journal.

Lourida I., Soni M., Thompson-Coon J., Purandare N., Lang I.A., Ukoumunne O.C., Llewellyn D.J. (2013). Mediterranean diet, cognitive function, and dementia: a systematic review. US National Library of Medicine. National Institutes of Health.

Lyndhurst, B., Food Behaviour Consumer Research – Findings from the Quantitative Survey, in "Briefing Paper", WRAP, 2007.

Lyon MR, Kacinik V. (2012). Is There a Place for Dietary Fiber Supplements in Weight Management? US National Library of Medicine. National Institutes of Health.

Martínez-González M.A., Salas-Salvadó J., Estruch R., Corella D., Fitó M., Rosce E. (2015). Benefits of the Mediterranean Diet: Insights From the PREDIMED Study. Progress in Cardiovascular Diseases. Volume 58, Issue 1, July–August 2015, Pages 50-60.

Muth M. K., Kosa K. M. and Karns S. A. (2007), Explanatory research on estimation of consumer level food conversion factors, RTI International.

National Zero Waste Council. A Food Loss and Waste Strategy for Canada. 2018.

Nastasijevic I., Lakicevic B., Petrović Z. (2017). Cold chain management in meat storage, distribution and retail: A review. IOP Conference Series Earth and Environmental Science 85(1):012022

Nordqvist C. (2017). Nutrition: What is it and why is it important? Medical News Today.

Novotny Janet A., Gebauer Sarah K., Baer David J., Discrepancy between the Atwater factor predicted and empirically measured energy values of almonds in human diets. United States National Center for Biotechnology Information.

Ohio State University Center for Clinical and Translational Science. Toddler temperament could be influenced by different types of gut bacteria. ScienceDaily. (27 May 2015).

Paddock C. (2018). Cancer: 'Ultra-processed' foods may increase risk. Medical News Today.

Pan American Health Organization. Food security and lifehood. Identification of people most at risk of food insecurity.

Parfitt J., M. Barthel and S. Macnaughton (2010), Food waste within food supply chains: quantification and potential for change to 2050, The royal society.

Perlman, H. (2014) Runoff (Surfacewater runoff), USGS Water Science School.

Rapporto Coop 2018. Economia, consumi e stili di vita degli italiani di oggi.

Roger A. (2015). "The Consumption Function". Economics (12th ed.). Cengage Learning. Pp. 259–60. ISBN 978-1-305-46545-9.

Rothman S., Liebow C., Isenman L., (2002). Conservation of Digestive Enzymes. Physiological Reviews. Volume 82. Issue 1. (Pp 1-18).

Scott E., (2003). Food safety and foodborne disease in 21st century homes. US National Library of Medicine. National Institutes of Health.

Selhub Eva. (2018). Nutritional psychiatry: Your brain on food. Harvard Medical School. Nutritional psychiatry.

Siddiqui M. W.. Temperature and Relative Humidity. Postharvest Biology and Technology of Horticultural Crops. (pp. 21-23).

Siddiqui M., Ahmad M.S.. Temperature and Relative Humidity. Postharvest Quality Assurance of Fruits. (pp. 27-28).

Terry E. Acree (2013). National Meeting of the American Chemical Society.

The Journal of Nutrition, Volume 135, Issue 10, 1 October 2005, Pages 2372–2378

Thompson, J., Kader, A., & Sylva, K. (1999). Compatibility chart for fruits and vegetables in short-term transport or storage. University of California, Publication 21560.

Thompson A.K., Fruit and Vegetables: Harvesting, Handling and Storage. 1999.

UNESCO Intangible Cultural Heritage. (2013). Mediterranean diet.

United Nations Population Fund. State of world population 2007. Unleashing the Potential of Urban Growth.

United Nations Population Division. World Urbanization Prospects: 2014 Revision

United Nations. (2014). The millennium development goals report: 2014. New York.

United Nations. (2017). Revision of World Population Prospects.

United Nations. (2018). Food and Agriculture Organization. The state of food security and nutrition in the world.

United Nations (2018). World Urbanization Prospects: 2018 Revision. UN Population Division. Department of Economic and Social Affairs (UN DESA).

Waste and Resources Action Programme (WRAP) (2011), New estimates for household food and drink waste in the UK, November.

World Health Organization (2002). Diet, nutrition and the prevention of chronic diseases. Report of the joint WHO/FAO expert consultation.

WEBOGRAPHY

(Internet sources such as websites, blogs,
interview transcripts, videos, etc.)

https://21stcenturychallenges.org/urbanisation-2/
https://www.abc.net.au/radionational/programs/scienceshow/substantial-energy-difference-between-raw-food2c-cooked-food-a/4556402#transcript
https://www.agric.wa.gov.au/fruit/storage-fresh-fruit-and-vegetables
http://www.agrifoodmonitor.it/en/food-consumption
https://www.barillacfn.com/m/publications/eating-in-2030-trends-and-perspectives.pdf
https://blog.nationalgeographic.org/2013/04/12/what-you-see-is-what-you-taste-says-scientist/
https://www.bosch-home.com/us/specials/fresh-by-design
https://www.bosch-home.com.sg/experience-bosch/living-with-bosch/fresh-reads/a-comprehensive-guide-to-your-fridges-humidity-drawers
https://brainworldmagazine.com/are-we-what-we-eat/
https://www.businessinsider.com/how-long-people-wait-to-upgrade-phones-chart-2017-3?IR=T
https://cellkraft.se/humidifiers/flow-through-humidifiers/
https://citygeographics.org/2016/04/04/environment-planning-featured-graphic-world-city-populations-time-series-map/
https://www.citylab.com/life/2012/04/why-bigger-cities-are-greener/863/
https://www.conserve-energy-future.com/various-waste-disposal-problems-and-solutions.php
http://content.time.com/time/specials/2007/article/0,28804,1628191_1626317_1626671,00.html
https://www.csiro.au/en/Research/Health/Food-safety/Refrigerating-foods
https://www.eatforhealth.gov.au/food-essentials/five-food-groups
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics
https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_consumption_by_purpose
https://ec.europa.eu/eurostat/statistics-explained/pdfscache/21759.pdf
https://www.ers.usda.gov/data-products/food-consumption-and-nutrient-intakes/food-consumption-and-nutrient-intakes/#Food%20Consumption%20Estimates
https://en.wikipedia.org/wiki/Atwater_system
https://en.wikipedia.org/wiki/Healthy_diet#cite_note-:0-9
https://en.wikipedia.org/wiki/Human_overpopulation
https://www.euronews.com/2019/02/06/how-is-food-waste-regulated-in-europe
http://family.jrank.org/pages/1732/Urbanization-Social-Impacts-Urbanization.html
http://www.fao.org/3/t0098e/T0098E01.htm
http://www.fao.org/americas/noticias/ver/en/c/1152157/
http://www.fao.org/docrep/007/y5113e/y5113e04.htm#TopOfPage
http://www.fao.org/state-of-food-security-nutrition/en/

http://foodfromthesky.org.uk/food-consumption-evolution/
https://www.forbes.com/sites/nancyhuehnergarth/2016/03/14/study-finds-nearly-60-of-calories-in-the-american-diet-are-from-ultra-processed-foods/#ca4849d173ba
https://www.frontlineservices.com.au/Frontline_Services/Storage_temperatures_for_fresh_produce.html
https://www.gizmodo.com.au/2014/10/dysons-humidifier-uses-uv-light-to-kill-germs-in-its-water-reservoir/
https://www.gdrc.org/uem/waste/uwm-issues.html
https://www.health.harvard.edu/blog/nutritional-psychiatry-your-brain-on-food-201511168626
https://www.healthline.com/nutrition/raw-food-vs-cooked-food#section3
http://healthysleep.med.harvard.edu/healthy/matters/benefits-of-sleep
https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/nutrition-basics/processed-foods
http://idonika.com/en/id/articles/periphery-between-nowhere/
https://www.inboundlogistics.com/cms/article/the-dairy-supply-chain-from-farm-to-fridge/
https://www.istat.it/it/files/2018/06/Spese-delle-famiglie-Anno-2017.pdf
https://italiani.coop/wp-content/uploads/pdf/rapporto-coop-2017.pdf
http://www.iucnredlist.org
https://www.lexiconoffood.com/post/flavor-science
https://www.lifeder.com/factores-que-influyen-en-la-salud
http://luminocity3d.org/WorldCity/#3/12.00/10.00
https://www.medicalnewstoday.com/articles/320932.php
https://mynutritionadvisor.com/ketogenic-diet-overview-beginners-guide/
https://naldc.nal.usda.gov/download/IND43893659/pdf
https://www.nationalgeographic.com/environment/global-warming/toxic-waste/
https://www.nationalgeographic.com/environment/habitats/urban-threats/
https://www.nationalgeographic.com/magazine/2015/12/food-science-of-taste/
https://news.nationalgeographic.com/news/2015/01/150118-evolution-flavor-taste-hamburger-ngfood/
https://nationalpost.com/health/when-a-calorie-isnt-a-calorie-parsing-the-raw-vs-cooked-food-debate-and-the-curious-case-of-almonds
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2722699/
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC318470/
https://www.ncbi.nlm.nih.gov/pubmed/22611521
http://ndpublisher.in/admin/issues/IJAEBv10n6f.pdf
https://www.nhs.uk/live-well/eat-well/what-are-processed-foods/
https://www.nhs.uk/news/medical-practice/tobacco-alcohol-and-illegal-drugs-are-global-health-threat/#
https://www.nutrition.org.uk/nutritionscience/foodfacts/functional-foods.html?limitstart=0

https://www.optibacprobiotics.co.uk/learning-lab/blog/gut-brain-axis
http://wwf.panda.org/our_work/wildlife/problems/habitat_loss_degradation/
https://www.samsung.com/levant/news/global/samsung-new-tmf-refrigerator-rt7000-locks-in-moisture-and-keeps-food-fresher-longer/
http://www.sci-news.com/biology/diets-organisms-affect-dna-04374.html
https://sciencebasedmedicine.org/let-food-be-thy-medicine-and-medicine-be-thy-food-the-fetishism-of-medicinal-foods/
https://www.sciencedirect.com/science/article/pii/S0033062015000286
https://sciencesamhita.com/methods-of-food-preservation/
https://sites.google.com/site/impactsofurbanisation/economic-impacts
http://www.slowfood.it
https://staticmy.zanichelli.it/catalogo/assets/9788808737885_04_CAP.pdf
https://www.statista.com/chart/8348/smartphone-life-cycles-are-changing/
https://www.statnews.com/2017/08/07/food-medicine-hippocrates/
https://www.ted.com/talks/giulia_enders_the_surprisingly_charming_science_of_our_gut
https://theconversation.com/why-most-food-labels-are-wrong-about-calories-35081
https://thetakeout.com/how-do-refrigerator-crisper-drawers-work-1826545233
https://time.com/4474874/exercise-fitness-workouts/
http://tucarnetdemanipuladordealimentos.com/la-cadena-frio-los-alimentos/
https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html
https://www.unequalscenes.com
https://www.unfpa.org/sites/default/files/pub-pdf/695_filename_sowp2007_eng.pdf
https://www.unidine.com/ccgblogs_processedvsfresh/
https://www.verywellfit.com/nutrition-vs-exercise-80-nutrition-wins-3121406
https://www.verywellfit.com/the-raw-food-diet-89877
https://www.whirlpoolindia.com/faq/refrigerators#gref
https://www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/
http://www.who.int/gho/ncd/risk_factors/unhealthy_diet_text/en/
http://www.worldometers.info/watch/world-population/
https://www.wsj.com/articles/the-science-of-neurogastronomy-or-how-our-brains-perceive-the-flavor-of-food-1447692443
https://wuhaus.com/2017/02/08/2017131foods-for-gut-health/
https://www.youtube.com/watch?v=WhSpDRbG308