Evaluation of bagged lettuce quality stored in different packaging and fridge conditions

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MASTER THESIS

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This Master's thesis has been done within the Erasmus Mundus Joint Master Degree FIPDes, Food Innovation and Product Design.

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Abstract

The convenience that bagged lettuce offers has often coupled with consequence of rapid quality deterioration, especially at home after the consumers open the package. In this study, the quality of bagged lettuce during storage in different packaging and fridge conditions was evaluated. The aim was to understand the problems that consumers encounter while storing bagged salad in the household fridge. Lettuce was stored in different temperatures (2 ^{o}C, 5 ^{o}C, 8^{o}C), different relative humidity (RH) (21%, 56.5%, 82.5%), and different packaging types (sealed bag, open bag, folded bag, unpackaged) for 8 to 14 days. The following quality parameters were assessed throughout the storage period: weight loss, texture, color change, vitamin C, and condensation build-up in the packages. Several quality parameters were affected by both temperature and RH, such as weight loss and condensation. Meanwhile, some others were affected by only temperature (e.g. texture) or RH (e.g. color change), which higher RH could give better quality preservation. As for packaging types, it was shown that higher exposure to oxygen resulted in higher quality deterioration rate. Storing lettuce in folded bag could preserve the quality much better than just leaving the bag opened in the fridge. The online survey showed that most consumers rely on their personal judgement when it comes to salad quality assessment. Although the quality perception varied between individuals, the majority have similar perception on bad visual quality linked to color change of lettuce. Consumers demanded for clearer instructions on how to store the bagged lettuce in their fridge properly and better fridge design or cooling system to support the storage of this product.

Keywords: bagged lettuce, household fridge, packaging, quality, relative humidity, temperature profile, visual quality

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Lund, May 2020

Nalaputi Basoeki

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List of acronyms and abbreviations

A-PET	Amorphous polyethylene terephthalate
BOPP	Bi-orientated polypropylene
IFT	Institute of Food Technology
LDPE	Low-density polyethylene
MAP	Modified atmosphere packaging
OPP	Oriented polypropylene
POD	Peroxidase
PP	Polypropylene
PPO	Polyphenol oxidase
PVdC	Polyvinylidene chloride
QC	Quality control
WVTR	Water vapor transfer rate

1 Introduction

1.1 Background

According to Merriam-Webster dictionary, the word ‘salad’ can be defined as: *any of various usually cold dishes or a green vegetable or herb grown for salad, especially lettuce*. Salad has been popular in Europe since the Greek and Roman era. The importance of fruits and vegetables consumption has been well-known to maintain a healthy and balanced diet since then. The majority of European citizens correlate consumption of fruits and vegetables with a healthy lifestyle, therefore the salad has a high popularity in the European food culture (Eufic, 2012).

Lettuces are marketed fresh, with the majority being sold as head-salad or in intact form. Around one-fourth of all harvested lettuces continue to be processed into pre-packaged salad and bagged fresh-cut lettuce (AgMRC, 2018). The consumption of bagged fresh-cuts began in the early 1990s. It was introduced as a more convenient option of healthy vegetables (The Independent, 2005). The products have increasingly emerged on the market for both fruits and vegetable commodities, where fresh-cut vegetables, especially bagged lettuce, dominate the European market with about 50% of the fresh-cut volume market (Yildiz and Wiley, 2017). Some reasons of its popularity are the quick meal-preparation and leafy vegetable variations in one bag. Most of fresh cut salad is packed using plastic films formed into plastic bags.

Despite its convenience, fresh-cut lettuce remains a challenging commodity in terms of quality preservation throughout its shelf life. The injured tissue caused by the processing steps increases the quality deterioration, especially on its organoleptic properties, e.g. color, smell, and texture. Various treatments have been developed to prolong the shelf life, such as modified atmosphere, low temperature, packaging types, and the use of chemicals in processing water (Artes, Martinez and Marin, 1999). However, it is forbidden to use chemicals, like chlorine, in some European countries, like Sweden, Germany, and Switzerland (Uhlig et al., 2017).

In Sweden, the lettuces are mostly imported from Spain (Prieto, 2020). The delivery time generally takes around 5 days. Quality control (QC) is performed as soon as the lettuces arrive in the factory. Since vegetables are perishable products, time is a very important aspect in handling and processing the products to ensure the highest quality. The lettuces must be processed within the maximum of 4 days upon arrival. The first step of processing is removal of external parts, which is done manually with manpower. Lettuces are cut into 20 mm x 10 mm size, then they will continue to washing process using cold tap water (2-4ºC). After that, the cuts will enter a huge spin dryer to remove excess water. The drying process is done in batch. QC takes place after drying using color sensor to separate lettuces with bad quality. Those which pass the QC stage will enter a resting room, which has 4ºC for 24 hours, before finally being packed into packages with different sizes. The products are distributed to retailer stores (for small serving packages) and restaurants (for big packages). Temperature should be maintained at 4ºC throughout the supply chain (Prieto, 2020).

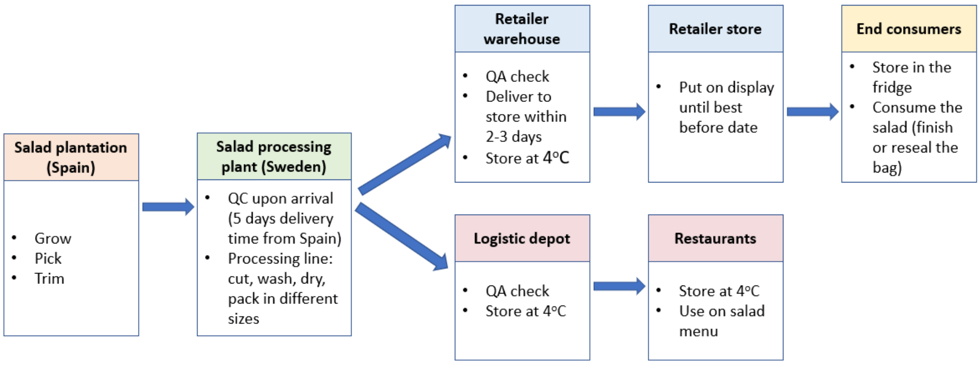


Figure 1 Supply chain map of bagged lettuce. This was mapped according to interview with Vidinge Grönt AB (2020)

Most of the conventional household refrigerators have a static cooling system, although fridges with dynamic cooling system have started to become more available in the market (Marklinder et al., 2004). Regardless the type of installed cooling system, temperature stability remains as one of the inevitable issues in household fridges. The combination of different cooling system and control algorithm gives different temperature profile, which consists of average temperature, temperature amplitude, and cycling period. It differs for different shelves in the refrigerator. The temperature and its fluctuation may affect the quality change of products stored inside the fridge.

Various research investigation has been conducted on fresh-cut lettuces quality change during storage, but most of this research was focused on a specific temperature in a controlled environment with limited information on storage from consumers' perspective. In reality, consumers store the product in the fridge they have at home (household fridge). This kind of fridge has a different temperature profile over time, depending on the type of fridge, which shelf the product is placed, frequency of opening the fridge door, etc. For the real application of research, it is important to mimic the storage condition in the fridges in the laboratory, where the research is being conducted, as close as possible to the actual household fridge conditions of consumers. This thesis contributes to the gap of knowledge on bagged salad quality depending on different storage conditions and different types of packaging with the emphasis on consumers' perspective.

1.2 Description of major quality challenges

The quality issues begin to emerge and to worsen during post-purchase of bagged lettuce at consumer's household. As soon as consumer opens the lettuce bag, the barriers (atmospheric and physical) that have been protecting the salad quality will be broken. This results in the acceleration of salad quality degradation, shortening the shelf life of product. This is undesirable from a consumers' perspective as they expect longer freshness quality, especially when the products are stored in the fridge. This study aims to provide thorough understanding of the behavior change of fresh cut products at end-consumers with different possible scenarios on how consumers store the product in their fridge.

The main research questions for this study are:

- What is the impact of storage in several different fridge conditions on the "freshness qualities" of bagged lettuce?
- What is the impact of different types of packaging on the quality deterioration of bagged lettuce during storage?

1.3 Objectives

The objectives of this study are:

- To evaluate the impact of storage on several freshness quality parameters in different fridge conditions focusing on: temperature and relative humidity
- To understand consumer behaviors on salad storage and the effect of different packaging scenarios on salad's quality degradation

1.4 Focus and delimitations

The study was focused on evaluating the bagged lettuce quality during storage in some different types of fridge models of Electrolux and competitors. The evaluation and comparison between samples were based on the several quality parameters, such as weight loss, color change, texture, condensation formation, and ascorbic acid content. Interviews with salad producer, packaging company, and retailer were done to obtain more information regarding salad production and supply chain to give further understanding on planning the research direction in the beginning of project. Consumer survey was also conducted to complement the information related to consumer behaviors on salad storage and consumption to better correlate the experiments with the actual consumer's attitudes.

The project is time-limited and some quantitative analysis methods are not feasible to be conducted in the lab (unavailable equipment, e.g. for assessing the packaging performance in terms of barrier properties, gas injection for mimicking MAP condition, etc). The atmosphere inside packaging is not considered as the sample is packed manually with no atmosphere regulation involved in the process. Microbiological analysis is not conducted in this project as the research is focused on the visual quality assessment.

2 Literature Review

2.1 Physiology of fresh cuts

The term *fresh-cut* is used for fresh vegetables that have been cut into small portion that fit for one or few servings and are ready to be consumed, either directly or for cooking. Garande and Patil (2014) mentioned that there is no additional preparation required for the use of fresh-cut vegetables. This indicates that the products can be immediately prepared and consumed straightaway. Other names of fresh cut are lightly-processed and minimally-processed vegetables (Saltveit, 2003). The processes, such as peeling, trimming, cutting, washing, disinfection, rinsing, etc., can result in damage to plant tissue, which later on referred as wounding.

According to Saltveit (2000), fresh-cut lettuce is produced through several steps. Fresh lettuce is chilled upon harvesting and then the unwanted or defected layer is manually removed. The remaining parts are mechanically cut into smaller salad pieces before being washed. An interview with Aleksandar Trkulja from Pacsystem AB (2020) informed that cold and clean drinking water from the tap is used to wash the salad in Sweden. Addition of chlorine is forbidden in some European countries, such as Sweden, Germany, and Switzerland (Uhlig et al., 2017). The salad pieces then continue to drying process to remove excess water, generally using forced air or centrifugation using a large, perforated stainless-steel basked which is spun at high speed rates before finally being packed in the designed and appropriate packaging.

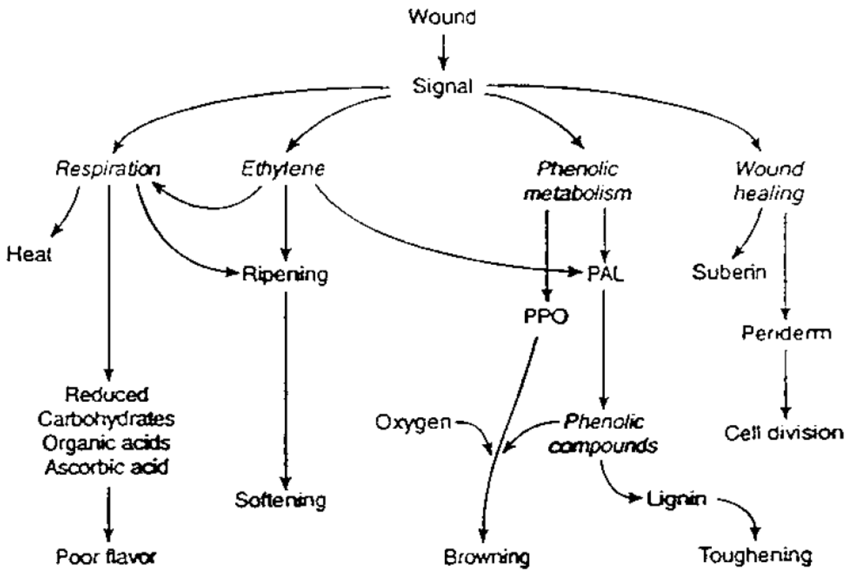


Figure 2 The wounding effects on physiological processes in fresh-cut vegetables (Saltveit, 1997)

Ke and Salveit (1989) defined wounding as *a physical stress that damages spread over the leaf blade in severe cases plant tissue, increases the rate of respiration and water loss and increases the likelihood of attack by pathogens*. There are some immediate physical effects that the fresh-cut processing results in, such as mechanical shocks to the tissue, removal of protective epidermal layer, accumulation of surface moisture, and tissue exposure to contaminants. These effects cause the evaporation of surface water, which affects the physiological behavior of vegetable tissue that will further have an impact on quality and length of shelf-life, as well as change on surface appearance, such as discoloration (Saltveit, 2003) and dehydration (Watada and Qi, 1999). Leafy vegetables, in particular, undergo dehydration mainly due to transpiration as they generally have a high surface to volume ratio, making them more prone to water loss after harvest as compared to fruits or fruit vegetables (Zhan et al., 2013). The interrelationship among several effects of wounding on physiological processes in fresh-cut vegetables is presented on Fig. 2.

One of the factors that determine the quality deterioration of lettuce during storage is the severity of tissue damage caused by manufacturing process. It was found that cutting with sharp blades caused less damage than dull blades, whereas tearing along sutures caused the least damage. Other things that determine the tissue reactions are cutting orientation (i.e. transverse, longitudinal, or diagonal) and cutting methods, such as shredding. Severe friction on the leaf surface due to shredding process causes the most damage during processing (Brecht, 1995). Another determining factor is the size of lettuce cuts. It was reported that smaller size of cuts resulted in higher respiration rate and ethylene production, which stimulate the biosynthesis of enzymes, such as Phenylalanine ammonia-lyase (PAL) that is highly linked to browning phenomenon (Martínez et al., 2005).

The combination of packaging use and storage condition plays a significant role in preserving the quality and extending the shelf life of fresh-cut lettuce. In this Master thesis project, some of the challenges related to packaging and storage of fresh-cut lettuce, partly due to the additional processing that bagged salad requires, are addressed.

2.2 Freshness quality

2.2.1 Quality parameter

Visual appearance of lettuce has been linked directly to its freshness quality perception. Some of the most common causes of quality loss are discoloration, browning, skin softening, and dehydration (Rojas-Graü, et al., 2009). Visual appearance is the first thing that consumers judge from fresh-cut products and immediately link it to the quality perception, therefore it is one of the most important quality parameters that needs to be investigated in assessing the quality of fresh-cut lettuce. The explanations of each parameter can be found in the paragraphs below.

2.2.1.1 Color and appearance

Surface browning has been investigated as an important defect of fresh-cut lettuce (López-Gálvez et al., 1997). It occurs due to enzymatic reaction, which is considered as one of the most important disorders as the browning effect can be easily detected by consumers and negatively affect marketing of the product (Degl'Innocenti et al., 2007). The formation of browning color does not indicate a loss of nutrient nor result in health issue (Berkeley Wellness, 2020).

Lettuce is classified as vegetable with low levels of naturally occurring phenolic compounds. However, wounding or injury due to processing stimulates phenylpropanoid metabolism which results in the accumulation of phenolic compounds. Another discoloration phenomenon that may occur during lettuce storage is leaf yellowing from loss of chlorophyll and reduced color brightness. Both browning and yellowing are a result of broken cells, letting off acids and enzymes that are liable for deterioration occurrence of lettuce when coming in contact with their substrates (Brecht et al., 2003). Browning mostly occurs on the midribs or white part of lettuce (Martínez-Sánchez et al., 2011), whereas yellowing occurs on the leaf part where it contains the highest chlorophyll level or recognized by the dark-green part of the vegetable.

Phenolic compounds are the plant secondary metabolites that are responsible for browning phenomenon in lettuce. The oxidation of this compound eventually leads to browning on the lettuce surface (Brecht et al., 2003). Polyphenol oxidase (PPO) and peroxidase (POD) are the two enzymes that will react with phenolic compounds, leading to the production of brown polymers (melanines) (Tomás-Barberán and Espín, 2001). These substances are identified by brown, reddish, or black coloration on lettuce (Castañer et al., 1996)

2.2.1.2 Texture

Leafy vegetables have different characteristic and quality changes as compared to fruits and fruit vegetables. They generally have a large surface to volume ratio, thus the fresh weight decrease during postharvest storage is mainly due transpiration process (Kays, 1991). Large exposed surface area of lettuce leaf prompts a higher level of dehydration, leading to rapid weight loss resulting in lower turgidity and freshness quality of lettuce.

Texture changes in most fresh-cut products have been found to be mainly determined by the rate of water transfer. The water that leaks from damaged cell will diffuse through the tissue, eventually leading to evaporation from the surface to surrounding air (Artés, Gómez and Artés-Hernández, 2007). This explains the importance of regulating storage humidity and maintaining low temperature to retain the moisture of products. Lower humidity will escalate the rate of water vapor transfer from leaf surface. The negative effects of processing are minimized at chilling temperature because the diffusion rate and deterioration reactions are decreased at lower temperature (Martin-Belloso and Soliva-Fortuny, 2006).

2.2.2 Factors affecting quality

To maintain the defined quality parameters, there are several affecting factors that need to be controlled and monitored. Storage temperature is considered as one of the most important factors in preserving the quality of fresh-cut products (Artés and Allende, 2015). Nevertheless, relative humidity and atmosphere composition are not less important than temperature. The proper regulation of these factors will help achieving the maximum quality and shelf life of products. The explanation of each factor will be discussed in paragraphs below. However, it is also important to note that packaging role is inseparable in the effort of maintaining quality of fresh-cut products. Different ways of selecting and using packaging may affect the effectivity of the chosen and regulated storage condition. This will be further discussed in the packaging section.

2.2.2.1 Temperature

High temperature during handling or storage is undesirable as it can increase the quality deterioration of lettuce, such as respiration acceleration, leaf discoloration, weight loss, and rapid senescence process (Nunes, 2008). Proper temperature regulation is required to ensure that the quality is maintained throughout its supply chain. Finding the right temperature is also highly essential to guarantee the safety of fresh-cut products. FDA (2010) suggested that cut leafy greens should be refrigerated at 5^{o}C or less which can prevent the growth of pathogen during storage. Storage at >5^{o}C will negatively result both the microbiology and sensory quality of the product. In Sweden, the temperature of 3-4^{o}C is imposed in the distribution and storage process of bagged salad in Coop retailer (2020). Any change in temperature will result in the change of respiration rate and gas diffusion between the cell liquid and intercellular spaces. It will also affect the plastic film behavior, especially in terms of permeability (Robertson, 2012).

It is important to note that optimal temperature may differ for different types of salad. The deterioration effect on the salad quality also depends on the type of salad. For instance, Iceberg lettuce stored at 0^{o}C showed main deterioration of browning, rotting, and russet spotting, whereas for Boston lettuce stored at the same temperature, the main deterioration effect was wilting (Nunes, 2008).

2.2.2.2 Relative humidity

Relative humidity (RH) is one of the factors influencing transpiration of vegetables, which is directly correlated to weight loss. Vegetables continue to lose water after being harvested. The loss of water is one of the causes of quality deterioration where the failure of slowing down this process will result in wilting, shrinkage, and decrease of firmness, crispness, and succulence. Water loss of 3%-10% of the initial weight leads to the loss of freshness, negatively affecting the appearance, texture, and flavor (Robertson, 2012). Optimal RH for most of fruits and vegetables are between 85% and 100% RH. This best optimum condition is often difficult to be fulfilled during the supply chain as the products are rarely stored exclusively and have to be mixed with other products, thus applying general condition suitable for all products (Paull, 1999)

2.2.2.3 Atmosphere

The concentration of O_2 and CO_2 during storage of fresh cut have great influence in affecting the quality deterioration of bagged salad. By decreasing the level of O_2 and increasing the level of CO_2, the respiration rate can be lowered, thus the shelf life can be extended (Robertson, 2012). However, different types of vegetables have different resistance to low O_2 level as adequate O_2 level should be maintained to ensure that aerobic respiration still can happen. Lettuce has minimum O_2 level of

2% (Robertson, 2012). Storing lettuce in a condition with O_2 level below 2% will result in anaerobic reaction, leading to the production of acetaldehyde and ethanol that are toxic to plant cell.

2.3 Fresh-cut Packaging

Packaging is one of the important determinant factors in ensuring the quality of bagged salad. It is crucial to guarantee that the atmosphere equilibrium state inside packaging is maintained considering the respiration rate of salad and the gas permeability of packaging film. However, it is important to note that the respiration rate is more highly influenced by surrounding temperature change than the film permeability (Martin-Belloso and Soliva Fortuny, 2011). In designing the MAP, consideration of temperature and storage condition along the supply chain is very crucial to ensure that the atmosphere is maintained until the end. The collaboration between all parties included in the supply chain is required to achieve this optimum packaging design for the product.

Plastic is the material commonly used for salad packaging. According to an interview with Alexander Trkulja from Pacsystem AB (2020), non-perforated PP film, particularly Oriented Polypropylene (OPP), is the material mostly used by salad producer for the plastic bag packaging and Amorphous Polyethylene Terephthalate (A-PET) for tray packaging. In Sweden, almost all fresh-cut salad products are packed in plastic bag packaging. PP film is a multifaceted material, which can be formed into bags and film for various applications. It is thin and thermoformable with the ability to be modified through orientation, leading to the formation of OPP.

Modified atmosphere (MA) is applied inside the packaging to extend the shelf life of salad. For 200 g of bagged lettuce, the MA consists of 2.5% O_2 and 5% CO_2 (Prieto, 2020). An interview with a Coop retailer revealed that the combination of current treatments allows bagged salad cuts to have an estimated shelf life of 11-12 days with the recommended storage condition from producer (max 4^{o}C) (Andersson, 2020).

The use of OPP as packaging material is growing in recent years due to the possibility of orientation variation, resulting in large properties options that can be adjusted to the desired characteristics (Robertson, 2012). However, it is important to note that OPP has low barrier to gas, thus coating with other material is needed to meet the barrier properties required for salad protection. Polyvinylidene chloride (PVdC) copolymer and low-density polyethylene (LDPE) are commonly used as the coating. These two polymers are also needed as fusible coating if heat sealing is to be done on the packaging. PvDC copolymer is more advantageous as coating material as it increases the resistance to water vapor and O_2, although it has higher price than LDPE (Robertson, 2012)

2.4 Future trends in bagged salad

According to Global Top Ten Food Trends 2018 by Institute of Food Technology (IFT), it was reported that the food industry is mainly driven by convenience. About two third of millennials are familiar with minimally processed food (such as fresh cuts) reaches more than 60% of the young people. This trend is expected to continue growing through the years ahead. Consumers seek for convenient, healthy, and safe products to be consumed. This is a challenge for bagged salad production as one of the major issues of this product is safety and sensory quality retention during storage. FDA (2010) suggested that the shelf life of fresh cut leafy vegetables is 12-16 days in the package. Nevertheless, this ultimately depends on the handling and storage which need to be properly regulated. Maintaining the correct temperature throughout the supply chain is one of the most essential factors to achieve the maximum shelf life and quality retention of bagged salad.

The current packaging films available for fresh cuts have limited permeability properties which have not perfectly matched the respiration rate, especially for product with high respiration rate. This results in the accumulation of CO_2 and very less O_2 in the packaging headspace, which is often detrimental for the product quality (Martin-Belloso and Soliva Fortuny, 2011). Active packaging is a type of packaging that can respond to the environmental change. Some films can transmit gas higher when the temperature arises due to the reversible melting of sidechains in the polymer. Further development of active packaging can be an alternative for better protection of bagged salad. Another thing related to packaging material of bagged salad is that consumers demand for more sustainable packaging. One of the concerns about current packaging is that it is plastic-based. More and more people try avoiding the use of plastic as it is perceived as non-environmentally friendly. There is possibility that in the future, consumers demand for non-plastic based packaging for fresh-cut products although such packaging is not commercially developed yet as for now.

Another possible development of bagged salad is in terms of storage equipment, such as refrigeration system. Ensuring that the system is properly developed to meet the requirement of salad storage in all points throughout the supply chain is one of the ways to optimize salad production.

2.5 Cooling technology

Storage temperature is considered as one of the most important factors in preserving the quality of fresh-cut products (Artés and Allende, 2015). Cooling technology has been developed since the 18th century and found to be a vital part of food preservation, especially for fresh food, such as vegetables and fruits. This technology was further utilized as the basis of fridge system, which can be found in almost every household in the world. To further analyze how the storage condition affects salad quality, it is important to first understand how the household fridge works. This section of literature review will provide thorough understanding on the principle of household fridges and how the condensation can be formed during storage in this system.

2.5.1 Refrigeration system

In 1834, Jacob Perkin developed the first vapor-compression cycle using ether as refrigerant, which can be operated as refrigeration machine. He is often regarded as the father of refrigerator. His work was then continuously developed by several scientists to make the refrigerator suitable for normal standard household appliance (Radermacher and Kim, 1996). Refrigeration system is based on the principle of heat removal from the substance in the refrigerated space. To maintain the system to operate a cycle where the heat transfer continuously occurs from cooler to hotter body, vapor compression cycle is applied in the actual applications of refrigeration. The basic component of vapor compression systems involves an evaporator, a condenser, and an expansion device (Granryd et al., 2005). A refrigerant is a compound that can absorb heat at low temperature and transfer it to the cooling medium through the vapor compression cycle. The refrigerant has lower temperature than the heat's source, thus it absorbs the heat and decrease the temperature of the heat's source. The temperature of refrigerant becomes higher than the heat sink, thus it can deliver the heat (Dincer, 2003).

2.5.2 Household refrigerators

The refrigeration principle has been used to develop household refrigerators (or fridge) and freezers that are intended for storing food at lower temperature and extending the shelf life. The fridge has temperature above 0ºC (typically 0 to 10ºC) for storing fresh food and vegetables, whereas temperature below 0ºC (-6 to -18 ºC) is normally used for freezer, suitable for storing frozen food (Björk, 2012). However, household fridges normally have several different compartments intended for storing specific types of food. Some of the common compartments are chiller, crisper, cellar, and fresh food compartment.

Household refrigerators are available in several different styles, such as side-by-side, top freezer, bottom freezer, and French door. The configurations differ considerably depending on the region. Top freezer dominates the global market (nearly 40%), followed by bottom freezer which occupies about 33% of market and side-by-side at about 13% (Harrington, 2009). However, the fridge development continues to develop to ensure that consumer's demands on longer and better food preservation, as well as the convenience aspect can be fulfilled. This development includes the fridge design, cooling system, and integration with advanced technology, such as smart-fridge (which includes touch-screen and functional door).

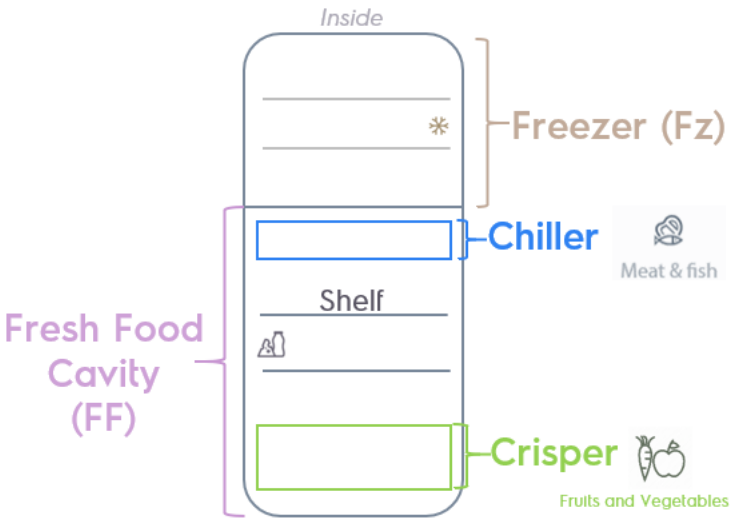


Figure 3 Fridge compartments (Electrolux, 2020)

In 2007, International Electrotechnical Commission (IEC) 62552:2007 "Household Refrigerating appliances – characteristics and test methods" was published with the definition and temperature of different fridge compartments (see Table 1)

Table 1 IEC 62552:2007-specified domestic refrigerator storage temperatures (IEC, 2007, cited in James, Onarinde and James, 2016)

Compartments	**Fresh food storage**	**Chiller**	**Cellar**
Definition	Intended for storing unfrozen food at the specified temperature	Intended specifically for storing highly perishable food in which the temperature can be maintained	Intended for storing food and beverage with the temperature above fresh food storage
Temperature range	0-8°C (mean ≤4°C)	-2-3°C	8-14 °C

Most of the conventional household refrigerators have a static cooling system, although fridges with dynamic cooling system have started to become more available in the market (Marklinder et al., 2004). A static cooling system typically consists of two motors, which result in the fridge and freezer that operate independently. Fridge with static cooling system generally has larger temperature fluctuation and more humid air in a longer term. However, it operates in a perpetual cycle: cooling – freezing – defrosting. The defrosting process must be done manually by turning off the fridge. The frequency of defrosting depends on the specification of fridges. Meanwhile, dynamic system results in the absence of frost on fridge walls due to an installed inbuilt fan which causes a better and more uniform air circulation. Because of this feature, dynamic cooling system is often referred as "no frost". The rapid air movement in the system results in small temperature fluctuation and lower drier air humidity inside the fridge (Brown, 2018). Fridge with this type of cooling system is generally more expensive than that with static cooling system.

Heat transfer occurs in the system with the utilization of forced air. The air is moved around by the installed fans, which could determine the heat transfer speed and relative humidity of the fridge. The faster the air flows, the more quickly heat is removed from food (Zizi, 2010). Another thing that is crucial for fridge system is relative humidity or the maximum water-holding capacity which air contains at specific time, usually expressed as a percentage. Relative humidity and temperature are interrelated. Different temperatures will affect the amount of water which air can hold.

Controlling the air flow is important for obtaining the desired relative humidity, where faster air flow results in lower relative humidity. This is the reason why there is usually a separate drawer in the fridge to store fruits and vegetables because higher relative humidity is needed to maintain their freshness quality. This drawer is called as crisper. It restricts the air flow, thus resulting in higher humidity inside the drawer as compared to other parts of shelves in the fridge (Zizi, 2010).

The variables in the household fridge explained above remain as challenges that consumers face while using the fridge to store food, in particular packaged fresh cuts. Some of the challenges are temperature fluctuation, different RH depending on the type of fridge, different ways of storing food, etc. In this study, the actual fridge is used to imitate the condition that consumers have at home and to further understand how these variables will affect salad quality during storage period.

2.5.3 Condensation formation

Condensation formation is a phenomenon that occurs on product surface stored inside the fridge. This is particularly unwanted on fruit and vegetable surfaces as the water condensate may lead to deterioration of their visual quality. The condensate has high relative humidity (>95%), which provides a favorable condition for unwanted microbes to grow (Linke and Geyer, 2012).

Temperature fluctuation has been identified as the major cause of condensation in the package. Even small fluctuation may lead to condensation formation due to the temperature falling below the dew point (Linke and Geyer, 2012). Speight (2018) defined dew point as *the temperature at which the water vapor or low-boiling hydrocarbon derivatives contained in the gas is transformed into the liquid state*. When the temperature is lower than dew point, the water vapor will turn into liquid state or known as condensate.

In packaged fresh cuts, there are some factors that may affect the condensation amount formed inside the packages. The shape, dimension, and surface structure of vegetable have immediate impact on the amount of condensation. External factors, such as temperature, humidity, and air flow, also may affect the condensation rate and retention time inside the package (Linke and Geyer, 2012). In packaged fresh cuts with saturated RH condition, transpiration occurs due to internal heat generation caused by respiration of lettuce. Whenever salad transpiration rate is higher than water vapor transmission rate, the water molecules that remains in the package will enhance the water vapor pressure, leading to water condensate formation (Volpe et al., 2017).

In this study, condensation build-up and its effect on other quality parameters would be analyzed. This was performed to confirm the existing literature, to observe the fridge performance, and to understand whether condensation negatively affect the salad quality during storage in the fridge.

3 Methodology

3.1 Overall research procedure

This study was conducted as the initial approach of understanding packaged food behavior, focusing on lettuce, in different fridges at Electrolux. It consisted of several stages: preliminary, first, second, and third stage (see Fig. 4 for overview of the research). Prior to starting the project, the major activities were to define the quality parameters of the lettuce to be evaluated, establishing new research protocols for conducting the experiments and for the quality assessment, and planning the project direction. This was an important preparatory phase as the existing protocol in the company was mainly made for evaluating non-packaged food, such as strawberry and mushroom. The details and performance of each stage in this project are described in the paragraphs below.

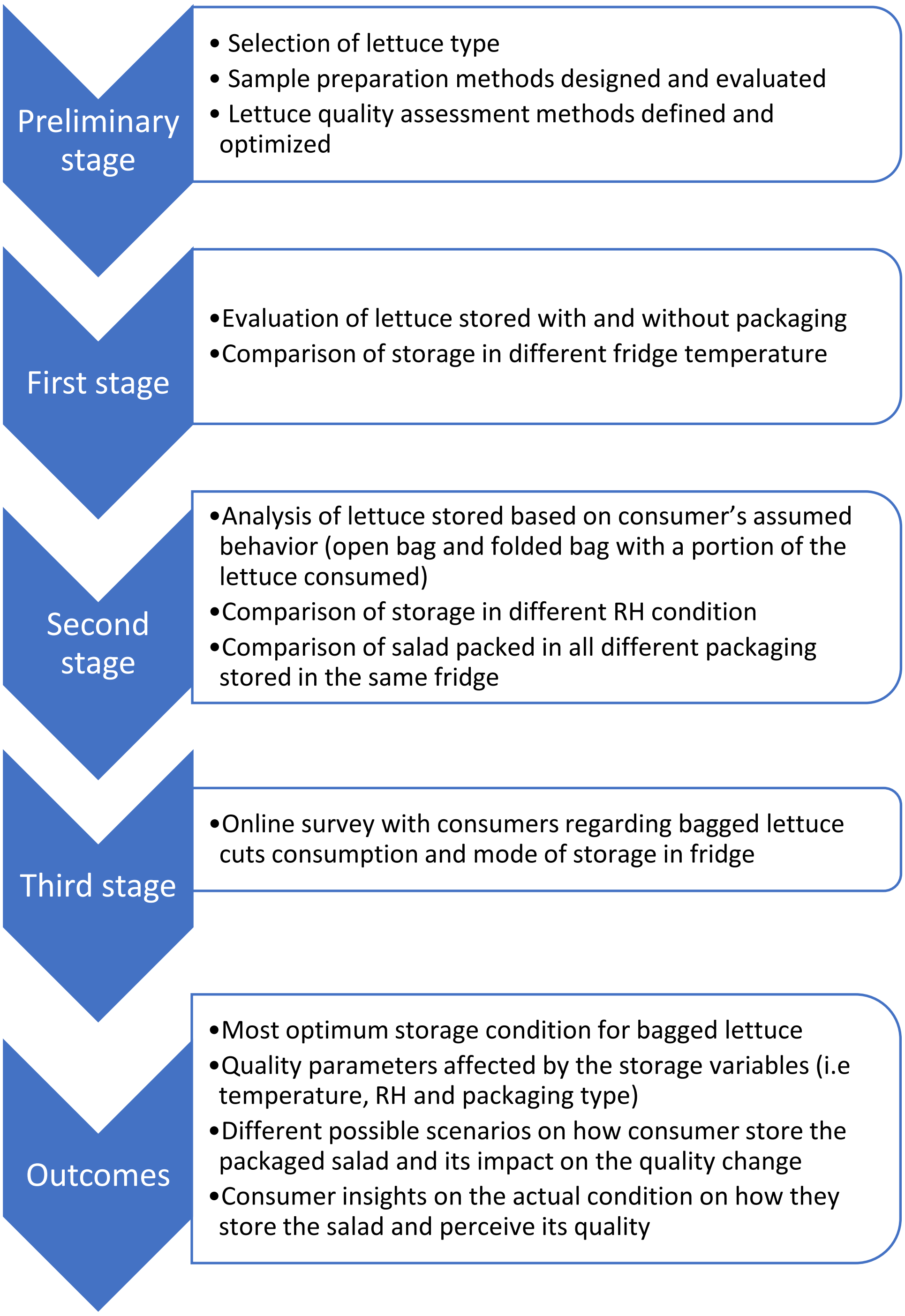


Figure 4 Overview of research procedure

3.2 Materials

The materials used in this project are categorized into several main groups: various types of lettuces, packaging materials, cooling systems (fridges), and analysis equipment. The details for each group are described in Table 2 below.

Table 2 List of materials used in the study

	Materials	Details
Salad	Romaine lettuce	Fresh head: intact, packaged by "wrapping plastic"
		Commercial bagged romaine cuts packed in MAP atmosphere (Producer: Vidinge Grönt AB, storage temperature recommendation: max. 4°C)
	Iceberg lettuce	Fresh head: intact, wrapped in plastic
		Commercial bagged Iceberg cuts packed in MAP atmosphere (Producer: Vidinge Grönt AB, storage temperature recommendation: max. 4°C)
	Lamb's lettuce (Mâche salad)	Commercial bagged lamb's lettuce; intact rosettes (Producer: Vidinge Grönt AB, storage temperature recommendation: max. 4°C)
Packaging materials	Short food container without lid (3.8 cm height): Polypropylene (PP)	Used for unpackaged lettuce
	Tall food container without lid (7.8 cm height): Polypropylene (PP)	
	Roll of plastic film: Biaxially-Oriented Polypropylene (BOPP)	Opened bag
		Folded bag
		Sealed bag
	Heat sealer	
Cooling system	Fridge B	Same fridge, different setting (temperature, RH) for different stages, from producer Y (producers not specified due to confidential issue)
	Fridge E	
	Fridge G	
	Fridge A	From producer X (producers not specified due to confidential issue)
	Fridge C	

	Fridge D	
	Fridge F	
Analysis equipment	Digital scale	**Producer**: Kern & Sohn **Model**: PCB 1000-1
	Image analysis	• ***A colour digital camera***, model Nikon D3300 digital SLR camera (AF-P DX NIKKOR 18-55 f/3.5-5.6G VR, Nikon, Thailand) • ***A lighting system***, using two parallel **lamp housings** with two compact fluorescent tubes in each housing (Kaiser R1 System, model RB 5055 HF, 4×55 w) with a colour temperature of 5400 K (daylight-type, colour rendition index (CRI) 90 - 100), and provided with **light diffusers** (Kaiser Diffusion Screens 5593) • A laptop that is also equipped with **Adobe Photoshop CS6** (version 13.0.1 ×64 Bit) and **MATLAB R2017b** (The Math Works, Inc., USA) software including the *Image Processing Toolbox* for image processing, analysis, and algorithm development.
	Salad spinner	**Brand**: Gefu ® **Model**: Special Salladsslunga
	Knife	
	Cutting board	
	Ascorbic acid kit	HI 3850 Ascorbic Acid Test Kit by Hanna Instruments
	Vacuum blender	
	Texturometer	**Brand**: Agrosta **Model**: ®Belle Texture Analyzer
	Temperature and RH logger	**Brand**: Onset HOBO Bluetooth **Model**: MX1101

3.3 Experimental setup and performance

In the following section the performance of the experiments in the different stages outlined in Fig. 1 will be described in detail. Primarily the preliminary stage including selecting lettuce type, selection and optimization of sample preparation and quality assessment methods will be described followed by the actual performance of evaluating behavior in different storing conditions using various QA methods and finally how the results were analyzed and evaluated.

For each experiment, the prepared salad cuts were placed in different commercial fridges. The fridge was opened approximately 10 times (total time around 10 min) for taking the samples in every analysis day. The temperature and humidity were continuously recorded using HOBO temp data logger during the storage period. The position of samples was continuously rotated on every analysis day to ensure that all samples were exposed to the same temperature and RH condition throughout the storage period.

3.3.1 Preliminary stage

As there was no specific type of salad defined in the beginning of project, the first two weeks were dedicated for selecting the lettuce, design sample preparation methods, and selection, development/optimization of methods and protocols for quality assessments. The major existing quality assessment method in the lab was and imaging system where the method had been carefully designed to assess the color change for almost any type of food object. However, as lettuce was not previously well-observed yet, the modification and adjustment of the system were continuously done throughout the project, especially during this preliminary stage in order to optimize it for imaging differences over time of lettuce samples. In addition to the imaging method, protocols for the following methods for quality assessment were developed during this preliminary stage: texture analysis, condensation amount and ascorbic acid content measurement. The outcomes of this initial phase (preliminary stage) were selected lettuce type (see details in 3.3.1.1), sample preparation protocols describing how the lettuce should be prepared for the experiments in the first and second stage (see details below), and a series of assessment protocols to be used for the remaining stages of the project (see section "4. Quality assessment".

3.3.1.1 Selection of lettuce type

This stage was intended to select the type of lettuce, for the remaining parts of the project, by comparing the behavior of several potential lettuce types during storage in one fridge condition. The lettuce type that showed the most prominent observational change on its visual characteristic was selected, as visual characterization was the main analysis of this project (using an imaging system).

The lettuce types were selected based on their various characteristics such as morphology and popularity on the Swedish market. Three different lettuce varieties chosen were: iceberg, romaine, and lamb's lettuce (*Mâche sallat*).

Figure 5 Different types of lettuces used in preliminary phase: a) Romaine, b) Iceberg, c) Lamb's lettuce (Mâche sallat) (Source: amazon.co.uk)

To decide which lettuce to choose for further experiments, commercial bagged lettuce cuts were purchased from retailer and stored in the fridge with and without package. Lettuce cuts were removed from the commercial packaged and placed on a tray, which then called as non-packaged sample in this stage. Meanwhile for packaged sample, the commercial bagged lettuce cuts were stored without being opened at all.

The lettuce cuts were then stored for 8 days in the same fridge with the temperature inside ranging from 4.9-8^{o}C depending on the position of respective shelf. Temperature and RH logger was placed in each shelf to record the profile throughout the storage period. Based on Table 1, the coolest position was at bottom shelf and the temperature increased at the higher shelf. The lettuces were placed in all the shelves inside the fridge (see Fig 6). Daily evaluation on the visual changes with the imaging system and weight loss were carried out during storage period.

Table 3 Average temperature and RH during stable cycle in between 2 defrosts in preliminary stage experiment

	T (^{o}C)	RH (%)	Logger position (shelf no.)
Fridge X	8.0 ± 1.4	67.3	1
	6.2 ± 1.9	75.3	2
	5.8 ± 1.8	84.1	3
	5.5 ± 1.5	76.1	4
	4.9 ± 2.7	78.5	5

Figure 6 Selection of lettuce type. The image shows the set-up of three different lettuce types

3.3.1.2 Design of sample preparation methods

Determining the sample preparation method was a part of the preliminary stage. Commercial, premade lettuce cuts that were purchased in the bag from the retailer, was compared with cuts that were manually done in the laboratory from fresh intact lettuce. This comparison was done for iceberg and romaine lettuce. Lamb's lettuce was packed without the cutting process, thus there was no need to differ in terms of preparation method.

Figure 7 Samples for preliminary test

Fresh lettuces were bought from the local supermarket (Coop, Sweden) from the same brand and batch. The romaine and iceberg lettuce head were wrapped with plastic film, whereas the cuts were packaged in a plastic bag with modified atmosphere. For lamb's lettuce, only the bagged cuts that was purchased from the store. Upon purchasing of romaine and iceberg lettuce head, the products were examined and the non-satisfying part is removed (e.g. outer layer). They were cut into small pieces (around 2 cm x 2 cm) using a sharp knife with the cut as similar as possible with the commercial products. The cuts were then washed in cold drinking water from tap for 5 min and placed in a manual salad spinner for 2 min to remove the excess water (Volpe et al., 2018). After that, 100 g of samples were placed in the packages (sealed bags and without package). For the sealed bag, the lettuce cuts were picked randomly and placed inside the BOPP packaging film and then sealed using a plastic heat sealer. The atmospheric condition inside the package was not measured due to the unavailability of equipment to do so. For unpackaged sample, lettuce cuts were placed in the food container without lid. This preparation method continued to be used to prepare the salad cuts for the experiments in the next stages.

The plastic bags were provided by PacSystem AB, a major packaging supplier for bagged salad companies. The plastic was delivered in reel and the bags were manually cut in the lab with the dimension of 480mm (width) x 270mm (length) x 30µm (thickness), which is the same size with commercial bagged salad packaging. The material of the plastic was BOPP (bi-orientated polypropylene).

Figure 8 Plastic reel and bags manually cut in the lab

3.3.2 First stage

Based on the obtained results in the preliminary stage it was decided that Romaine lettuce was selected for all further experiments. The romaine cuts, prepared as described in the sample preparation section above, were evaluated with and without package in 3 different fridges (see Fig 9). This phase was intended to understand the difference in salad quality stored in extreme temperature comparison and to find the most suitable temperature to be further used in the remaining stages of the research. The samples were stored in 3 fridges with different temperatures. The temperatures were chosen based on average temperature of Swedish household fridge (8ºC), intermediate value (5ºC), and recommendation from the salad producer (2ºC). Experiments were done in duplicate, where two identical samples stored at the same time. As the quality evaluation analysis was using destructive methods, one sample for each sampling point was prepared. As the analysis performed was destructive analysis, 4 identical samples were prepared of each type (un-packaged or bagged) to be evaluated every 2 days (day 2, 4, 6, 8) for 8 consecutive days. The following quality parameters were evaluated: weight loss, texture, condensation amount, and vitamin C content.

Table 4 Average temperature and RH during stable cycle in between 2 defrosts in first stage experiment

		T (ºC)	RH (%)	Logger position (shelf no.)
Stage 1	Fridge A	3.1±0.6	80	2
		3.5±0.6	77	3
	Fridge B	4.7±0.9	73	2
		3.9±1.1	-	3
	Fridge C	8.0±0.5	83	2
		7.8±0.5	87	3

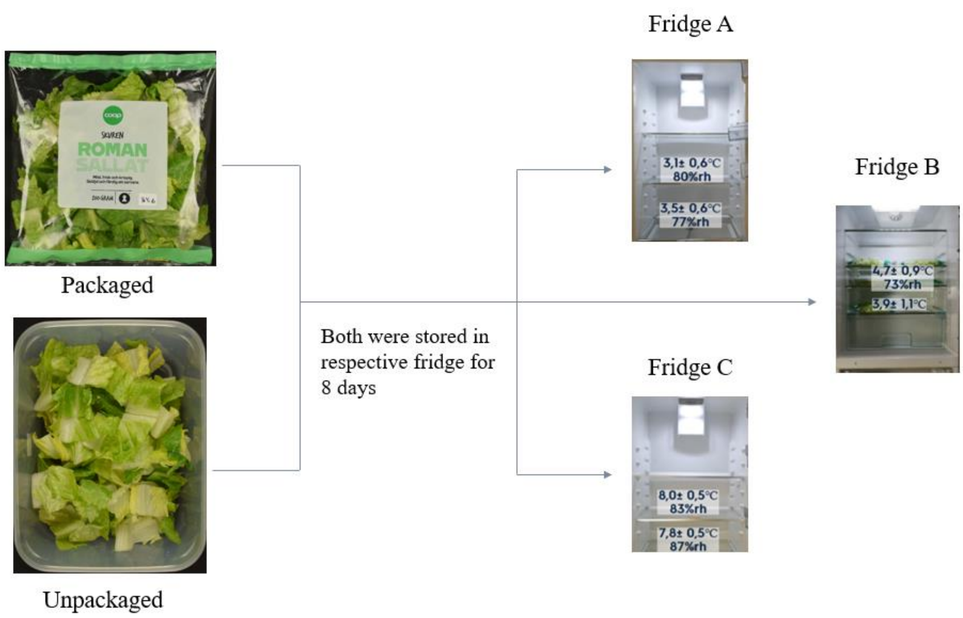


Figure 9 Evaluation of salad quality stored in different temperature. The image shows the set-up of first stage experiment

3.3.3 Second stage

The next stage consisted of comparison of romaine lettuce quality stored based on consumer's assumed behaviour and comparison of different types of packages stored in the same condition. The variables were chosen based on possible scenarios on how consumers store the opened bagged salad. In addition to temperature, relative humidity (RH) played an important role on salad quality. Therefore, different RH condition was compared in this phase to further understand the most optimal storage condition. This is an important insight for the fridge companies as they produce various types of fridges and different fridges have different RH according to the type of installed cooling system. It is not, in contrast to temperature, possible for consumer to set or adjust this parameter in a consumer fridge. The fridges used were chosen based on their RH conditions, from the driest (Fridge D - 27% RH), intermediate (Fridge E - 56% RH), to the most humid (Fridge F - 86% RH) (see Fig 10). The details of fridge condition can be seen in table 5.

Salad stored in open and folded bags were stored in these fridges for 14 days. The storage period was extended to obtain more severe quality degradation for better comparison between samples. For folded bag, the plastic bag was being folded manually after lettuce cuts were placed inside the package, whereas the plastic bag was left opened during storage for open bag. The analysis was carried out on day 0, 4, 7, 10, and 14. The following quality parameters were evaluated: weight loss, texture, condensation amount, color change, and vitamin C content.

Table 5 Average temperature and RH during stable cycle in between 2 defrosts in second stage experiment

		T (ºC)	RH (%)	Logger position (shelf no.)
Stage 2	Fridge D	3.1±2.6 C	-	2
		3.4±2.1 C	21	3
	Fridge E*	4.1±0.3 C	56	2
		4.7±0.2 C	57	3
	Fridge F	7.0±1.1 C	-	1
		4.3±2.2 C	79	2
		5.0±2.1 C	86	3
		6.1±1.1 C	-	4
	Fridge G*	4.5 ± 3.3	-	1
		5.0 ± 2.5	78.3	2
		6.0 ± 2.5	69.6	3

*Fridges marked with * are from the same producer*

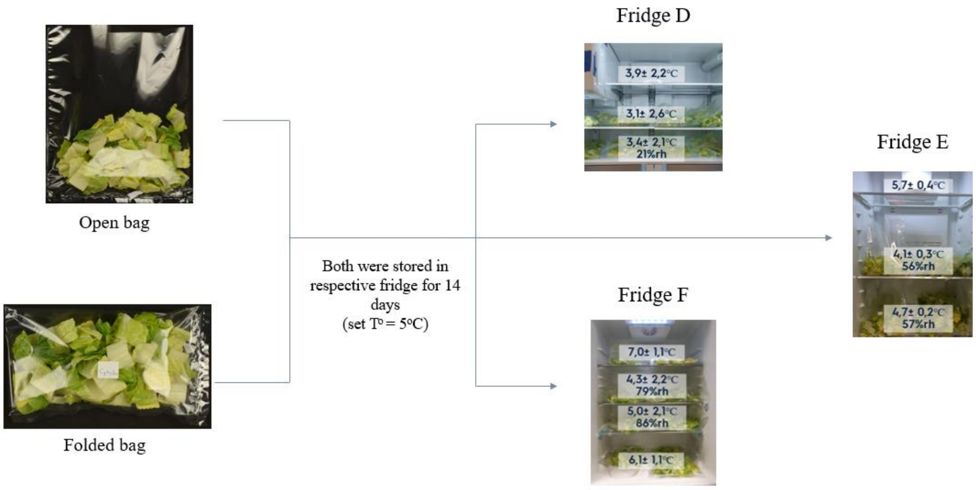


Figure 10 Evaluation of salad quality stored in different RH. The image shows the set-up of second stage experiment

Another experiment accomplished in the second stage was the comparison of salad quality in all different packages stored in the same condition. This experiment was exclusively performed to understand the effect of different packaging on salad quality. Lettuce cuts were packed in 4 different packaging (unpackaged, open bag, folded bag, sealed bag) with duplicates for each bag. All samples were stored in Fridge G for 13 days (see Fig 11). The quality assessments were based on image analysis and weight loss. The evaluation was carried out on day 0, 4, 7, 10, and 13. By the end of this stage, a series of data was gathered to get a comprehensive understanding on how packaging and storage condition affect the bagged salad quality.

Figure 11 Evaluation of salad quality stored in different packaging. The image shows the set-up of this experiment

3.3.4 Third stage

This stage was aimed to gather consumer insight related to bagged salad consumption and storage in fridge. It was initially planned to be an on-site evaluation where panelists can assess the salad quality directly. However, due to the unprecedented situation, the evaluation was conducted through online platform within internal company. The online questionnaire consisted of 11 questions that covered the consumer's behavior on buying bagged salad, storing in the fridge, assessing the quality based on provided pictures, and consuming the salad (see Appendix). There were 81 responses recorded in total by the end of survey period. The information gathered on this stage was used to complement the data collected in the lab and to provide more insight about the real condition about bagged salad consumption and storage from consumer's point of view.

3.4 Analysis of quality parameters

For the quality analysis, the measurements were performed on the parameters that had been previously defined in the company based on the existing equipment. The main assessment was related to salad appearance, especially color change and browning formation, using the image analysis. Other performed measurements were on weight loss, texture change, ascorbic acid content, and condensation formation. The methods used for each measurement will be described in the following paragraphs.

3.4.1.1 Visual quality assessment

The visual quality assessment was carried out using an imaging system or machine vision (Fig. 12). The imaging system consisted of:

- ***A colour digital camera***, model Nikon D3300 digital SLR camera (AF-P DX NIKKOR 18-55 f/3.5-5.6G VR, Nikon, Thailand)
- ***A lighting system***, using two parallel **lamp housings** with two compact fluorescent tubes in each housing (Kaiser R1 System, model RB 5055 HF, 4×55 w) with a colour temperature of 5400 K (daylight-type, colour rendition index (CRI) 90 - 100), and provided with **light diffusers** (Kaiser Diffusion Screens 5593)
- A laptop that is also equipped with **Adobe Photoshop CS6** (version 13.0.1 ×64 Bit) and **MATLAB R2017b** (The Math Works, Inc., USA) software including the *Image Processing Toolbox* for image processing, analysis, and algorithm development.

Each sample was captured using the installed equipment. The image was then analyzed using MATLAB to evaluate the visual change throughout the storage (e.g. color change and browning percentage). The color change was expressed by $\Delta_{L^*a^*b^*}$ and browning was presented in percentage to total area of object.

Figure 12 Machine vision set-up

The colour difference or colour changes is calculated using the Eq. (1).

$$\Delta_{L^*a^*b^*} = \sqrt{(L_0^* - L_n^*)^2 + (a_0^* - a_n^*)^2 + (b_0^* - b_n^*)^2} \quad (1)$$

where:

L_0^*, a_0^*, b_0^* is the $L^*a^*b^*$colour measurement of the sample surface at day 0.

L_n^*, a_n^*, b_n^* is the colour measurement of the sample surface after n days in storage.

It should be noted that $\Delta_{L^*a^*b^*}$ values ≥ **5 units** is considered the threshold for human detection.

3.4.1.2 Weight loss

Weight loss was estimated based on the percentage of weight reduction with respect to initial weight. After being removed from the packaged and the condensates were wiped off from the leaves surface, the lettuce cuts were placed on a weighing scale with accuracy of ±0.01 g. Weighing was carried out using digital scale from Kern & Sohn with the model of PCB 1000-1. The analysis was performed in airconditioned area to avoid condensation of atmospheric water vapor on the packages. The data was taken on specified analysis day depending on the stage, then the trend was analyzed.

3.4.1.3 Texture analysis

The texture change of a sample was evaluated using AGROSTA Texture Analyzer (model: ®Belle Texture Analyzer). The speed of the probe was set to 1 mm/s. The probe will go through the sample and the force needed to break the sample was expressed in the form of peaks. Firmness data are expressed in gram (g). During the textural test the maximum peak and total area were recorded, then analyzed using MATLAB. The analysis was performed three times for each sample, then the results would be averaged. 10 g of sample was used for each analysis with the blade aiming to cut the midrib part of the lettuce.

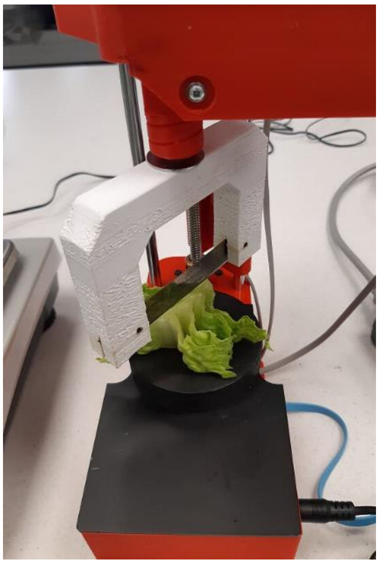


Figure 13 Sample placement on texturometer

3.4.1.4 Condensation quantity estimation

Condensation quantity estimation was performed using tissue. The analysis was carried out on the specified analysis day, depending on the experiment stages. The condensation amount is expressed in gram (g). The tissue was used to wipe condensates inside the package and on lettuce surfaces. The difference between weight of tissue before and after wiping was calculated using the following equation:

$$C = (P^*-P) + (T^*-T)$$

where P = packaging (g), P* = packaging after lettuces were removed (after storage), T = tissue (g), and T* = tissue weight after wiping the condensates on lettuce surface.

3.4.1.5 Ascorbic acid content

The ascorbic acid (later referred as vitamin C) levels were determined at the beginning of experiment on lettuce cut samples, middle day of period storage, and last day of experiment, using HI 3850 Ascorbic Acid Test Kit by Hanna Instruments that is based on Skoog, et al. (1990). The analysis was performed three times for each sample, then the result was averaged.

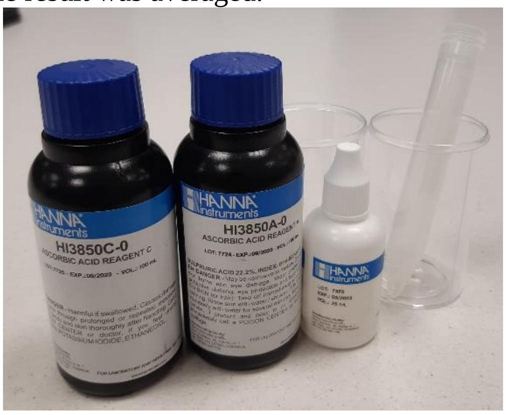


Figure 14 HI 3850 Ascorbic Acid Kit by Hanna Instruments

Samples are mixed with water with ratio of 1:4 using a vacuum blender for 1 min. 10 mL of filtrate is moved to a calibrated vessel, then added by deionized water up to 50 mL for dilution. 1 mL of HI 3850A-0 reagent (lot no. 7724) is added to sample and mixed homogenously, followed by addition of 4 drops of starch indicator. Drops of HI 3850C-0 (lot no. 7725) reagent are added until a persistent blue color is developed. Concentration of ascorbic acid is calculated with the following equation:

$$\textbf{Number of drops x 10 x 5 (dilution factor) = ppm } \mathbf{C_6H_8O_6}$$

3.5 Experimental constraints

Different constraints appeared due to the unforeseeable pandemic situation. The company regulation changed in the middle of thesis work, thus some changes in the research plan were made. The constraints will be stated prior to presenting the results of the research.

The first constraint was the sample quality. The source of sample was uniformed as much as possible. However, the samples were not all from the same batch of productions due to limited stock in the store. This may affect the initial quality of lettuce.

Secondly, the experiments were only performed in duplicates at the same time. Repetition of the same experiment was not performed due to time constraint.

Thirdly, it is important to note that the fridge condition in this research represented the actual condition in the household. It was not possible to set the storage condition precisely on specific temperature and RH because of the cooling system and temperature fluctuation of the fridges. However, fridges with similar behavior were used to obtain a better data comparison (e.g. in the first stage, fridges with similar RH were used). The actual temperature and RH varied throughout the experiment, thus the stated condition in this report was based on the average value.

4 Results & Discussions

4.1 Preliminary test – Sample selection

The preliminary stage to select the type of lettuce and preparation method was established prior to conduct the first stage of experiments. Some lettuces have similar characteristics, but it was decided that one specific type of lettuce would be chosen for this study given the restricted time and numerous variables that needed to be observed during the project. The selection process was based on visual comparison throughout the storage period and the characteristic suitability with available equipment in the lab. Sample preparation method was also determined during this stage to ensure that the method would deliver the best outcome for the project.

4.1.1 Visual comparison of lettuce types

Three types of lettuce were compared based on their visual quality change during a storage period of 8 days. Iceberg and Romaine are two of the most popular types of lettuce. Iceberg is more dominant in northern and western Europe, whereas Romaine is more popular in the Mediterranean countries (Nag, 2017). Iceberg lettuce has a spherical shape with its head that is compact with broad, thick, and crisp leaves that have a high water content. It has crunchy and juicy texture with mild flavor. Romaine lettuce has an elongated shape with stiff and upright leaves. The leaves are broad with dark green color in the outer part and paler color on the inner parts of the head. It has a crispy and crunchy texture with mild, slightly bitter taste. Lamb's lettuce (Mâche salad) is commonly used for French and Italian cuisine. It has dark green color, soft texture, and small-sized leaves. It is normally sold in bag with intact leaves and branches, unlike romaine and iceberg that undergo cutting process.

After being stored in the fridge at 5.8 ± 1.8^{o}C and 84.1% RH for 8 days, the visual quality of the three lettuces was compared. It was observed that on the 8th day, all lettuces showed significant quality degradation, especially on color, texture, and aroma. Both romaine and iceberg had severe browning in almost all leaves, with some yellowing occurred on romaine lettuce. However, lamb's lettuce did not show change in color. Its main quality deterioration is on the texture and aroma. The details of characteristic descriptions are provided in Table 6.

Table 6 Visual comparison of different lettuce types from commercial bagged lettuce before and after 8 days of storage in 5.8 ± 1.8ºC, 84.1% RH

Type of Lettuce	Day 0		Day 8	
	Image	**Characteristics description**	**Image**	**Characteristics description**
Romaine		Green aroma, yellow part ±30%, hints of sour smell, firm and crispy texture		Browning and yellowing occurred in all leaves (on surface and edge), slimy texture, unpleasant smell, organoleptically non-acceptable
Iceberg		Green and fresh aroma, firm texture, light green color		Browning occurred in all leaves (on surface and edge), slimy texture, unpleasant smell, organoleptically non-acceptable

Lamb's lettuce (*machesallat*)		Fresh green aroma, dark green color		Strong unpleasant fusty smell, wilting leaves, organoleptically non-acceptable

From the visual evaluation result, romaine and iceberg showed the most significant change on their quality during storage. As image analysis is one of the important assessment methods in this study, color change is a crucial parameter to be observed. Lamb's lettuce did not show color change, thus it was not suitable for this method. Moreover, the leaves severely wilted on the 8th day, making it hard for the texture analysis to be carried out. Therefore, the possible option was between romaine and iceberg. Next consideration was about the suitability of sample for texture analysis. Romaine has firmer texture and a midrib part, which allows the pieces to stand and be analyzed using the texturometer. It was difficult to perform texture analysis on iceberg lettuce due to thinner and softer leaf structure. Based on these collected observations, romaine lettuce was selected as the sample to be studied further in this Master thesis project.

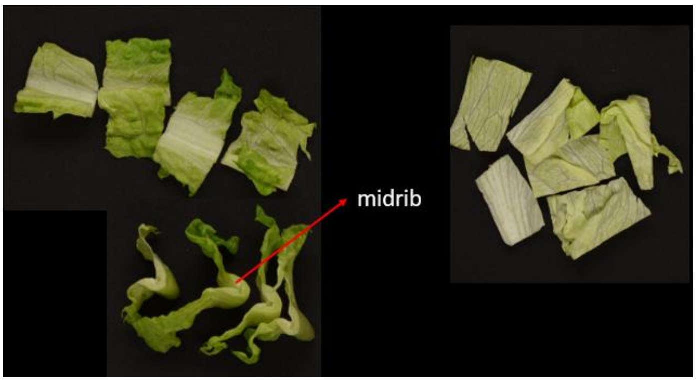


Figure 15 Physiology of romaine (left) and iceberg (right) lettuce

4.1.2 Sample preparation method (self-prepared & pre-cut purchased from retailers)

Manually prepared romaine lettuce cuts and bagged lettuce cuts purchased from retailer were visually compared after being stored in the same condition (5.8 ± 1.8ºC and 84.1% RH) for 8 days. This stage was performed to find out whether there was any difference in quality change between samples prepared using two different methods. Prior to this project, lettuce cuts bought from retailers had always been used in the lab for various experimental purposes. However, it was observed that the results of quality evaluations during storage were not consistent. It was suspected that the underlying reason for this was due to the different initial quality of bagged lettuces, as it was not possible to source them directly from the producer. Therefore, the manual preparation of sample was then developed in the initial phase of this project based on the method used by Volpe et al. (2018). The details of characteristic descriptions are provided in Table 7.

Table 7 Visual comparison of romaine lettuce from manual preparation and commercial bagged lettuce cuts stored at 5.8 ± 1.8ºC, 84.1% RH for eight days.

Source of sample	Day 0		Day 8	
	Image	Characteristic description	Image	Characteristic description
Manually prepared		Fresh and "ground" aroma, firm and crispy texture, light green color		Wilted leaves, browning only on the edge of leaves, midrib part was firm enough for texture analysis, slight unpleasant smell but still acceptable

Purchased from retailer		Green aroma, yellow part ±30%, hints of sour smell, firm and crispy texture		Browning and yellowing occurred in all leaves (on surface and edge), slimy texture, unpleasant smell, organoleptically non-acceptable

The initial freshness quality of pre-cut lettuce cuts purchased from retailer was lower than that of manually prepared cuts. The latter was prepared from a head of lettuce, therefore the quality was much closer to the fresh lettuce as compared to commercial cuts as they had gone through processing and a storage period in the supply chain. On the 8th day, lettuce cuts obtained from retailers showed severe quality degradation as compared to those self-prepared. Pre-cut lettuces have been processed through harsh processes in the manufacturing company. The process do not only involve numerous blades during the cutting process, but also high-speed centrifuges are used to remove the excess water (Saltveit, 2000). The combination of these processes results in severely damaged tissues. The quality deterioration is slowed down due to modified atmosphere (MA) in the packages. According to interview with Vidinge Grönt, the MA consists of 2.5% O_2 and 5% CO_2 for 200 g of bagged lettuce (Prieto, 2020). Hence, in this experiment where the lettuce was transferred from the bag to the plastic container, the deterioration rate drastically increased again once the cuts were exposed to oxygen in the air (Brecht et al., 2003). On the other hand, self-prepared lettuce did not go through severely damaging process as it was done manually with simple equipment. This can be the reason why the quality deterioration was slower than that of the commercial lettuce cuts.

Considering the variability of initial quality of commercial lettuce cuts, it was decided that manual preparation would be the method used to prepare the sample in this project. Although the deterioration was not acute, it was easier to ensure the uniformity of sample and remove the unnecessary variability. More severe degradation could be achieved later on, e.g. by prolonging the storage period.

4.2 Lettuce quality change in different temperature profiles

The first objective of this study was *to evaluate the impact of freshness quality of bagged salad stored in different fridge conditions*. The first compared condition was temperature, as there are several possible options for consumers to set their fridge temperature. Marklinder et al. (2004) revealed that the mean average of storage temperature of ready to eat salad in consumer's house in Sweden is 7.4ºC. Meanwhile, Vidinge AB as the salad producer, recommends the temperature of 2 ºC as the ideal condition for storing bagged salad. On this basis, different fridges with set temperature of 2ºC, 5ºC, and 8ºC were used to store packaged and unpackaged salad cuts, where 5ºC was selected as the intermediate value and the closest temperature to factory setting of Electrolux's household refrigerators (4ºC). However, the actual temperature inside the fridge varied due to its cooling system. The average temperature and RH value for each fridge used in this stage is presented in Table 8.

Table 8 Average temperature and RH of each fridge used in first stage to observe the salad quality difference stored at different temperature with and without packaging

	T (ºC)	RH (%)
Fridge A	3.3±0.6	78.5
Fridge B	4.3±1.0	73
Fridge C	7.9±0.5	85

Packaged and unpackaged Romaine lettuce cuts were used in this stage to portray the extreme comparison of storage scenario at different temperatures in each fridge condition. The quality analysis was performed on four quality parameters: weight loss, texture, condensation, and vitamin C content. However, due to different size of box used to store the unpackaged salad in fridge B, the data was not comparable with unpackaged salad stored in fridge A and C. Therefore, unpackaged salad in fridge B is opted out from the comparison of quality parameters except for weight loss as repetition was done using the same box size with fridge A and C for weight loss analysis. The storage period was 8 days and analysis of each parameter was carried out on day 0, 1, 4, 6, and 8. The experiment was done in duplicate with no repetition of experiment at different time.

4.2.1 Weight loss

Weight loss is related with water movement from salad. Transpiration process is the major cause of weight loss on leafy vegetables as they have a large surface to volume ratio, resulting in rapid water loss during postharvest storage (Kays,1991). The rate is higher on fresh cuts as the surface area is larger and the inner cells are openly exposed to surrounding air. Figure 16 shows the weight loss of both packaged and unpackaged salad during the storage period in all the fridges. It was observed that weight loss increased over time for both packages However, the unpackaged salad showed more rapid loss, about 10 times more than packaged salad in all the fridges.

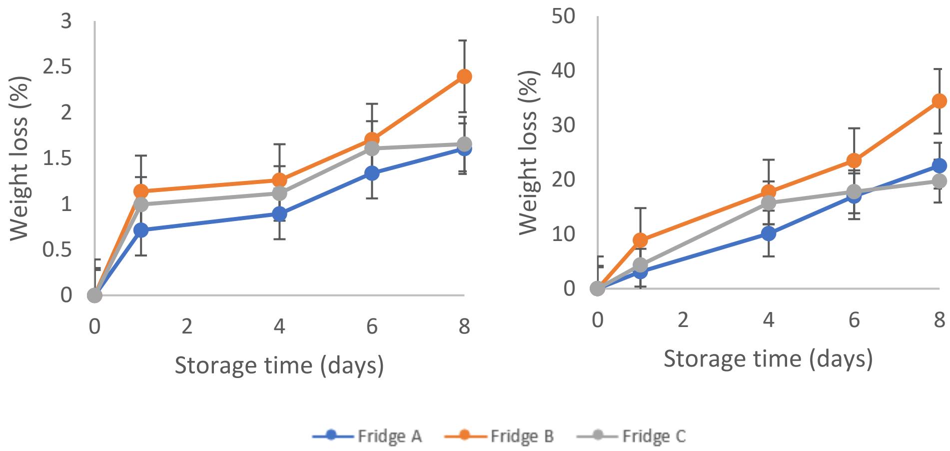


Figure 16 Average values of weight loss (including standard error) of two independent experiments of <u>packaged (left)</u> and <u>unpackaged (right)</u> salad during 8 days storage in different fridges - Fridge A (3.3±0.6°C, RH 78.5%); Fridge B (4.3±1.0 °C, RH 73%); Fridge C (7.9±0.5 °C, RH 85%)

ANOVA test showed that the weight loss between the fridges was significantly different ($p<0.05$) for both packages. Samples stored in fridge B (4.3±1.0 °C, RH 73%) had the highest weight loss throughout the storage time. For packaged salad, fridge C generally had higher weight loss than fridge A (3.3±0.6 °C, RH 78.5%). On the other hand, unpackaged salad showed slightly different behavior in fridge C (7.9±0.5 °C, RH 85%), where the weight loss increased rapidly in the first 4 days and then remained stagnant during the rest of the storage period. Meanwhile, unpackaged salad in fridge A showed a linear increase of weight loss over the storage time.

4.2.2 Texture

Texture is one of the important attributes for fresh vegetables. Texture changes in most fresh-cut products have been found to be mainly determined by the rate of water transfer. The water that leaks from damaged cells will diffuse through the tissue, eventually leading to evaporation from the surface to the surrounding air (Artés, Gómez and Artés-Hernández, 2007). From the texturometer result, there were two parameters that could be used to analyze the result: maximum peak, which reflects the maximum force (g) needed to break the sample, and total area of peak, which expresses the total force (g) needed to break the sample. The higher force needed, the lower firmness and crispiness of salad because of high water loss from the cells, making it hard for the texture to break. On this basis, texture change and weight loss are interrelated.

Correlation test between weight loss and both texture parameters was performed prior to the analysis to decide which texture parameter would best describe the result. Maximum peak values showed slightly better correlation with weight loss (R=0.83) than total area of peak (R=0.81). Therefore, maximum peak values were chosen to be used to analyze the texture result for all experiments in this study.

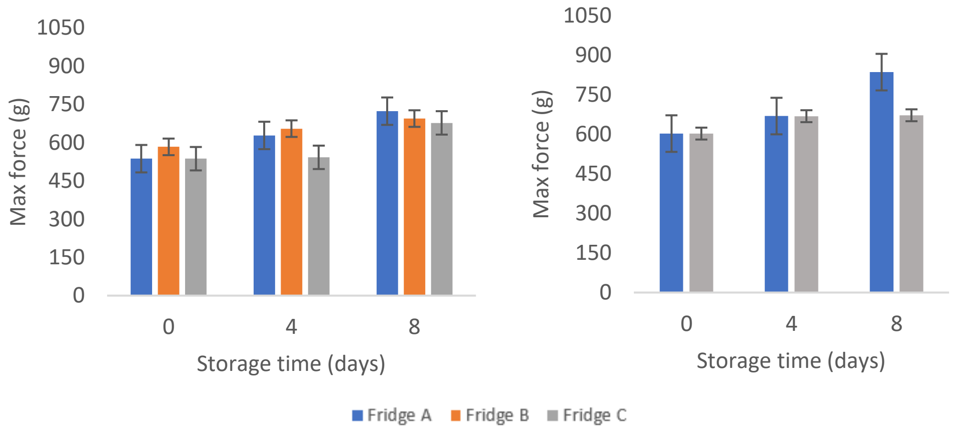


Figure 17 Average values of texture (including standard error) of two independent experiments of packaged (left) and unpackaged (right) salad cuts during 8 days storage in different fridges - Fridge A (3.3±0.6 °C, RH 78.5%); Fridge B (4.3±1.0 °C, RH 73%); Fridge C (7.9±0.5 °C, RH 85%)

Packaged salad stored in fridge A (3.3±0.6 °C, RH 78.5%) showed gradual increase of maximum force over time, followed by fridge B (4.3±1.0 °C, RH 73%), and the least was fridge C (7.9±0.5 °C, RH 85%). However, ANOVA test showed that the texture of packaged salad was not significantly different between all the fridges ($p>0.05$). Meanwhile for unpackaged salad, the peak rise was similar for fridge A and fridge C until day 4. The maximum force for breaking the salad stored in fridge

A, which had a lower temperature, dramatically increased on day 8, whereas it remained stagnant for salad stored in fridge C. ANOVA test showed that the texture of unpackaged salad was significantly different between fridge A and fridge C ($p<0.05$).

4.2.3 Condensation

Condensation is one of the quality deterioration phenomena that occurs during storage in the fridge, mainly in packaged products. In the package with saturated RH condition, transpiration occurs due to internal heat generation caused by respiration of lettuce. Whenever salad transpiration rate is higher than water vapor transmission rate, the water molecules that remains in the package will enhance the water vapor pressure, leading to water condensate formation (Volpe et al., 2017). The regression test showed that there is positive correlation between condensation amount and weight loss of packaged salad ($r=0.92$).

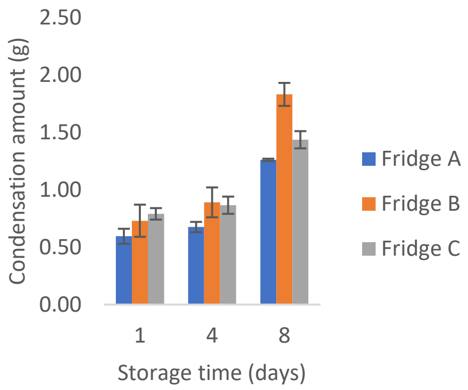


Figure 18 Average values of condensation build-up (g) inside the packaged salad (including standard error) of two independent experiments during storage in different fridges – Fridge A (3.3±0.6 °C, RH 78.5%); Fridge B (4.3±1.0 °C, RH 73%); Fridge C (7.9±0.5 °C, RH 85%)

From the graph (Fig. 18), it can be observed that the amount of condensation build-up increased over storage time for all samples. Packaged salad stored in fridge B, with the intermediate temp of 4.3±1.0 °C and RH 73%, showed the highest condensation amount among all with the significant increase on day 8. ANOVA test revealed that there was significant different of condensation amount between the fridges ($p<0.05$).

4.2.4 Vitamin C content

Romaine lettuce has the highest vitamin C concentration compared to other types of lettuce (Mou and Ryder, 2004). Therefore, its degradation during storage was analyzed in this study, as the degradation of vitamin C is a function over time (Zee et al., 1991). The comparison was done on vitamin C retention in salad on day 8.

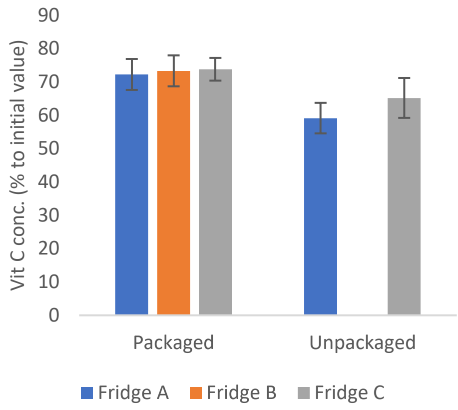


Figure 19 Average values of vitamin C concentration (% to initial content) (including standard error) of two independent experiments on day 8 in different fridges - Fridge A (3.3±0.6 °C, RH 78.5%); Fridge B (4.3±1.0 °C, RH 73%); Fridge C (7.9±0.5 °C, RH 85%)

It can be seen from the graph (Fig. 19) that packaged salad could retain the same percentage of vitamin C concentration up to 75% until day 8 in all fridges condition. Meanwhile, the retention was around 13-18% lower in unpackaged salad. Unpackaged salad stored in fridge C had slightly higher concentration than that in fridge A. However, ANOVA test showed that the vitamin C content was not significantly different between the fridge conditions for both packages.

4.3 Effect of relative humidity (RH) on lettuce quality

This stage was aimed to understand the effect of RH on lettuce quality. This stage was performed according to the first stage results, where it was observed that RH of fridge may have some effects on lettuce quality. Moreover, different fridges have different RH depending on its cooling system and the consumers are not able to change the setting for this parameter. Therefore, it is an important insight to understand how different fridges affect salad quality. Three fridges with different RH were used and the temperature was set to 5°C. As there was no specific temperature that can be considered as the best condition from the results of the previous stage, 5°C was selected because it is the closest temperature to factory setting of commercial fridges. It is also more commonly used by consumers for their fridge as compared to 2°C and 8°C based on the conducted online survey. Although the temperature for all fridges was set to 5°C, the actual storage condition for each fridge varied throughout the storage period. The average temperature and RH of each fridge used for this experiment is presented on Table 9.

Table 9 Average temperature and RH of each fridge used in second stage to analyze the salad quality in different RH conditions

	T (ºC)	RH (%)
Fridge D	3.25±2.4	21
Fridge E	4.4±0.3	56.5
Fridge F	5.6±1.6	82.5

Romaine lettuce cuts were packed in plastic bags and stored based on the most possible scenarios on how consumer store their salad in the fridge after they open it and started eating from it. According to the conducted survey, two of the most performed actions were either folding the top of the bag (where it was opened) or leaving the bag open in the fridge. For this experiment, the storage period was extended to 14 days to obtain higher level of quality deterioration. The quality parameters analyzed in this experiment were weight loss, texture, color change, condensation, and vitamin C content.

4.3.1 Weight loss

From the graph (Fig. 20), it can be seen that open bag lettuces had much higher weight loss than folded bag in all the fridges. Fridges with higher RH exhibited lower weight loss compared to low RH for open bag. On the contrary, folded bags appeared to have almost identical amount of weight loss in all the fridges. ANOVA test showed that there was no significant difference for weight loss of folded bags stored in different fridges ($p>0.05$), whereas open bags showed significant difference between the fridges ($p<0.05$).

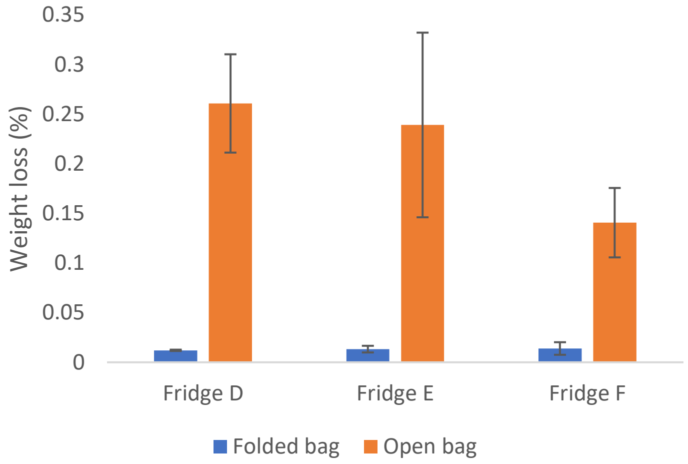


Figure 20 Average values of salad weight loss (including standard error) of two independent experiments on day 14 stored in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

Figure 21 described the weight loss of open bags during storage period. Fridge D (3.25±2.4°C, RH 21%), which had the lowest RH, showed higher level of weight loss, especially during the second week of storage. Meanwhile, lower rate of loss was observed on fridge F (5.6±1.6°C, RH 82.5%), which had the highest RH. The difference between fridges was small in the first week of storage, then it became larger during the remaining period, especially with fridge F. There was no significant difference between fridge D and fridge E ($p>0.05$) as it displayed similar rate throughout the storage period.

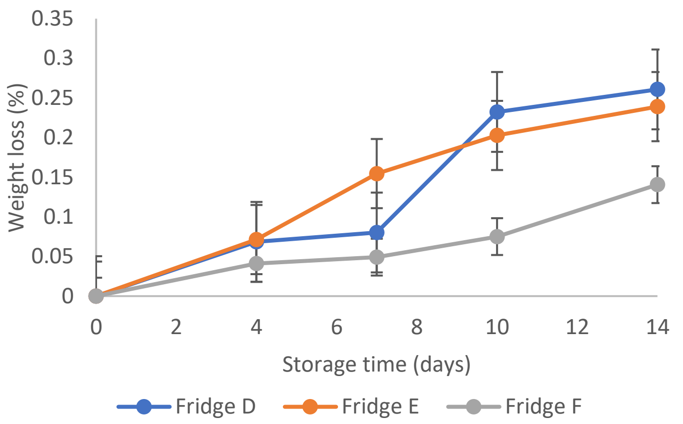


Figure 21 Average values of salad weight loss (including standard error) of two independent experiments stored in open bag during 14 days of storage period in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

4.3.2 Texture

According to the graph (Fig. 22), the force needed to break the samples generally increased during storage period in all fridges. The texture of open bags of salad stored in fridge D (3.25±2.4°C, RH 21%) and E (4.4±0.3°C, RH 56.5%) increased gradually until the end of storage period. Meanwhile, the change in fridge F (5.6±1.6°C, RH 82.5%) slowed down after the first week of storage. Different trends were observed for folded bags. The increase was seen on fridge E and fridge F, whereas fridge D did not show any increase after the first week of storage. However, ANOVA test revealed that there was no significant textural difference between salad stored in both open and folded bag in all the fridges. Meanwhile, there was significant difference over storage time for both packages in all the fridges, where it increased over time. Higher force means lower crispiness as the lettuce starts to lose its turgidity.

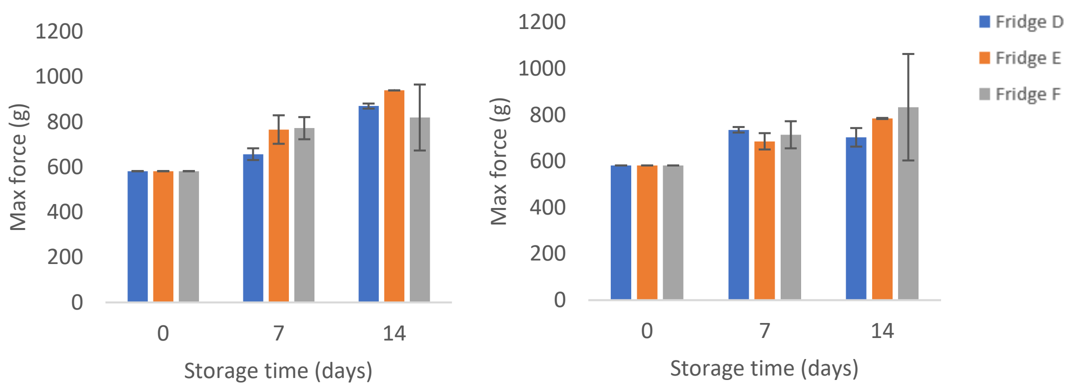


Figure 22 Average values of salad texture (including standard error) of two independent experiments stored in open bags (left) and folded bags (right) during storage of 14 days in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

4.3.3 Color change

The image of lettuce was captured using an imaging system, which then translated into Lab and browning values using MATLAB software to analyze the color change during storage. The color change is expressed in Δeab value, where higher value means higher level of change. From the graph (Fig. 23), it was found that salad stored in open bags and folded bags displayed similar trends of color change during storage, with higher value of Δeab in open bags. Fridge with lower RH exhibited higher level of change compared to its counterparts with higher RH for both open and folded bags.

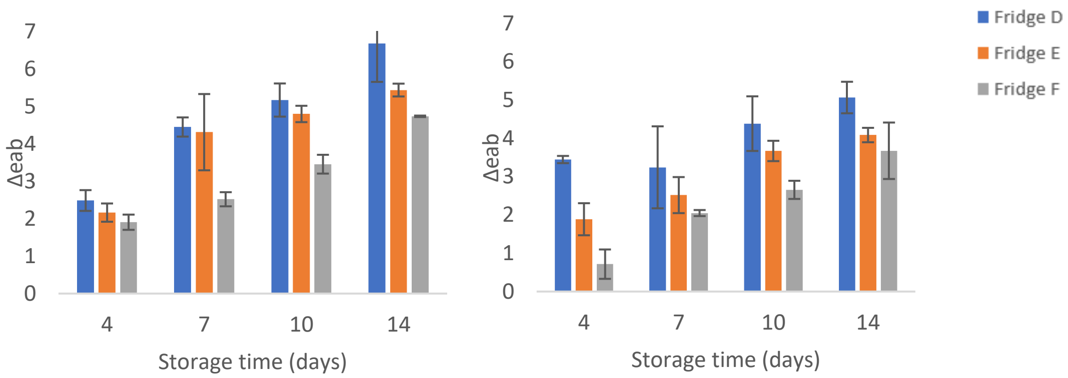


Figure 23 Average values of salad color change (including standard error) of two independent experiments stored in <u>open bag (left)</u> and <u>folded bag (right)</u> during 14 days of storage period in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

Browning on lettuce edges and surfaces was analyzed using a segmentation process by MATLAB and the result is expressed in percentage to total area of lettuce. From the graph (Fig. 24), higher degree of browning can be found on open bags stored in lower RH. The higher RH, the less browning formation on the leaves. On the contrary, salad with folded bag in fridge F (5.6±1.6°C, RH 82.5%) exhibited the highest level of browning. ANOVA test showed that there was no significant difference of browning between salad stored in all the fridges for both open and folded bags.

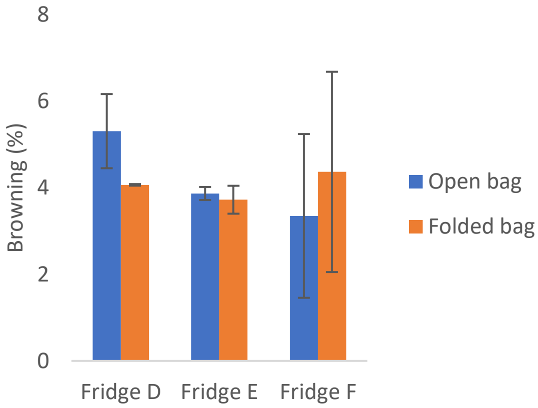


Figure 24 Average values of browning percentage (including standard error) of two independent experiments of open bag and folded bag on day 14 in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

4.3.4 Condensation

Based on the graph (Fig. 25), it was observed that the amount of condensate increased during the storage period. ANOVA test showed that there was significant difference between salad stored in different fridges for both open and folded bags ($p<0.001$). Another thing to notice is that the condensate amount inside the package of folded bag was generally higher than open bags. Condensate is formed when the rate of water vapor transfer rate (WVTR) is lower than transpiration rate. In open bags, the WVTR is more rapid than folded bags due to the existence of open space allowing water to evaporate to the surrounding air. However, this is very much affected by RH of surrounding air. Fridge F (5.6±1.6°C, RH 82.5%) had the highest RH, thus the water transfer rate would be much less than that with low RH. This resulted in the accumulation of condensate inside the package during storage period. As for folded bags, those stored in fridge F had the highest condensate amount compared to other. Even so, folded bags did not have open space that allow water to evaporate to the air, thus the transfer only occurred through the packaging film. In this case, other factors aside from RH are suspected to affect the condensation formation in folded bag. This will be further discussed in the discussion section of this chapter.

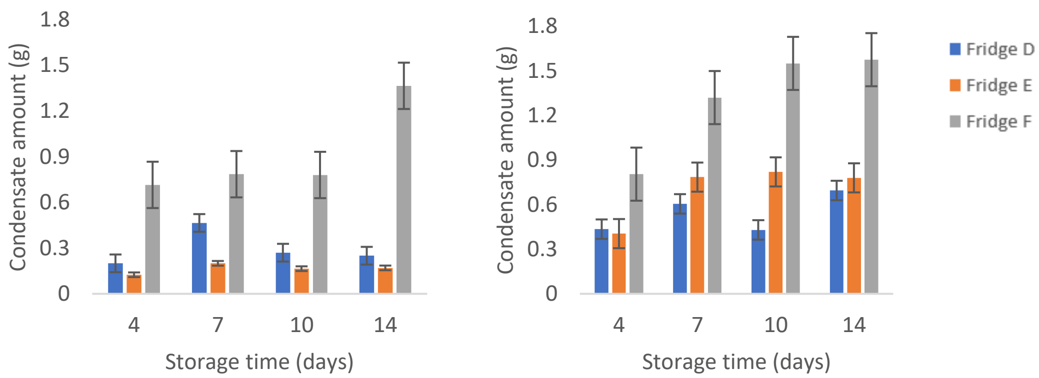


Figure 25 Average values of condensation build-up (g) (including standard error) of two independent experiments inside <u>open bags (left)</u> and <u>folded bags (right)</u> during 14 days of storage period in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

4.3.5 Vitamin C content

From the graph (Fig. 26), it was observed that open bags and folded bags showed a similar trend where salad stored in fridge D (3.25±2.4°C, RH 21%) had the highest vit. C concentration. Salad retained up to 60% of its vit C content during the two weeks storage in fridge D, whereas it was lower by around 10-20% in other fridges.

Aside from different RH, the actual temperature of the fridge may also affect the vit C retention as it is a temperature-sensitive compound. Fridge D had the lowest temperature among all fridges, thus the retention may be better in this temperature than other fridges. However, ANOVA revealed that the vitamin C content of salad stored in different RH was not significantly different (p>0.05).

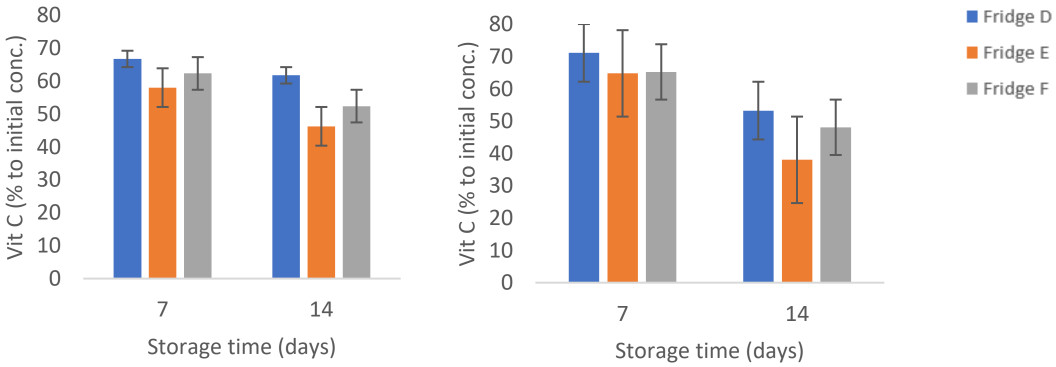


Figure 26 Average values of salad vitamin C content (including standard error) of two independent experiments stored in <u>open bags (left)</u> and <u>folded bags (right)</u> on day 7 and day 14 in different fridges - Fridge D (3.25±2.4°C, RH 21%); Fridge E (4.4±0.3°C, RH 56.5%); Fridge F (5.6±1.6°C, RH 82.5%)

4.4 Effect of different packaging on lettuce quality

The second objective of this study was *to understand the effect of different types of packaging on salad quality during* storage. Lettuce cuts packed in four different types of packaging were stored in the same Fridge G (5.2±2.8ºC, RH 74%) for 13 days to analyze the impact of different packaging on three quality parameters (weight loss, color change, and browning). From the data, weight loss was the parameter that showed the most significant difference (see Table 10). On day 13, it was observed that unpackaged lettuce had the highest weight loss and sealed bag had the least, with more than ten times less weight loss than unpackaged lettuce. The same result was observed for color change (Δeab) where the highest change occurred in unpackaged salad and the least in sealed bag. However, the value was slightly different for browning percentage. ANOVA test revealed that there was a significant difference between packages in weight loss and Δeab (p<0.001), whereas no significant difference was found in browning percentage (p>0.05).

Table 10 Evaluation result of salad stored in different packages on Day 13

	Weight loss (%)	Δeab	Browning (%)
Unpackaged	49.40	6.88	4.53
Open bag	21.01	6.46	4.96
Folded bag	7.57	4.98	4.16
Sealed bag	4.35	4.54	4.04

Further analysis was carried out to know whether a slight change of packaging affected the quality parameters of lettuce. Open and folded bag represented the most possible conditions on how consumers store the product after they open the package. The ANOVA test showed that there are significant differences in all defined quality parameters ($p<0.05$) for the lettuces stored in the two packages.

Figure 27 Lettuces stored in a) open bag; and b) folded bag on 13th day (samples were transferred to black tray for image analysis purpose)

Another performed comparison was on the unpackaged lettuce. Two boxes without lid were used to store the lettuce in the same fridge condition. These boxes have different height (3 cm difference), which was suspected to give different protection level for the lettuces due to different lettuces' surface area that were exposed to the air. Large exposed surface area of lettuce leaf prompts a higher level of dehydration, leading to rapid weight loss (Kays, 1991). However, the ANOVA test revealed that there is no significant difference ($p>0.05$) between the weight loss of tall box and short box during 8 days of storage (see Fig. 29). Both boxes showed similar trend of weight loss throughout the storage period.

Figure 28 Unpackaged lettuce stored in short box (left) and tall box (right) on day 0

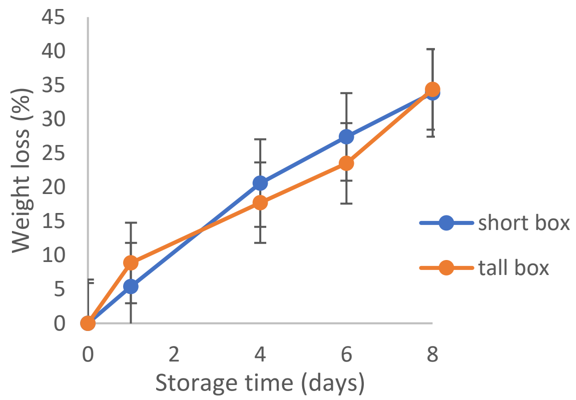


Figure 29 Average values of salad weight loss (including standard error) of two independent experiments stored in tall and short box without lids during 8 days storage

4.5 Consumer insights

An online survey was conducted internally within the company to obtain further insight about consumer behavior regarding bagged lettuce consumption and storage in household refrigerators. There were 81 responses recorded in total by the end of survey period. Overall, it was found that bagged lettuce is a popular packaged product with a majority of respondents being regular consumers of it. The consumers have similar perceptions on salad visual quality, but different behaviors on product treatments, such as way of storing in the fridge and attention to best before dates.

After opening the package, about 56% of consumers store the bagged salad by folding the top of the plastic bag while storing in the fridge, whereas 21% leave the bag opened. The remaining respondents said that they either move the salad to food container or use clipper to reseal the bag.

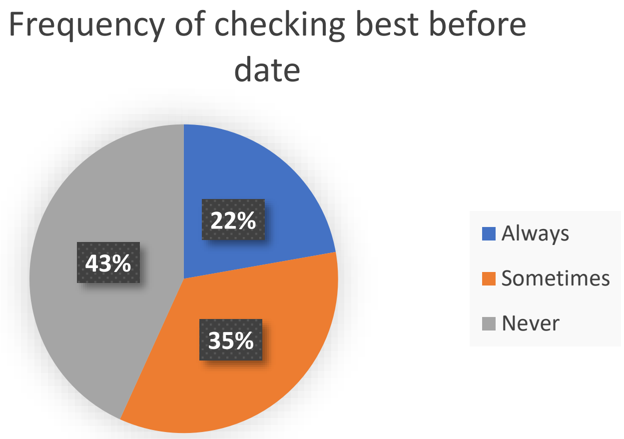


Figure 30 Consumer frequency on checking best before date of bagged lettuce

The next question was related to best before date of bagged lettuce. Almost half of the total respondents said that they never check the best before date (see Fig. 30). Only around 22% always check the date, while the remaining respondents check it sometimes. Another question was related to the consumers' reaction when they find out that the salad is past its best before date. Almost 25% of consumers do not care about it and they only rely on their personal judgements, whereas the rest of consumers will separate the ones that still look good and throw the rest that look bad. Only around 6% of consumers throw the salad right away without further judgement on its quality. This implies that most consumers understand the meaning of best before date, which is about the quality of product. The date tells consumers that the salad is still safe to eat after the date, but it may not be at its best quality (e.g. color, flavor, texture) (Food Standard Agency UK, 2018).

Figure 31 Images of salad in different qualities provided in the questionnaire

On the next section, five images of salad cuts in different quality were provided (Fig. 31). Based on the visual quality, respondents were asked to select the action that they would do on each tray, whether they would eat everything, select the good ones to eat and throw the rest, or throw everything. All the consumers would eat everything on tray 1 as they perceive that the quality is good. However, the number decreased to 80.5% of consumers who would eat everything on tray 2. The remaining consumers start to select the good ones and throw the rest as it appeared that slight browning starts to occur on tray 2. As the browning gets more severe on tray 3, consumers' actions also shift drastically where majority of consumers will select the good ones to eat and throw the rest, whereas only 8% will eat everything. One-fourth of total respondents chose to throw everything starting from tray 3. The number of consumers throwing everything increases up to 72% for tray 4, while the rest will still select the good ones to eat. About 88% of consumers will throw everything when they find salad on tray 5.

Table 11 Consumer perception towards condensation amount on bagged salad

Image of bagged salad with condensation	**Average level of annoyance (1-not at all, 5-very annoyed)**
 High amount of condensation	**2.85** (slightly annoyed)

 Medium amount of condensation	**2.37** (neutral)
 Low amount of condensation	**1.44** (not annoyed)

In the next questions, consumers' responses regarding the reaction on salad bags with condensation, were observed. Three images with different amount of condensation were given in the questionnaire and the respondents were asked to rate the degree of annoyance from 1 (not annoyed at all) to 5 (very annoyed) for each amount of condensation. As seen in Table 3, the average score for the highest condensation amount is 2.85, just slightly above middle point. Meanwhile, the score is very low for low amount of condensation, meaning that the consumers are not annoyed. From the responses, it was observed that in general, consumers are not really bothered about the formation of condensates in the package. Some comments in the open question in the end of questionnaire mentioned that they did not understand why they were asked about condensation in the package, as it is considered as a normal phenomenon. However, there were also few respondents that considered condensation as an important quality parameter.

The next section was dedicated for understanding consumer behaviors regarding usage of fridge. Respondents were asked about the temperature of their fridges at home. The answers varied from 2^{o}C to >8^{o}C. Interestingly, about 21% of respondents do not know about their fridge temperature. This is lower than reported by Marklinder et al. (2004), where they found that up to 76% of Swedish consumers did not know their fridge temperature. This showed that there is an increase of consumers knowledge on their home appliances as compared to in 2004. However, the respondents of this survey are Electrolux employees who are most likely more knowledgeable about home appliances than regular consumers. Majority of respondents set their fridge at 4ºC, which is also the factory setting of European household refrigerator at Electrolux.

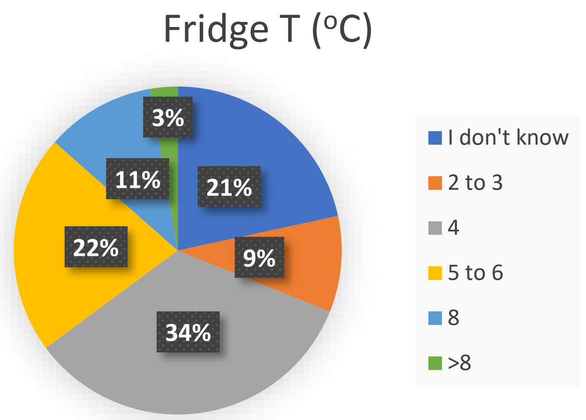


Figure 32 Temperature setting of consumers fridge

Respondents were also asked where they store the bagged salad in fridge. Up to 80% of respondents store it in the crisper, while another 16% store in chiller shelves. Based on this result, it was observed that most consumers understand the function of compartments in the fridge. Crisper is designed to prolong the shelf-life of fruits and vegetables. The humidity can be regulated by controlling the amount of space in drawers left open for airflow (Steed, 2016). It is commonly used for storing fresh fruits and vegetables. However, if bagged salad is not open yet, it can be stored in other compartment, such as the chiller shelves. Plastic film can provide protection for the salad as long as it is kept sealed, as what this study has proven in the result.

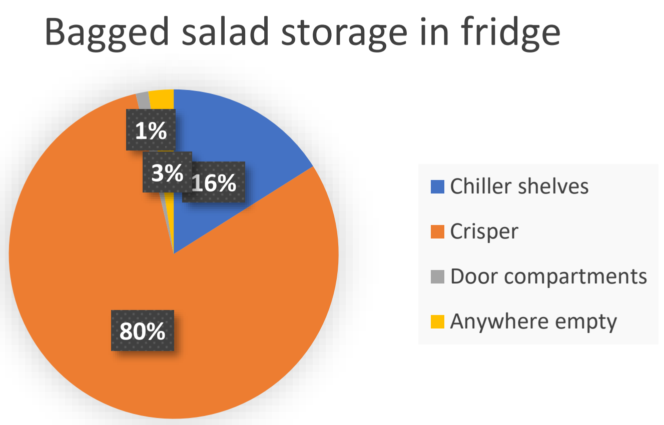


Figure 33 Survey result on where consumer store bagged salad in the fridge

Last question in the questionnaire was an open question related to consumers personal experience with bagged salad consumption and storage. Many respondents complained about that the salad quality does not last long after the bag is opened. Some tried to slow down the deterioration process by moving the salad to a food container and placing paper below the salad to absorb excess moisture. Other complaints about bagged salad were the use of plastic, which is considered as non-environmentally friendly, and the safety of salad cuts as the consumers link it to bacteria contamination. This is understandable as several outbreaks related to bagged salad consumption occurred worldwide, such as outbreak of *E.coli* infection linked to bagged romaine lettuce consumption in several states in USA in Dec 2019 (Centers for Disease Control and Prevention, 2020). As a result of bad image of bagged salad, some respondents said that they prefer fresh intact lettuce over bagged salad cuts to be consumed. Some suggestions given were related to storage system in the fridge. Few respondents demanded for more information or symbols in the fridge to inform where to place the products accordingly and some others felt that the current cooling system is not enough to preserve bagged salad quality.

4.6 Discussion

The preliminary stage of this research revealed the importance of initial quality of lettuce cuts in determining the deterioration level during storage. Lettuce that has more damaged tissues will undergo more severe and more rapid deterioration process than that with less damage. It also proved that the quality preservation is a challenging issue as soon as the packaging of commercial bagged lettuce is opened and the modified atmosphere condition is broken. The latter stages explained how temperature, RH, and packaging play important roles in determining lettuce quality during the storage phase in consumers' fridge.

The first stage was aimed to assess the effect of different fridge temperatures (2^{o}C, 5^{o}C, and 8^{o}C) on several quality parameters of salad stored in packaged and unpackaged bag. From the summary of results obtained in this stage (see Table 12), it can be seen that weight loss, texture, and condensation are the quality parameters that were affected by different storage temperatures.

Table 12 ANOVA summary of salad stored in fridges with different temperatures

	Packaged	Unpackaged
Weight loss	**	*
Texture	ns	*
Vitamin C	ns	ns
Condensation	*	-

ns = not significant p>0.05; *= significant p<0.05; **= significant p<0.01; star means significant difference value of salad stored in 3 different fridges (for packaged) or 2 different fridges (for unpackaged)

Second stage was aimed to evaluate the effect of different RH on several quality parameters of salad stored in open and folded bag. From Table 13, it was found that the quality parameters affected by relative humidity were weight loss, condensation, and color change.

Table 13 ANOVA summary of salad stored in fridges with different RH for 13 days

	Open bag	Folded bag
Weight loss	*	ns
Texture	ns	ns
Vitamin C	ns	***
Condensation	***	**
Color change	**	***
Browning	ns	ns

ns = not significant p>0.05; *= significant p<0.05; **= significant p<0.01; ***= significant difference p<0.001; star means significant difference value of salad stored in 3 different fridges

Weight loss was observed to be the highest on salad stored at 5ºC and the lowest at 8ºC. This result is in contrast with Lineberry (2011) who reported that romaine lettuce lost more moisture at 7ºC than 5ºC at 75% RH. Manolopoulou et al. (2010) also reported that salad stored at 5ºC has higher weight loss than 0ºC, although the difference was not significant. Meanwhile from the second stage, it was observed that weight loss was significantly affected by relative humidity, especially in the open bags. Open bags provided space for interaction between salad and the air. Salad that was located in the top part of the package had higher exposure to the air, making it drier compared to the one located in the bottom of the package. With this reason, RH inside the fridge will affect the rate of water loss. This finding is in agreement with Lineberry (2011) who found that lower RH resulted in higher moisture loss in romaine lettuce stored at the same temperature. In contrary with open bags, folded bags did not allow the interaction between salad and the surrounding air inside the fridge, thus restricting water loss to occur. Therefore, it had very low weight loss (<0.02%) and it was not affected by RH as there was no significant difference between the fridges.

Texture was found to not be significantly affected by temperature and relative humidity in this study. However, the firmness decreased over storage time in all conditions. This is in agreement with Manolopoulou et al. (2010) who reported that no significant difference of mean force was found between storage at 0ºC and 5ºC.

Nevertheless, positive correlation test between texture and weight loss proved that both parameters are directly related with each other, as similarly reported by several authors (Cantwell, 2004; Raffo et al., 2007; Martínez et al., 2008). The midrib part was used as the texture indicator because of its firmer texture as compared to leaf part that gets wilted rapidly. The method used was considered to have low sensitivity, as sometimes there were part of lettuce that got wilted severely (generally the leaf part) and the midrib part that was still firm. This method did not really represent the whole texture deterioration of lettuce, which could best explain the low sensitivity of the method.

Condensation was noticed to be significantly affected by temperature and relative humidity. In the first stage, it was found that the highest amount of condensate appeared in the packaged salad stored at 5ºC (fridge A). Linke and Geyer (2012) revealed that higher temperature fluctuation resulted in higher intensities of condensate formation on fruit surfaces. Looking at the actual temperature profile of all the fridges in this stage, fridge B had the highest temperature fluctuation (±1.0ºC) as compared to fridge *A* and fridge C, which proved the argument of Linke and Geyer (2012). Meanwhile for RH effect, it was observed from the second stage results that relative humidity played an important role in determining the condensation amount. Lower RH resulted in less amount of condensate, as it accelerated the transfer rate of moisture produced by transpiration to surrounding air. According to this result, temperature fluctuation was not the major cause of condensation formation, as the trend was slightly different with the previous stage. Based on the actual fridge condition, it was found that the condensation was higher on fridge with higher temperature, although its fluctuation was not necessarily the highest as well. This result implied that temperature, its fluctuation, and relative humidity are the combination of storage conditions that affect the condensation phenomenon in bagged salad.

Color change was an important visual quality parameter that showed significant difference in different relative humidity condition. The result showed that color change was higher in a lower RH condition. Similarly, Agüero et al. (2011) also reported that lower RH resulted in higher chlorophyll loss, resulting in yellowing or green discoloration. Higher water loss due to low RH could contribute to chlorophyll loss due to water movement. Other influencing factor for lettuce discoloration is oxygen level, which leads to the formation of browning. From the result, it was found that browning was not influenced by RH.

The comparison of packaging types revealed that there was a huge difference in weight loss of salad between that stored in sealed bag and without package. This outcome is quite obvious since lettuce that has no protection will have higher transpiration rate, resulting in higher turgidity loss of the leaves. The more barrier exists between the leaves and the surrounding air, the less moisture transfer will occur. This allows the leaves to maintain its texture throughout the storage period. The same thing applies for color change parameter. The more lettuces are exposed to oxygen in the air, the more enzymatic browning and chlorophyll degradation may occur. Interaction between phenolic compounds in lettuce and oxygen leads to oxidation process, which is especially increased due to wounded tissues on lettuce cuts (Brecht et al., 2003). This result is in accordance with Manolopoulou et al. (2010) which showed that packaging reduced weight loss at temperature of 0^{o}C to 5^{o}C.

Other performed analysis is the comparison between salad storage after the bag is opened from consumer’s perspective. Lettuces stored in the folded bag had three times less weight loss, better color retention, and lower browning formation as compared to open bag. This is an important insight for the consumers as it proved that a small action of folding the bag can preserve the freshness quality of lettuce better than just leaving the bag opened in the fridge.

Bagged salad is a popular packaged ready-to-eat product, but the quality preservation at consumer’s home remains a problematic and challenging issue as there are still a lot of complaints from consumers related to its short shelf-life after the bag is opened. The survey revealed that consumers are getting better in storing the product in their fridge. Majority of respondents follow the recommended fridge temperature from authority (below 5^{o}C) and they know where to place the vegetables properly.

The questions related to visual assessment and condensation acceptance were asked to understand the consumers perception about salad quality. The visual assessment question revealed the importance of color on salad quality perception as consumers link browning to bad quality. Color is an important attribute in vegetable’s quality (Jung et al., 2012). The responses for both questions also showed that the quality perception varies among individuals. Péneau et al., (2006) reported that quality perception is affected by individual background, such as age, gender, consumption habits, and knowledge on the product. Becht et al. (2001) also reported that individual experiences and learning process are the factors that determine quality perception. It can best explain why the variation exists in the visual acceptance of salad images in this survey. Consumers are more confident in judging the quality of lettuce, as most respondents do not follow best before date strictly. It is presumably due to rising awareness on food waste issue as the campaign of food waste reduction has been actively done by Swedish government to reach the sustainable development goal 2030 to halve the global food waste (Livsmedelsverket, 2018).

5 Conclusions and recommendations

The conclusions drawn from this study are based on the designed research questions and objectives:

To evaluate the impact of storage on several freshness quality parameters in different fridge conditions focusing on: temperature and relative humidity (RH)

- The following quality parameters were affected by both temperature and RH: weight loss and condensation. Meanwhile, texture was affected by only temperature and color change was affected by only RH. Vitamin C and browning were not affected by temperature nor RH.
- Higher RH was more favorable for salad storage with better retention of the following quality parameters: color change and weight loss
- It was not possible to pinpoint the most optimum temperature because there was no noticeable trend in the observed quality parameters

To understand consumer behaviors on salad storage and the effect of different packaging scenarios on salad's quality degradation

- Different types of packaging provided different level of protection on salad quality, with sealed bag provided the highest protection and unpackaged provided the least. Higher exposure to oxygen resulted in higher deterioration rate of salad quality
- By folding the salad bag during storage in the fridge after the package is opened, salad freshness quality can be preserved much better than just leaving the bag opened
- The perception of salad quality varied between individuals, but the majority have similar perception on bad visual quality linked to color change of lettuce

The most important question after the completion of this study is: **how can the obtained data be best used by salad producers, packaging companies, and fridge manufacturers?**

From this study, it was clear how different salad preparation methods can give different impact to the quality of fresh-cut products. It is important for the salad producer to carefully design the production line to minimize the damage to plants tissues as much as possible. There has been existing research related to how different kinds of knifes will result in different severity of lettuce damage. Further research can be done to find out the most suitable type of cutting process that can provide better cuts quality and uniformity, as it was found that the current existing commercial bagged lettuce did not have uniform cuts and already showed early stage of quality deterioration when purchased in the store. Another thing to consider is to reduce the portion size to a single-serving portion. The survey results showed that most people do not finish the bag in one consumption, thus they have to re-seal the product and store in the fridge. This increases the risk of food waste as salad goes bad easily when the packaging barrier has been broken.

The packaging company may consider redesigning the packaging to give better protection for salad during storage after the bag is opened. Making the packaging to be easily resealable, such as adding zipper or removable tape, is an alternative of preserving salad quality during storage at home. Information and recommendation to consumer to be more cautious in storing the bagged salad should also be provided on the packaging label. This information can be provided in a form of graphical information, with picture and brief explanation on why plastic is the best material to protect the salad and prevent food waste as it was observed from the survey that some consumers complained about the use of plastic. There is clearly a lack of understanding from consumers about the danger of food waste to environment, thus this message should be clearly delivered on the packaging.

For the fridge company, the data obtained in this study can be used as a starting point to design freshness scorecard as a guideline on how to assess salad quality during storage. However, more repetition of experiments is needed as the number of experiments performed in this study were too limited. Different types of bagged fresh cuts can further be observed, preferably that with different characteristic, such as rocket salad and carrot slices, to provide a more complete, overviewing portrayal on the behavior change of bagged fresh cuts during storage in a household fridge. Deeper analysis on the quality change of salad stored in crisper can also be performed, as only chiller shelves were used in this study. Thorough studies in this topic can help the company in assessing whether current cooling system and fridge design are sufficient in preserving the freshness quality of fresh cut products. More information related to the use of each compartment in the fridge should be provided to consumers as it was seen from the survey that there is still some confusion on how to store food properly in the fridge.

Future research recommendation

The comparison of packaging type in this study was based on the most possible actions taken by consumer on bagged salad storage after opening the packages. As further development on resealable salad bag has been done (such as zipper or tape), it might be interesting to compare the effectivity of such packaging with the current ways of storing salad in the fridge. Further research may include modified atmosphere to better mimic the real condition of commercial bagged lettuce, as it was not possible to do so in this study.

The lettuce used in the experiments were self-prepared and may not reflect the real condition of commercial fresh-cut lettuce. It is recommended to cooperate with salad producer to obtain lettuce cuts that are produced in the plant. The damages that lettuce have affect the deterioration rate during storage in the fridge, thus getting the samples from salad industry will give better portrayal of the actual problems that consumers face. Sourcing the samples directly from salad company can also help increasing the uniformity of initial lettuce cuts quality based on the production batch (better than buying lettuce cuts in retailer).

Microbiological assessment might be conducted in the future research as it is one of the major concern of consumers. Various outbreaks that occurred in the past affect the consumer behaviors in salad consumption, especially when they link the color change to food safety, thus making them feel insecure to consume the salad. The information of microbiological quality of salad during storage in the household fridge would be a valuable insight for salad company, fridge manufacturers, and consumers to have better understanding in salad quality assessment and to determine more appropriate actions on salad storage and consumption.

6 References

Agüero, M., Ponce, A., Moreira, M. and Roura, S., 2011. *Lettuce quality loss under conditions that favor the wilting phenomenon*. Postharvest Biology and Technology, 59(2), pp.124-131.

Andersson, E., 2020. *Bagged Lettuce in Retailers*.

Artes, F., Martinez, J. and Marin, J., 1999. *Quality Changes in Minimally Processed Romaine Lettuce as Affected by Several Treatments*. In: M. Hagg, R. Ahvenainen, A. Evers and K. Tiilikkala, ed., *Agri-Food Quality II - Quality Management of Fruit and Vegetables*, 1st ed. Helsinki: Woodhead Publishing.

Artés, F., Gómez, P. and Artés-Hernández, F. (2007). *Physical, Physiological and Microbial Deterioration of Minimally Fresh Processed Fruits and Vegetables*. Food Science and Technology International, 13(3), pp.177-188.

Artés, F. and Allende, A., 2015. *Chapter 31 - Minimal Processing of Fresh Fruit, Vegetables, and Juices*. In: D. Sun, ed., Emerging Technologies for Food Processing, 2nd ed. [online] Dublin: Elsevier Ltd., pp.583-597.

Bech, A.C., Grunert, K.G., Bredahl, L., Juhl, H.J., Poulsen, C.S., 2001. *Consumer's quality perception*. In: Frewer, L.J., Risvik, E., Schifferstein, H. (Eds.), Food, People and Society: A European Perspective of Consumers' Food Choices. Springer, Berlin, pp. 97–113.

Berkeley Wellness, 2020. *Brown Lettuce*. [online] Berkeley Wellness. Available at: <https://www.berkeleywellness.com/healthy-eating/food-safety/article/brown-lettuce> [Accessed 19 May 2020].

Cantwell, M., 2004. *Recommendation for Maintaining Post-Harvest Quality*. [online] Bell Pepper. Available at: <http://postharvest.ucdavis.edu/Produce/ProduceFacts/ Veg/pepper.shtml> [Accessed 13 May 2020].

Castañer, M., Gil, M., Artes, F. and Tomas-Barberan, F. (1996). *Inhibition of Browning of Harvested Head Lettuce*. Journal of Food Science, 61(2), pp.314-316.

Centers for Disease Control and Prevention, 2020. *Outbreak of E. Coli Infections Linked To Romaine Lettuce*.

Degl'Innocenti, E., Pardossi, A., Tognoni, F. and Guidi, L. (2007). *Physiological basis of sensitivity to enzymatic browning in 'lettuce', 'escarole' and 'rocket salad' when stored as fresh-cut products*. Food Chemistry, 104(1), pp.209-215

Dincer, I. (2003). *Refrigeration Systems and Applications*. West Sussex: John Wiley & Sons, Ltd.

FDA (2010). *Program Information Manual Retail Food Protection: Recommendations for the Temperature Control of Cut Leafy Greens during Storage and Display in Retail Food Establishments*.

Food Standard Agency UK, 2018. *Best Before and Use by Dates*.

Garande, V. and Patil, R., 2014. *Technology of minimally processed fruits & vegetables*. In: 3rd International Conference on Agriculture & Horticulture. Hyderabad.

Goldschmidt, B., 2018. *Limiting the Impact of the Romaine Lettuce Recall. [online] Progressive Grocer*. Available at: <https://progressivegrocer.com/limiting-impact-romaine-lettuce-recall> [Accessed 12 May 2020].

Granryd, E., Ekroth, I., Lundqvist, P., Melinder, Å., Palm, B. and Rohlin, P. (2005). *Refrigerating engineering*. Stockholm: Royal Institute of Technology - Department of Energy Technology.

Harrington L. (2009). *A new global test procedure for household refrigerators*, proceedings at the 5th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'09).

James, C., Onarinde, B. and James, S. (2016). *The Use and Performance of Household Refrigerators: A Review*. Comprehensive Reviews in Food Science and Food Safety, 16(1), pp.160-179.

Jung, Y., Padmanabahn, A., Hong, J., Lim, J. and Kim, K., 2012. *Consumer freshness perception of spinach samples exposed to different storage conditions*. Postharvest Biology and Technology, 73, pp.115-121.

Kays, S. J. (1991). *Postharvest physiology and handling of perishable plant products*. New York: Van Nostrand Reinhold Inc.

Ke, D. and Saltveit, M. (1989). *Wound-induced ethylene production, phenolic metabolism and susceptibility to russet spotting in iceberg lettuce*. Physiologia Plantarum, 76(3), pp.412-418.

L.C. Supplies. 2020. *Iceberg Lettuce 10-12*. [online] Available at: <https://www.lcsupplies.co.uk/iceberg-lettuce-9-12-class-1.html> [Accessed 12 May 2020].

Lineberry, K., 2011. *The Impact of Household Refrigerator Storage Conditions on The Shelf Life Of Fruits And Vegetables*. Ph.D. Iowa University.

Livsmedelsverket, 2018. *Government Commission to Reduce Food Loss and Waste*. [online] Available at: <https://www.livsmedelsverket.se/en/matvanor-halsa--miljo/ta-hand-om-maten-minska-svinnet/food-waste-reports> [Accessed 13 May 2020].

López-Gálvez, G., Peiser, G., Nie, X. and Cantwell, M. (1997). *Quality changes in packaged salad products during storage*. Zeitschrift fr Lebensmitteluntersuchung und -Forschung A, 205(1), pp.64-72.

Marklinder, I., Lindblad, M., Eriksson, L., Finnson, A. and Lindqvist, R., 2004. *Home Storage Temperatures and Consumer Handling of Refrigerated Foods in Sweden*. Journal of Food Protection, 67(11), pp.2570-2577.

Martin-Belloso, O. and Soliva-Fortuny, R. (2006). *Effect of modified atmosphere packaging on the quality of fresh-cut fruits*. Stewart Postharvest Review, 2(1), pp.1-8.

Martin-Belloso, O. and Soliva Fortuny, R. (2011). *Advances in Fresh-Cut Fruits and Vegetables Processing*. Boca Raton: CRC PRESS.

Martínez, J., Chiesta, A. and Tovar, F. (2005). *Respiration rate and ethylene production of fresh cut lettuce as affected by cutting grade*. Agricultural and Food Science, 14(4), p.354.

Martínez-Sánchez, A., Tudela, J., Luna, C., Allende, A. and Gil, M. (2011*). Low oxygen levels and light exposure affect quality of fresh-cut Romaine lettuce*. Postharvest Biology and Technology, 59(1), pp.34-42.

Martínez, I., Ares, G. and Lema, P., 2008. *Influence of Cut and Packaging Film on Sensory Quality of Fresh-Cut Butterhead Lettuce (Lactuca Sativa L., Cv. Wang).* Journal of Food Quality, 31(1), pp.48-66.

Nag, O., 2017. *World Leaders in Lettuce Production*. [online] World Atlas. Available at: <https://www.worldatlas.com/articles/world-leaders-in-lettuce-production.html> [Accessed 4 May 2020].

Nunes, M. (2008). *Color atlas of postharvest quality of fruits and vegetables*. Oxford, UK: Blackwell Pub.

Paull, R. (1999). Effect of temperature and relative humidity on fresh commodity quality. *Postharvest biology and technology, 15(3),* 263-277.

Prieto, C., 2020. *Bagged Salad Production*.

Raffo, A., Baiamonte, I., Nardo, N. and Paoletti, F., 2006. *Internal quality and antioxidants content of cold-stored red sweet peppers as affected by polyethylene bag packaging and hot water treatment.* European Food Research and Technology, 225(3-4), pp.395-405.

Radermacher, R. and Kim, K. (1996). *Domestic refrigerators: recent developments. International Journal of Refrigeration*, 19(1), pp.61-69.

Robertson, G. (2012). *Food packaging*. 3rd ed. Boca Raton, FL: CRC Press, p.26.

Rojas-Graü, M., Oms-Oliu, G., Soliva-Fortuny, R. and Martín-Belloso, O., 2009. *The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: a review*. International Journal of Food Science & Technology, 44(5), pp.875-889.

Saltveit, M. (2000). *Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock*. Postharvest Biology and Technology, 21(1), pp.61-69.

Saltveit, M. (2003). *Fresh-Cut Vegetables*. Bartz, J.A. and Brecht, J.K. (Eds.), Postharvest Physiology and Pathology of Vegetables (pp. 691-712). New York, US: Marcel Dekker Inc.

Steed, M., 2016. *Choosing the Right Crisper Drawer in The Refrigerator*. [online] Iowa State University - Extension and outreach. Available at: <https://blogs.extension.iastate.edu/answerline/2016/09/22/choosing-the-right-crisper-drawer-in-the-refrigerator/> [Accessed 11 May 2020].

Tomás-Barberán, F. and Espín, J. (2001). *Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables*. Journal of the Science of Food and Agriculture, 81(9), pp.853-876.

Trkulja, Aleksandar. CEO at Pacsystem AB, Helsingborg, Sweden. Conversation through video call (2020, 30 January)

Uhlig, E., Olsson, C., He, J., Stark, T., Sadowska, Z., Molin, G., Ahrné, S., Alsanius, B. and Håkansson, Å. (2017). *Effects of household washing on bacterial load and removal of Escherichia coli from lettuce and "ready-to-eat" salads*. Food Science & Nutrition, 5(6), pp.1215-1220.

Volpe, S., Mahajan, P., Rux, G., Cavella, S. and Torrieri, E. (2018). *Condensation and moisture regulation in packaged fresh-cut iceberg lettuce*. Journal of Food Engineering, 216, pp.132-137.

Watada, A. and Qi, L. (1999). *Quality of fresh-cut produce*. Postharvest Biology and Technology, 15(3), pp.201-205.

Yildiz, F. and Wiley, R., 2017. *Minimally Processed Refrigerated Fruits and Vegetables*. Springer Science+Business Media.

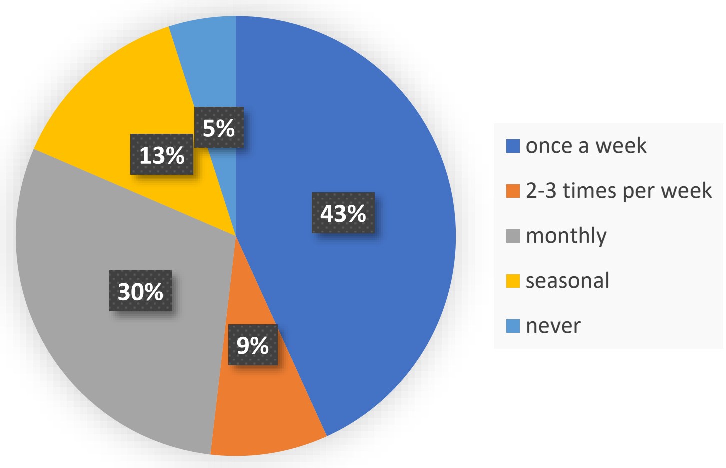
Zee, J., Carmichael, L., Codère, D., Poirier, D. and Fournier, M., 1991. *Effect of storage conditions on the stability of vitamin C in various fruits and vegetables produced and consumed in Quebec*. Journal of Food Composition and Analysis, 4(1), pp.77-86.

Zizi, F., 2010. *Refrigerator's Air Circulation and Humidity*. [online] Ezine articles. Available at: <https://ezinearticles.com/?Refrigerators-Air-Circulation-and-Humidity&id=3657755> [Accessed 22 April 2020].

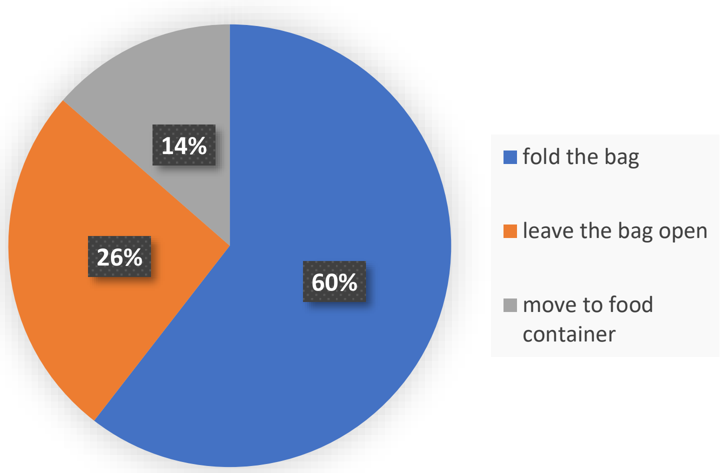
7 Appendix

Questionnaire questions and results

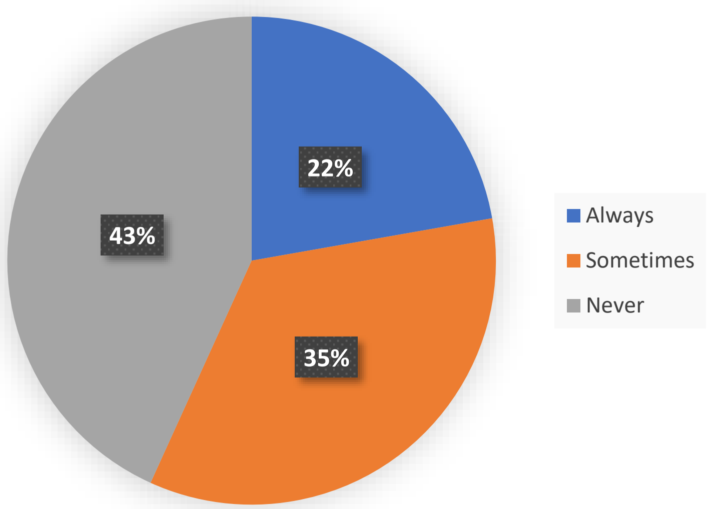
1. How often do you purchase bagged lettuce cuts?



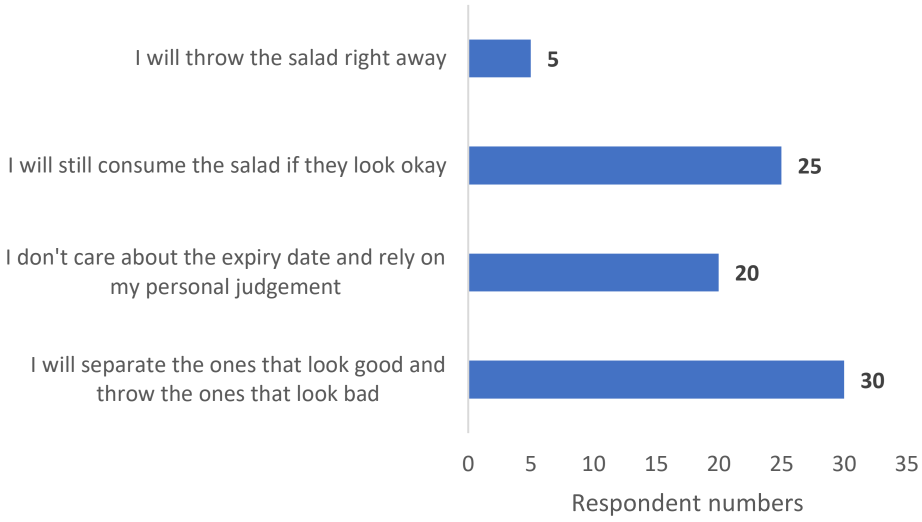
2. How do you normally store the unfinished bag of salad in the fridge?



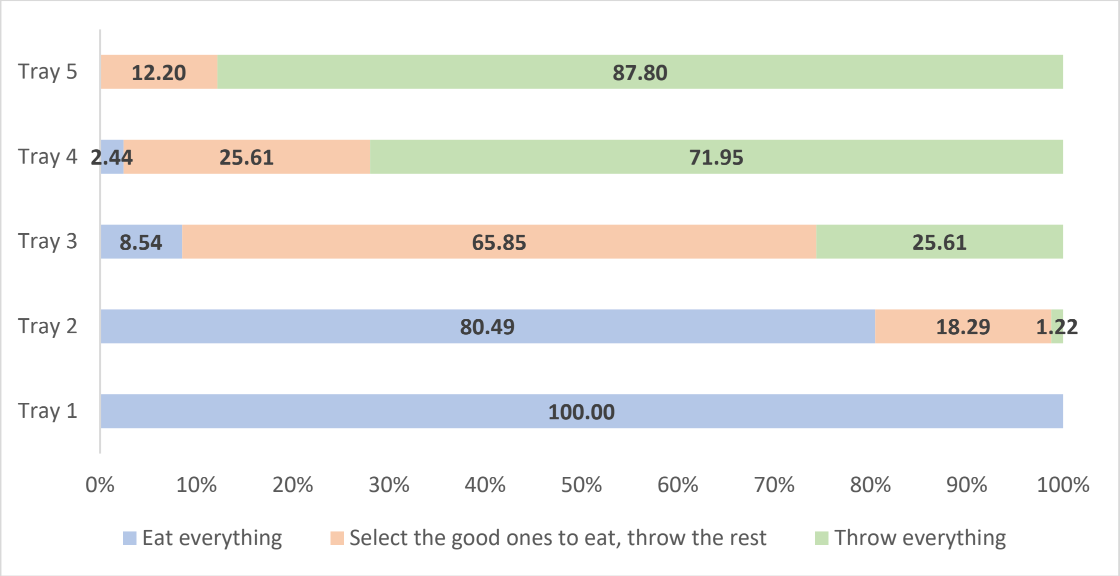
3. **Do you check the best before date of bagged lettuce on the package?**



4. **You have an unfinished bag of lettuce, then you realize that it's already past the expiry date. What do you normally do?**



5. **Based on visual comparison, select the action that you would most likely do on the specified tray (from left to right)**



6. **If you see this much condensation inside a bagged lettuce. How annoyed are you? (1-not at all annoyed to 5-extremely annoyed)**

Average number: **2.85**

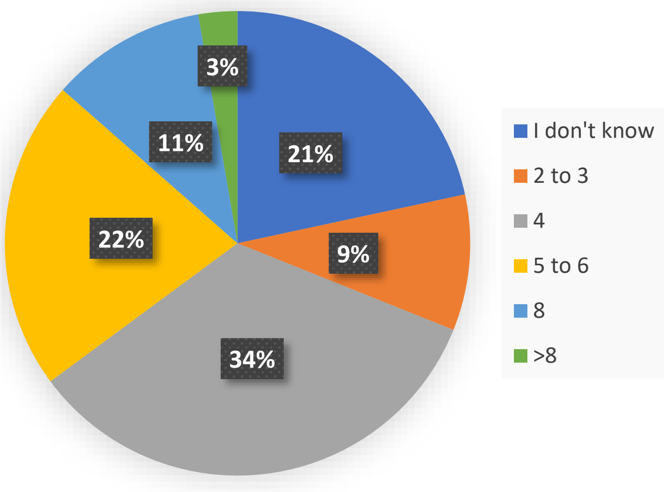
7. **If you see this much condensation inside a bagged lettuce. How annoyed are you? (1-not at all annoyed to 5-extremely annoyed)**

Average number: **2.37**

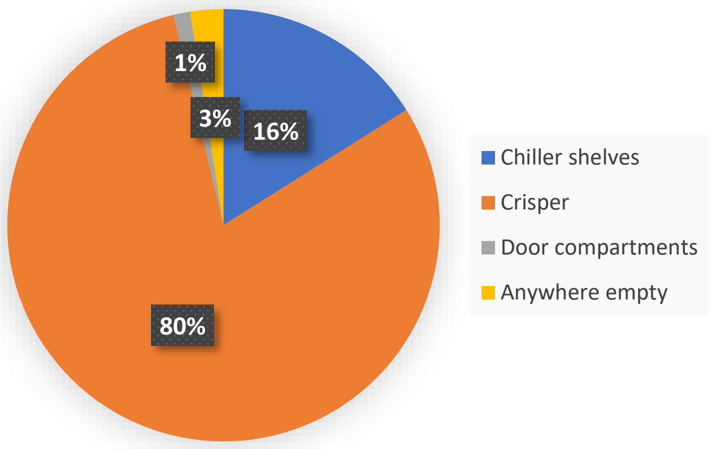
8. **If you see this much condensation inside a bagged lettuce. How annoyed are you? (1-not at all annoyed to 5-extremely annoyed)**

Average number: **1.44**

9. **What temperature do you set your fridge at?**



10. Where do you usually store the bagged lettuce?



11. Is there anything else you want to share about your experiences with bagged lettuce?

- all the answers related to bagged "baby spinach". I always buy the lettuce full-sized
- always unsure about storing in plastic.
- At first I like that it feels handy and already washed but then I normally don't use the full bag and then I normally have to trhough out half of the bag since it doesn't look fresh anymore.
- bagged lettuce is my second option, I prefer to buy fresh salad (without wrap or bag)
- Handle them very carefully- if you place something heavy or even something at all on them, they will easy get bad
- Hope you can invent systems to make the salad last longer.
- I always keep bags open, from scratch. otherwise salad goes bad in a sealed bag. opened bag gives enough dryness so the bag holds for 2-3 days.
- I answered on question 5 related to consumption of the family... as we have a rabbit, all is eaten anyhow (only what the rabbit doesnt eat is thrown away
- I don´t buy bagged lettuce upon advice of my son who is a food engineer :) i try never to buy any bagged food at all
- I don't buy it due to plastic.
- I prefer to buy bagged lettuce consisting of whole leafs instead of cut sallad since it lasts longer
- I rather often buy Spinach to use for my morning smoothies, In this case I always store the spinach in the freezer instead.

- I sometimes clean+dry the salad in a salad "tumble" before eating it after taking it out from the bag
- I used to buy it but due to reports on high levels of bacteria have switched to whole salads
- I usually buy the entire leaves, rarely the chopped one
- i usually store lettuce in containers as i buy enough for the week i add paper towel at the bottom on the container
- It doesnt last long after opening compared to the non cut salad
- It is better to store it in a sealed food box if not finishing using it at once, but always lazy to do so.
- it never last more than a week when opened
- It should be easier to see, where in the fridge it is best to store things, e.g. a symbol on the drawer. All fridges are different and people don't know where to put things to keep them as fresh as possible.
- Occassionally the bags may be stored on a shelf, when they are too big for the drawer, or drawer is full. Generally don't have a big issue with the condensation, as most lettuce will anyhow be rinsed before consumption.
- Prefer not to buy bagged
- Questions 6 to 8: I would not be 'annoyed' assuming I saw the bags in a shop?
- Referring to the pictures I get less annoyed if the price is lower for the less fresh bagged lettuce.
- The fresh appearance of the lettuce is critical to me. I am in general very strict in the selection of bagged lettuce. At the supermarket, condensation gives me a very bad signal of the way lettuces were handled.
- The one thing I'm concerned about re bagged lettuce is the health aspect. I can separate the "wilted" from the rest, but the worry still lingers about bacteria in these types of bags.
- They do go bad annoyingly quickly and I would appreciate any advice on how to keep them fresh for longer. In our fridge, the drawers in the bottom are far too cold, so we have changed behaviour to store fresh greens at the top, which works better.
- too much food lost as is not good after some days once we open it
- When storing leftover lettuce I place tissue paper in the bottom of the food container to absorb excess moisture.
- why would I be annoyed about the condensation? I don't think a lot of people understand the link between condensation and sallad freshness