Identifying possible quality deviations and establishing critical quality points in perishable fruits and vegetables with bio-based packaging materials

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1 Introduction

1.1 Background information

1.1.1 Packaging conditions in the market

Packaging is defined as all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer (Hänsch & Kinkel, 1995). Packaging can also be essential as it can combine various functions and serve the purpose of prevention of product loss, agglomeration of products etc. (Molenveld, Van den Oever, & Bos, 2015). Some of the functional requirements of packaging materials can be gas permeability, protection against environmental factors, mechanical properties, reactivity with food, marketing related properties and convenience (Jelen, 1985).

Presently, the aim of packaging is not only to contain the food but also to protect it throughout the production chain (Arrieta, Samper, Aldas, & López, 2017). Hence, the food industry has started focusing on new packaging concepts in order to fulfil the increasing demand of safe, minimally processed and "fresh" food products. Moreover, the food industry is facing challenges to incorporate the safety and quality of packaged foods via new packaging concepts (Jin & Zhang, 2008).

There are various materials used in packaging industry, plastic packaging being one of them. Due to the low prices, low weight and good product protection properties, plastics acquired the growth in packaging industry (Molenveld et al., 2015). Moreover, the packaging of fresh fruits and vegetables was observed to lead in single use of printed Polyethylene bags (Ščetar & Kurek, 2010). Furthermore, the plastics like Low Density Polyethylene and High Density Polyethylene (LDPE and HDPE), Polypropylene (PP), etc. are generally made from fossil-based materials which are not readily recyclable. Also, it is expensive to segregate the wide variety of different plastic materials. Therefore, these plastic materials end up in waste.

According to Eurostat ("Packaging waste statistics," 2019), the total quantity of packaging waste increased from 81.5 Million tonnes (Mt) in 2007 to 86.7 Mt in 2016. Out of which, the total of 16.3 Mt was contributed as waste by the plastic packaging materials in 2016.

1.1.2 Sustainable packaging initiatives

To overcome the increasing environmental impact caused by the packaging industry, mainly from plastic packaging materials, European Union (EU) is funding researchers to come up with sustainable food packaging from food waste. The researchers are trying to develop an alternative to petrochemical-based coatings on food and beverage packaging which is more environment friendly. This will in turn help in reducing the dependency on fossil fuel-based plastics leading to improvement in recyclability and landfill waste reduction (European Commission, 2015).

1.1.3 Quality of fruits and vegetables

Haugaard et al. (2001) stated that fruits and vegetables continue the process of respiration, transpiration and produce the ripening hormones like ethylene after harvesting. This results in the variation of carbon dioxide, oxygen, water and ethylene inside the storage packs. These changes might influence the quality and shelf life of fruits and vegetables. Furthermore, season variation and differences in supply location can be some of the specific challenges faced for fresh produce packaging .

Jongen (2002) defined shelf life for most of the fresh produce as, the period within which the product maintains acceptable quality for sale to the processor or consumer. Therefore, it becomes crucial to identify the meaning of the 'acceptable quality' to decide the point where product fails to satisfy those expectations. In case of fresh fruits and vegetables, the quality factors like appearance, texture and flavor/aroma can limit the storage and shelf life (Jongen, 2002). Hence, quality control can be a crucial process to maintain the quality of the food products (P. A. Luning & Marcelis, 2009). Quality control can be defined as continuation process of evaluating technological and managerial processes and when necessary taking the corrective action (Evans & Lindsay, 2005). Therefore, the control measures should focus on techno-managerial processes which are critical to the final quality of the product.

Since shelf-life of fresh produce can be influenced by packaging (Jacomino, Bron, Sarantópoulos, & Sigrist, 2005). It can be challenging to choose the packaging material which can maintain or optimize the quality of fresh produce.

1.1.4 Quality management system & Quality Analysis and Critical Control points (QACCP)

Quality management is defined as all activities operated by organizations to direct, control, and coordinate quality, including formulating a quality policy, setting quality objectives, quality planning, control, assurance and improvement (International Standardization Organization, 2005). Systems like Hazard Analysis Critical Control Points (HACCP) are effective management tools to attain and guarantee production and supply of safe foods (P.A. Luning, Marcelis, & Jongen, 2002; Ropkins & Beck, 2003). On the other hand, it is not precisely applicable for assessment of critical control points for quality attributes (P. A. Luning, Van der Spiegel, & Marcelis, 2007).

Therefore, the term QACCP has been introduced in parallel with the management tool HACCP (Van Boekel, 2005). QACCP functions as a tool used by management to take suitable technological actions to obtain a desired quality performance in a food chain (Verkerk, Linnemann, & van Boekel, 2007). Moreover, QACCP identifies the critical points that are responsible to affect quality and the translation of quality into special quality attributes. These critical points are termed as critical quality points (CQPs). Furthermore, the study conducted by Ali (2012) stated that the points in the supply chain where minor variation can result in large variation that can have decisive influence on the final quality attributes are termed as CQPs. Therefore, identification of these CQPs will further help us to improve the quality attributes.

1.1.6 Alternative packaging

Molenveld et al. (2015) mentioned two new types of sustainable materials being introduced in the packaging industry: bio-based materials and compostable materials. They also mentioned that the product's total environmental footprint can be reduced by selecting the suitable packaging. According to European standard EN 16575, 'Bio-based' is defined as 'derived from biomass'. Hence, a bio-based product can be wholly or partly derived from biomass. The materials made up of biological origin, apart from the materials embedded in geological formations and/or fossilized are called as biomass ("Bio-based products – Vocabulary," 2014). Some of the examples are paper, wood, plastics like Polylactic Acid (PLA) which is produced from sugars.

There are few researches being done to evaluate the effect of bio-based packaging material on the fruits and vegetables. There were some value-added functions observed for example in tomatoes, the suppression of ripening and uniform colour development was monitored by using packaging materials like starch, cellophane, etc. (Helén, 2000). Since petroleum-based polymers lack the function of degradability and are not eco-friendly, there is a growing attention of using bio-based plastic materials as a possible food packaging substitute (Galanakis, 2018). Thus, alternative packaging like bio-based material can play a key role by helping to prevent product loss and making the products more sustainable. Moreover, it will be interesting to identify the possible quality deviations occurring in fruits and vegetables on introducing the new packaging material concepts. Also, to investigate the challenges faced by the food companies to incorporate alternative sustainable packaging material. Along with the similar functional properties of the current plastic packaging material.

1.2 Demarcation

1.2.1 Fruits and vegetables

Fruits and vegetables continue to respire even after the harvest. This makes them vulnerable to physical, chemical and microbiological deterioration from the time of harvest until they are consumed (Barrett, Somogyi, & Ramaswamy, 2004). Also, fresh horticulture and agriculture produce sector is one of the largest packaging users within the food sector (Chiellini, 2008). The CQPs of supply chain of fruits and vegetables will be identified in this research. The specific fruits and vegetables are not demarcated due to the presence of limited literature sources.

1.2.2 Packaging material

Packaging material can play an essential role to maintain the quality and shelf life of fresh produce in the entire distribution chain (Barrett et al., 2004). Hence, it is very fundamental to select the correct packaging material for the fresh fruits and vegetables. The focus of this research will be on the functional properties of the bio-based packaging material.

1.2.3 Quality attributes

The product properties, noticeable by sensory observation are termed as quality attributes. In this manner, they contribute to the quality perception and experience of consumers and customers (Steenkamp, 1990; Van Trijp & Steenkamp, 2005). Quality attributes can be further distinguished as both internal and external.

The quality attributes like size, shape, colour and visible defects are categorized as external attributes since they are noticeable. On the other hand, the quality attributes like flavour, texture, nutrition, internal defect and safety are termed as internal quality attributes because they are not visible through a naked eye.

It can also lead to the acceptance of the product like using the bio-based packaging for the food product, which is more sustainable and can attract the consumers. Hence, in this research the internal and external quality attributes will be identified.

1.2.4 Process

The quality deviations can occur at any step of the supply chain for fruits and vegetables. The Figure 1 represents the general steps involved in the fresh fruits and vegetables supply chain. After the fresh produce is harvested, they are further processed (washing, sorting, etc.). Later the produce is then packaged and stored before it is distributed in various retail stores. To further demarcate this study, only four steps that is packaging, storage, distribution and retail will be focused.

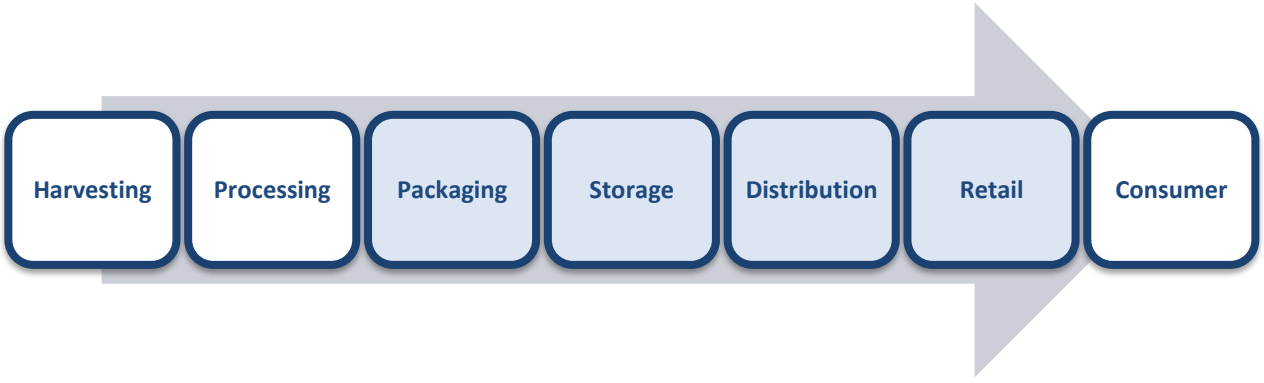

Figure 1 General supply chain of fresh fruits and vegetables

1.2.5 Technological and managerial factors

Luning & Marcelis (2009) stated that food quality management issues can be analysed by techno-managerial approach. This is so because both the food and human systems are the contributing factors to food quality. Food behaviour depends on the food dynamics and applied technological conditions. The product properties will be scrutinized as technological factors. On the other hand, human behaviour depends on the human dynamics and the administrative conditions (P. A. Luning & Marcelis, 2009). Decision making involved in connection to the technological factors will be analysed as the managerial factors.

1.2.6 Critical Quality Points

As defined by Ali (2012), the points in the supply chain where minor variation can result in large variation that can have decisive influence on the final quality attributes are termed as CQPs. To further demarcate this research, the QPs which influences the desired quality attribute of the final product and makes it of unacceptable quality by the consumers, will be defined as CQPs. The QPs will only fall under the category of CQPs if there are steps in the process which can prevent or reduce the quality loss of the final product to an acceptable level. The reference to Figure 2 will be taken to identify the CQPs. Figure 2 is explained in detail under Section 2.1.

1.3 Research aim

The bio-based packaging material is a novel concept which has less carbon footprint as compared to the packaging materials obtained from fossil fuels or non-renewable sources. The aim of the study is to identify the possible quality deviations by establishing the CQPs in fresh fruits and vegetables when petrochemical based packaging material is replaced by bio-based packaging material. Also, to identify which technological and managerial factors have critical influence on the quality of packed fruits and vegetables.

1.3.1 Research question

What are the possible quality deviations and CQPs in packed fruits and vegetables with bio-based packaging material?

1.3.2 Specific research questions (SRQs)

1. What are the main quality attributes of fresh fruits and vegetables according to consumers?
2. What are the possible quality deviations in packed fruits and vegetables with petrochemical based materials at the packaging, storage, distribution and retail stages of supply chain?
3. What are the possible quality deviations in packed fruits and vegetables with bio-based materials at the packaging, storage, distribution and retail stages of supply chain?
4. Which technological and managerial factors can influence the quality attributes of packed fruits and vegetables in bio-based materials at the packaging, storage, distribution and retail stages of supply chain?
5. Which of the identified factors lead to CQPs?

1.4 Research approach

The following research approach was developed to answer the specific research questions. A semi structured literature analysis was conducted to obtain the information relevant for the topic. The research strategy was developed to answer the specific research questions 1 to 5. The data was mainly collected from the Web of Science, Scopus and CAB Abstract. The articles obtained

from the relevant publications were then critically appraised in order to filter it down to the information relevant for the topic.

The data obtained by literature search was then verified by expert interviews. The experts were mainly selected from the companies using (or used) the bio-based packaging material to pack fresh fruits and vegetables or currently are in the process of replacing it with fossil-based (conventional) packaging material for their food product. To make the data obtained from the expert interview more reliable, 4 experts were selected to conduct the interview. The aim of the data collection was to verify the answers of the specific research questions obtained from literature analysis. Not all SRQs were verified by the expert interviews. The specific research question number 2 – 5 were verified via expert interviews. The literature review and expert interviews ultimately helped in narrowing down the CQPs to be focused on when the bio-based packaging is introduced as the alternative packaging material. Therefore, finally directing to answering the main research question.

2 Research methodology

This chapter presents the three different methodologies involved in answering the general research question: 1) QACCP tool, 2) literature review and 3) expert interview.

2.1 QACCP Tool

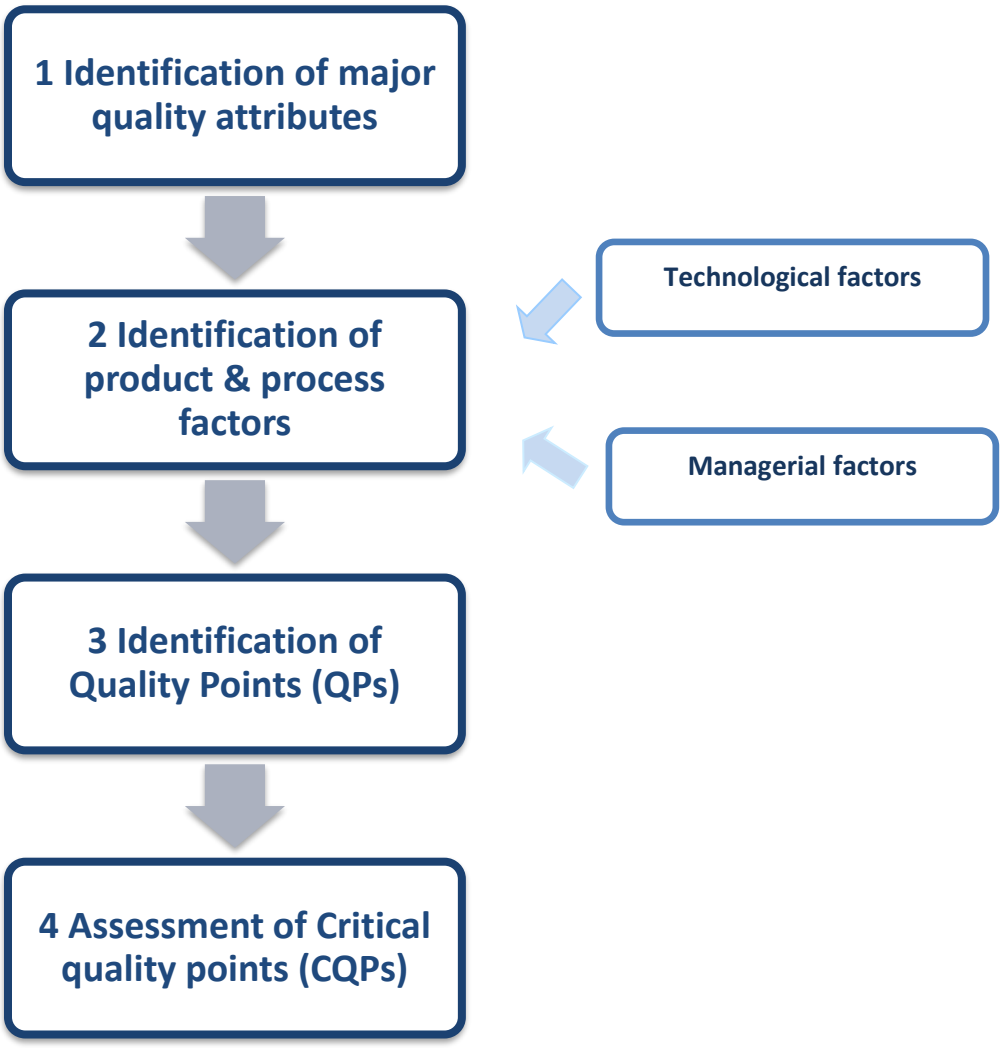

Figure 2 Steps involved in the identification of CQPs (Adapted from Ali, 2012)

The QACCP tool was developed (Figure 2 Steps involved in the identification of CQPs (Adapted from Ali, 2012)Figure 2) to assist in answering the specific research questions in a systematic manner. The steps mentioned in the Figure 2 depicts the steps involved in the identification of CQPs. These steps were adapted from the study conducted by Ali (2012) and modified according to the current study. The first step involves the identification of major quality attributes of fresh produce as identified by the consumers (Ali, 2012). The quality attributes like appearance (size,

shape, colour, defects), flavour, texture, nutritive value, defects and safety were studied in the fresh fruits and vegetables. The next step further classified the product and process factors which are responsible to the development of identified quality attributes. This identification was further simplified by understanding the possible technological and managerial conditions involved. In this study, the possible quality deviations on the fresh produce when alternate packaging material is used was also studied in various steps of the supply chain.

The step 3 identified the points where the product and process factors can influence the quality attributes, which in turn, determine the final quality of the product. These points were termed as Quality Points (QPs). The identified QPs can be utilised to control the influencing product and process factors. The last step involved assessment of CQPs, which is derived from the term QPs that can lead to large variation in the final product, making the product unacceptable by the consumers.

2.2 Literature review

The literature review involved the identification of relevant studies which are later sorted and summarized. In this study, the literature review was conducted to answer research questions 1-5 which is in line with the QACCP tool. The main focus was on the four main aspects: 1) Quality attributes of fresh fruits and vegetables with petrochemical based packaging, 2) Quality deviations in packed fruits and vegetables when bio-based materials are used, 3) Identification of quality points by investigating technological and managerial factors influencing the quality attributes of packed fruits and vegetables in bio-based materials and 4) Identifying the quality points which can be critical to the quality of the final product.

2.2.1 Development of inclusion and exclusion criteria

In order to obtain the relevant literature in terms to the research aim and questions, **4** inclusion and **2** exclusion criterias were formulated before searching the literature.

The inclusion criteria for this research are as follows: 1) documents published in peer reviewed journals or books; 2) documents comprising quality, quality attributes or quality deviations of fresh fruits and vegetables, conventional or bio-based (sustainable) packaging for fresh fruits and vegetables; 3) supply chain of fresh fruits and vegetables; 4) publications written in English language. On the other hand, exclusion criteria chosen for this research are: 1) quality control procedures and QACCP outside the food industry; 2) documents published before 2000.

2.2.2 Development of search procedure

The subjects and keywords that are a part of the research question were picked and all possible synonyms for these subjects and keywords were noted down. Some of the relevant subjects and keywords in this study are: quality, attributes, factor, fresh fruits, fresh vegetables, packaging, bio-based, plastic, impact, effect, texture, smell and appearance. In order to capture different types of spellings (American and European), truncations (*), wildcards (? #) and Boolean

operators (and, or, not) were used in the search. The search strategies are mentioned in Appendix 2: Search strategies.

The search strategy was focused on the title, abstract and keywords to obtain the most relevant publications for this study.

2.2.3 Identification of relevant publications

Three databases namely Scopus, Web of Science and CAB Abstract (Ovid) were utilised to provide publications which are relevant for the study and available for reading. The WUR Library was also utilised as a database to answer SRQ 1. After obtaining the results from each search strategy, the duplicates were removed. The title and abstracts of the publications obtained by applying above mentioned search strategy were screened for relevancy. In case of available insufficient information in the abstract, the entire publication was scanned. Thus, confirming the presence of inclusion and exclusion criteria. After the process of screening, the relevant publications were further analysed in detail.

The results of the search procedure are documented in the Appendix 3: Critically appraised SRQs. The table includes the total number of publications appeared in each database by using the search terms under the title "hits". Furthermore, it includes the number of relevant publications which were used to answer the SRQs. The screening procedure was conducted until the title and abstract of the publication stops showing the relevant information.

2.2.4 Critical appraisal of the relevant publications

The analysis of publications was done using a self-devised critical appraisal form. The critical appraisal form helped to standardize the analysis. The form is divided into 5 parts with 11 questions. Part 1 includes the general information from all papers whereas parts 2, 3 and 4 were formulated to identify the 4 steps of the QACCP tool which helped in answering the specific research questions.

No.	Question	Short answer	Detailed answer
Part 1 General information			
1.	What was/were the aim(s)?		
2.	Which category of the fresh produce was focused?	Fruits/Vegetables	
Part 2 Quality attributes of fresh fruits and vegetables			
3.	Which quality attributes are studied?	Intrinsic /Extrinsic	
4.	Are these quality attributes measurable?	Yes/No	
Part 3 Supply chain of fresh fruits and vegetables			
5.	Which stage(s) of the tertiary supply chain were involved?	Packaging/Storage/Distribution/Retail	
Part 4 Possible quality deviations and influencing techno-managerial factors			
6.	Is there any quality deviation mentioned when conventional	Yes/No	

No.	Question	Short answer	Detailed answer
	packaging is used?		
7.	Is there any quality deviation mentioned when bio-based packaging is used?	Yes/No	
8.	Which technological and managerial factors were influencing the quality deviation when bio-based packaging is used?		
Part 5 Critical quality points			
9.	Which quality deviations are affecting the identified quality attributes?		
10.	Are there any control measures mentioned for the identified quality deviations?	Yes/No	
11.	Were there any critical quality points reported?	Yes/No	

2.3 Expert interview

The aim of the interview was to verify the CQPs obtained from the literature review. This was done by comparing the data obtained from the expert interview to the data obtained by literature analysis. Also, to obtain insights on additional quality points which need to be controlled. The questionnaire was developed in line with the QACCP tool and covering the demarcated stages of the supply chain.

The interview was conducted face-to face in person or via call, depending on the availability and the location of the expert. Face to face interviews have an advantage over other types of interviews because it helped in obtaining in-depth information on the topic.

2.3.1 Identification of experts

The criteria for the identification of experts to participate in the interview was: 1) working in the fresh produce supply chain network which is in transition of alternating the conventional packaging material of the fresh produce with the bio-based material or 2) working in the bio-based packaging material manufacturing company for fresh produce. However, due to poor responses and shortage of time, the experts from the packaging consultancy and the scientific research background were also contacted for the expert interviews.

The experts were contacted via email or LinkedIn based on the contact information available. The interview dates were fixed based on their responses and availability.

Table 1 Job role of the interviewed experts

Expert	Description
Expert 1	Director, Retailers and suppliers of fresh fruits and vegetables
Expert 2	Business owner, Marketing and product development
Expert 3	Senior advisor packaging, Packaging consultancy
Expert 4	Senior scientist recycling

2.3.2 Design of the questionnaire

The 14 open-ended interview questions were formulated to fit the scope of the study. The questions of the interview were structured in 2 sets. The first set of questions gave the general overview of the interviewee's work experience while the other set focussed on the aim of the expert interview. The interview questions are presented in Appendix 5: Interview questions for the experts.

2.3.3 Interview procedure

The interview started with a short introduction explaining the aim of the topic, duration, etc. After introduction, the interview was commenced. The detailed steps on how the interview was conducted are mentioned in Appendix 4: Interview procedure.

2.3.4 Data analysis

The obtained data was analysed qualitatively. The following steps were performed to analyze the obtained data from the expert interview:

1) The interviews from each expert were transcribed by the same researcher who conducted the interview. The answers were summarized during the interview for more clarity in transcription.
2) The answers of the different experts on the same questions were then grouped together. These answers were reviewed, and the results based on the processed data were presented in the form of a table.
3) Based on these results another conceptual framework was formed indicating the CQP.

3 Results and discussions

This chapter presents the results and discussions in three parts: 1) systematic literature review, 2) expert interviews and 3) result analysis combining part 1 and part 2

3.1 Systematic literature review

After developing the literature search strategy, a total of 181 journals appeared on Web of Science, WUR Library and Scopus. All 181 documents were analysed and only 10 articles were found relevant which were included under the title "quality attributes of fresh fruits and vegetables" which helped in answering SRQ 1.

3.1.1 Quality attributes of fresh fruits and vegetables (Step 1)

Based on relevant papers obtained by searching and analysing the publications, 5 of them were solely based on the consumer's perceived quality attributes of fruits. On the other hand, the consumer perception on the quality attributes of vegetables were exclusively studied in only 1 publication and combination of both fruits and vegetables were studied in 4 publications.

Table 2 was tabulated for the better understanding of the general quality attributes and its components. As mentioned in Table 2, quality can be categorized into external and internal attributes (Mahajan et al., 2017). The six quality attributes which are generally defined for fruits and vegetables are appearance (size, shape, colour, defects), flavour, texture, nutritive value, defects and safety (Omar & MatJafri, 2013).

Table 2 Quality attributes and components of fresh fruits and vegetables (adapted from P.V. Mahajan, 2017 & Omar, 2013)

	Quality attribute(s)	Components
External	Size	weight, volume, dimension
	Shape	diameter, depth, ratio
	Colour	Uniformity, intensity
	Defect	Bruise, stab, spot
Internal	Flavour	Sweetness, sourness, bitterness, saltiness, astringency, aromas and taste compounds
	Texture	Firmness, crispness, juiciness, tenderness, crunchiness, chewiness, fibrousness and textural characteristics
	Nutrition	Carbohydrate, fat, proteins, vitamins and minerals
	Defect	Internal cavity, water core, frost damage, rotten
	Safety	Pathogenic microbial load, content of chemical contaminants or presence of physical foreign matter in the fresh produce

According to the study conducted by Belay, Caleb, and Opara (2019), physical quality attributes are the crucial criteria that are utilized by consumers to evaluate quality of fruits and vegetables. These quality attributes comprise of texture (firmness), colour, antioxidants, sugars and others.

Since the consumers lack the direct insight in intrinsic product quality attributes, consumer's perception is more frequently based on extrinsic product attributes (Orth, 2018). Barrett, Beaulieu, and Shewfelt (2010) stated the attributes colour and appearance, flavour (taste & aroma), texture and nutritional value affects the consumers in the specified order. This means, the visual appearance and colour is evaluated first which is followed by the taste, aroma and texture. Even though nutritional value cannot be perceived sensorially, but it is gradually becoming a valued attribute by the consumers. del Carmen, Esguerra, Absulio, Maunahan, and Masilungan (2012) performed a study on consumer's preference for fresh papaya. They observed that the consumers looked for external attributes like size, colour and free of defects and internal attributes like pulp colour, flavour (sweetness) and texture.

Chamhuri and Batt (2015) conducted a study in order to understand the quality cues consumers look for before purchasing fresh fruits and vegetables. The freshness variable was most often cited by the consumers when asked about the quality followed by safety and nutritional value. The indicators of freshness differed in different fruits and vegetables category. In case of potatoes and apples, skin colour, freedom from blemishes and bruises and texture (firmness) were the indicators of freshness. On the other hand, spinach was evaluated by the colour, freedom from wilting and appearance of the leaves. Furthermore, consumers associated vegetables freshness to quality attributes such as texture, taste, odour and aroma (Saba et al., 2018).

Texture (firmness), colour and flavour were considered the most important perceived quality attributes for tomatoes (Martinez-Carrasco, Brugarolas, Martinez-Poveda, Ruiz, & Garcia-Martinez, 2012). Moreover Opara, Al-Said, and Al-Abri (2007) concluded flavour, sweetness, colour and firmness as the most influential quality attributes for fruits (banana, date, apple, mango, orange).

In order to set quality specifications for marketing along with providing a guide for postharvest research for quality improvement of fresh produce, it is important to understand consumer perceptions and attitudes towards quality (Opara et al., 2007). Thus, it can be summarized that the quality attributes like appearance (size, shape, colour, defects), flavour and texture are the most crucial factors for consumers to evaluate the quality of the fresh fruits and vegetables they buy from the market.

3.1.2 Quality deviations in fresh fruits and vegetables (Step 2)

A total of 749 publications were found from three different databases namely CAB Abstract, Scopus and Web of Science. Different literature strategies were developed in order to systematically get the publications identifying different quality deviations in the fresh produce as a base to further identify these deviations to answer SRQ 2 & 3. The publications relating to petrochemical based packaging material was found in the majority whereas the publications on bio-based packaging materials was very few. After removing the duplicate publications appearing on different database, the total number of 481 unique publications were listed down.

All these publications were analysed, and the total of 24 publications were found relevant to answer SRQ 2 and 3.

In general, all publications found were not completely dedicated to what was asked in SRQ 2 and 3, which are, possible quality deviations at different stages of the supply chain. Instead, the publications were focussed on laboratory experiments. Therefore, a distinction was made to first cluster the possible quality deviations generally observed in the fresh fruits and vegetables followed by the quality deviations occurring when polymeric and bio-based packaging material are used.

3.1.2.1 Physiological deviation

Respiration

The fresh produce continues to respire after harvest, and this affects the quality and shelf life of the produce. Hence, the factors which can lower the respiration can lower the senescence and in turn help in maintaining quality (Aked, 2002). Senescence is the natural ageing process of the plant tissues and can be accelerated by presence of ethylene and increased respiration rates. It ultimately alters all quality attributes leading to the death of the product (Aked, 2002). However, the produce should still respire a little or else it can lead to direct death. For example, peas and beans with higher respiration rates have shorter shelf lives, whereas the potatoes and onions with lower respiration rates have longer shelf lives. Increased respiration rates lead to increased temperature which as a result causes internal tissue breakdown and the production of volatiles characteristic of the over-ripe fruit (Aked, 2002). Moreover, this respiratory heat if not controlled, can lead to increased water loss and can be conducive to bacterial and fungal infections.

Ethylene

Ethylene is a plant hormone responsible for ripening and senescence of the fresh produce. Ripening is the critical factor determining the fruit quality. The ripening process can be observed more evidently when the fruits starts to lose firmness (Siddiqui, 2015; Zerbini, 2002). This was further observed in the experiment conducted by Jomngam (2017) where fruit lost its firmness with increasing duration of ripening and temperature. Any stress to the plant tissues like water loss, physical damage or pathogenic attack can increase the level of ethylene synthesis. As a result, it accelerates the maturation and senescence stage, for example, loss of chlorophylls in green vegetables more rapidly, premature ripening in unripe fruits, etc. (Aked, 2002). Sahoo, Bal, Pal, and Sahoo (2014) enlisted weight loss due to moisture loss, degradation of chlorophyll causing change in the color, loss of turgidity causing change in texture and reduction in marketability as the consequences of the senescence stage.

3.1.2.2 Physical deviation

Physical injuries are the key attributes for the loss of fresh produce. These injuries can arise at any production stage of the fresh produce like from insect injuries or from poor post-harvest

handling. Poor packaging can result in cuts and bruises from the adjacent produce due to underfilling or dropping (Aked, 2002).

Structure and textural properties of fresh produce are entirely dependent on the maintenance of the enough cell turgor pressure which creates a force against the cell wall. Loss of water from the tissues can result in the fall of turgor pressure which will in turn lead to wilting or shriveling of the product (Aked, 2002). Nunes and Emond (2007) stated that minor water loss causes slight quality changes in color and texture, whereas major loss causes deleterious changes in turgidity, firmness, discoloration and flavor. Additionally, water loss is also responsible for the weight loss which varies between fruits and vegetables. This means, fruits and vegetables kept under same atmospheric conditions experiences weight loss from differences in physiological behaviours as well as differences in form and structure. For example, mushrooms are more susceptible to water loss than tomatoes due to absence of a protective cuticle. Moreover, mushrooms due to larger exposed surface area also have more rate of water loss as compared to the fruits like strawberries or raspberries in which waxed cuticle is absent (Nunes & Emond, 2007). The linear correlation was observed between weight loss and visual quality attributes. The increased weight loss resulted in softer, coloured or brownish and shriveled fruits and vegetables (Nunes & Emond, 2007). Thus, making the fresh produce unacceptable for sale.

Therefore, appearance, texture and flavor of the fruits degrades as the water loss increases. Water loss is also primarily dependent on the deficiency of the external vapour pressure (Aked, 2002).

3.1.2.3 Microbiological deviation

Fungi is the main microorganism responsible for postharvest loss of fresh produce. This is specifically true for fruits which suppresses the bacterial growth due to the presence of acidic conditions. On the contrary, vegetables with higher levels of pH tend to deteriorate from bacterial infections (Aked, 2002). The skin diseases caused by the pathogens may remain on the surface but leads to severe market losses due to the blemished appearance of the produce.

Therefore, the possible quality deviations occurring in fresh produce and the affected quality attributes is summarized in the Table 3. The table depicts the different types of quality deterioration fruits and vegetables undergo, the main processes involved and at last the consequences of these processes on the quality attributes specified in Section 3.1.1.

Table 3 Quality deviations in fresh fruits and vegetables

Types of quality deviation	Processes	Quality attributes affected
Physiological	Ripening	Appearance, texture, flavor
Physical	Water loss, cuts & bruises	Appearance, texture, flavor
Microbial	Growth of bacterial and fungal infections	Appearance

3.1.2.4 Quality deviation using polymeric packaging material

Table 4 was formulated to include the summary of the possible quality deviations occurring when conventional and bio-based packaging material is used to pack fresh produce. This table will be further explained in detail in the following section and in Section 3.1.2.5.

Table 4 Quality deviations in conventional/petrochemical and bio-based/biodegradable packaging

	Packaging material	Product	Possible quality deviations	Processes	Affected quality attributes	References
Conventional/petrochemical	Polyethylene terephthalate (PET), PE	Fig	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains texture)	Bouzo, 2012
	HDPE	Radish	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture)	Chandra, D., Lee, J. S., Choi, H. J., & Kim, J. G. (2018).
	PE	Dragon fruit	1*(Lowers physiological)	1*(Lowers ripening)	1*(Maintains appearance)	Chandran, S. (2010)
	Polyolephinic	Pomegranate	1*(Lowers physical)	1*(Reduces weight loss, scald and browning	1*(Maintains appearance, texture, flavor)	D'Aquino, S., Palma, A., Schirra, M., Continella, A., Tribulato, E., & La Malfa, S. (2010)
	PP	Broccoli	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture, flavor)	Fernandez-Leon, M. F., Fernandez-Leon, A. M., Lozano, M., Ayuso, M. C., Amodio, M. L., Colelli, G., & Gonzalez-Gomez, D. (2013)
	PP	Litchi	1*(Lowers physical)	1*(Reduces weight loss, lower pericarp	1*(Maintains appearance, texture, flavor)	Somboonkaew, N., & Terry, L. A. (2011)

	Packaging material	Product	Possible quality deviations	Processes	Affected quality attributes	References
				moisture content)		
	Perforated fruit boxes and wax-lined cartons sealed with LDPE films	Mango	Physical. physiological	Weight loss, ripening	Appearance, texture	Srinivasa, P. C., Susheelamma, N. S., Ravi, R., & Tharanathan, R. N. (2004)
	LDPE	Organic tomato	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture)	Kantola, M., & Helen, H. (2001)
	OPP	Cherry tomato and peach	Physical, microbial	Weight loss, pathogen growth	Appearance, texture, flavor, safety	Mistriotis, A., Briassoulis, D., Giannoulis, A., & D'Aquino, S. (2016)
	LDPE, PP	Bell pepper	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture, flavor)	Sahoo, N. R., Bal, L. M., Pal, U. S., & Sahoo, D. (2014)
Bio-based/biodegradable	Mixture of three biodegradable polyesters	Lettuce	2*	2*	2*	Del Nobile, M. A., Baiano, A., Benedetto, A., & Massignan, L. (2006).
	PLA	Cherry tomato and peach	1*(Delays microbial)	1*(Delays fungal decay)	1*(Maintains appearance)	Briassoulis, D., Mistriotis, A., Giannoulis, A., & Giannopoulos, D. (2013)
	Starch film	Raspberry	1*(Delays microbial, lowers physical)	1*(Delays fungal decay, reduces weight loss)	1*(Maintains appearance, texture, flavor)	Briano, R., Giuggioli, N. R., & Girgenti, V. (2016)
	PLA trays with non-commercial biodegradable and compostable film	Raspberry	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture, flavor)	Briano, R., Giuggioli, N. R., Girgenti, V., & Peano, C. (2015)
	PLA pouches in carton boxes	Strawberry, black currant and raspberry	2*	2*	2*	Dukalska, L., Muizniece-Brasava, S., Kampuse, S., Seglina, D., Straumite, E., Galoburda, R., & Levkane, V. (2008)
	Starch bags	Cherry	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture)	Giacalone, G., & Chiabrando, V. (2013)
	Non-commercial biodegradable and compostable	Raspberry	2*	2*	2*	Giuggioli, N. R., Briano, R., Baudino, C., & Peano, C. (2015)

	Packaging material	Product	Possible quality deviations	Processes	Affected quality attributes	References
	film					
	Wheat gluten-paper	Mushrooms	Physical	Weight loss	Appearance, flavor	Guillaume, C., Schwab, I., Gastaldi, E., & Gontard, N. (2010)
	PHB-coated paperboard trays overwrapped with perforated starch bags; PLA-coated paperboard trays overwrapped with perforated starch bags	Organic tomato	Physical	Weight loss	Appearance, flavor	Kantola, M., & Helen, H. (2001)
	Starch bags	Apricot	2*	2*	2*	Peano, C., Giuggioli, N. R., & Girgenti, V. (2014).
	Perforated fruit boxes and wax-lined cartons sealed with chitosan films	Mango	1*(Lowers physical, physiological)	1*(Reduces weight loss, delays ripening)	1*(Maintains appearance, texture)	Srinivasa, P. C., Susheelamma, N. S., Ravi, R., & Tharanathan, R. N. (2004)
	PLA	Cherry tomato and peach	1*(Lowers physical)	1*(Reduces weight loss)	1*(Maintains appearance, texture, flavor)	Mistriotis, A., Briassoulis, D., Giannoulis, A., & D'Aquino, S. (2016)

1* Positive effect; 2* No effect

Packaging has been introduced to maintain the quality as well as prolonging the shelf life of the perishable fresh produce (Chandran, 2010). Polymeric films have been in the market to package fresh produce from the past 35 years, carrying benefits like control of water loss, prevention from skin abrasion and lower contamination while handling the produce. These films are also responsible for affecting the movement of the respiratory gases which depends on the relative permeability of the film (Aked, 2002). As the fresh produce respires, the oxygen levels in the sealed bags decreases while the carbon dioxide increases. Thus, ensuring the reduction of the respiration rates (Chandran, 2010).

The experiment conducted by Bouzo, Travadelo, and Gariglio (2012), showed that the plastic packages (Polyethylene) with selective permeability (Modified Atmosphere Packaging; MAP) decreases the respiration rate which prolongs the storage life and quality appearance. The total of 5.9% of weight loss was observed in the fig fruit with the polymeric packaging whereas 18% was noted in the fruit without packaging along with the decreasing firmness.

The results obtained by the study conducted by Chandra, Lee, Choi, and Kim (2018) depicted that HDPE film helped in reducing the weight loss, maintaining color and firmness of the radish roots. He further recommended HDPE film to be a better option for packaging vegetables like radish roots for extended shelf life during storage. This was further supported by D'Aquino et al. (2010), who experienced excessive weight loss, scalp and peel browning of the unpacked pomegranate fruit. When unpacked Broccoli was compared with the plastic packed, 3.36% of weight loss was observed in the unpacked produce than 0.75% in the plastic packed produce (Fernandez, 2013). The similar weight loss was observed in the unwrapped Litchi fruit than the wrapped fruit (Polypropylene) in the experiment conducted by Somboonkaew and Terry (2011). Moreover, the physiological loss in weight (PLW) of unpacked bell peppers was 21.6 (±2.57) % as compared to the packed bell peppers with the PLW ranging between 0-10% (Sahoo et al., 2014).

3.1.2.5 Quality deviation using bio-based packaging material

In the comparative study conducted by Del Nobile, Baiano, Benedetto, and Massignan (2006), it was concluded that the biodegradable packaging with appropriate gas barrier properties perform similar to that of the commercially available polymeric packaging materials in terms of senescence level and color variation. Whereas Briassoulis, Mistriotis, Giannoulis, and Giannopoulos (2013) pointed out that the bio-based (PLA) packaging material showed improved quality of fresh produce in terms of delayed fungal decay as compared to the unpacked or packed plastic packaging material (PP). Furthermore, the 3 different types of non-commercial bio-based packaging material was able to retain aroma, turgidity and absence of fungal decay in raspberry fruits (Briano, Giuggioli, & Girgenti, 2016). The similar results were observed by Giacalone and Chiabrando (2013) where biodegradable films were successful in delaying the color change and the loss of firmness as compared to the plastic (PE) packaging films. Although the biodegradable film with high CO2 and low O2 permeability provided the better results in terms of color and firmness.

In the study conducted by Briano, Giuggioli, Girgenti, and Peano (2015), the minimal changes in the weight loss and the color indicated that biodegradable packaging material due to good permeability properties are good substitutes for the plastic films (PP) and can be utilized in the entire supply chain of the raspberry fruits. In another study conducted on raspberry fruits showed that the biodegradable films can be suitable as a packaging material due to more attractive color and flavor properties of the berries (Giuggioli, Briano, Baudino, & Peano, 2015). On the contrary, mushrooms packed in bio-based packaging material led to weight loss due to high water vapor permeability as compared to the plastic film but did not affect the overall quality within the storage duration (Guillaume, Schwab, Gastaldi, & Gontard, 2010). The similar results were obtained when Kantola and Helen (2001) investigated the quality factors of tomatoes in plastic (LDPE) and biodegradable packages. The results indicated that after 3 weeks of storage 1.7% weight loss was observed in tomatoes that were stored in LDPE bags against 2.5% weight loss for tomatoes that were stored in biodegradable packages due to poor water vapor barrier

properties whereas no significant changes in firmness was observed with the varied packaging material.

In the comparative study where fresh fruits like strawberries, black currants and raspberries were packed in the plastic (PP) trays and covered with plastic films (PP) and the other set was packed in carton boxes covered with the biodegradable films (PLA). This resulted in high content of carbon dioxide in the plastic films whereas an acceptable amount of carbon dioxide and oxygen was present in the biodegradable film. Since, the fruits require adequate amount of oxygen, biodegradable packaging films were considered suitable for the storage of these fruits (Dukalska et al., 2008). The biodegradable film was able to create the equilibrium atmosphere with the packed apricot fruits and was identified as the new flexible packaging material for storing apricots in modified atmosphere packaging material (Peano, Giuggioli, & Girgenti, 2014).

The highest weight loss was noted in the mangoes packed in perforated plastic box followed by the mangoes stored in cartons sealed with chitosan films (Srinivasa, Susheelamma, Ravi, & Tharanathan, 2004). Also, the retention of desirable firmness was found in the fruits stored in cartons sealed with chitosan films as compared to the fruits stored in perforated plastic box. The relative changes in color of the mangoes packed in chitosan films indicated the delayed ripening process. Furthermore, in LDPE sealed cartons, the condensation of water droplets and moisture was observed in the fruits whereas this type of condensation was absent in chitosan sealed cartons. Thus, indicating the higher water vapor transmission rates of chitosan film which in turn helps to establish the adequate moisture content in the cartons, leading to increased shelf life of mangoes (Srinivasa et al., 2004). Additionally, the study conducted by Mistriotis, Briassoulis, Giannoulis, and D'Aquino (2016) indicated that the cherry tomatoes were infected by the pathogen growth in the plastic packaging film due to higher levels of humidity and condensation as compared to the tomatoes packed in bio-based packaging.

3.1.3 Identification of technological and managerial factors (Step 2)

After developing various search strategies, 1003 publications for technological factors and 67 publications for managerial factors were obtained. The sum of 837 & 49 publications for technological and managerial factors were attained after removing the duplicates. These publications were finally analyzed. The total of 22 publications was found relevant out of which 17 publications were for technological factors and 5 publications for managerial factors, which are included in the following section.

Identified technological factors

The SRQ 4 involves the 4 stages of the supply chain which were demarcated for this study, but all the relevant publications were majorly focused on the storage stage of the fresh produce. Henceforth, the detailed technological factors influencing the quality attributes of the fresh produce at the packaging, distribution and retail stage will be obtained from the expert interview.

Table 5 Technological factors influencing the quality attributes of packed fruits and vegetables in bio-based materials

Technological Factors	Affected Quality Attributes
Packaging material properties: Gas barrier (CO_2 and O_2) Moisture barrier	Appearance, texture, flavor, nutritive value
Temperature	Appearance, texture, flavor
Time	Appearance, texture, flavor

Table 5 depicts the three identified technological factors which are influencing the quality attributes of fresh fruits and vegetables when packed in bio-based materials. It is important to maintain the internal atmosphere of the packed produce because it influences the respiration rate which in turn can influence the shelf life of the fresh produce (Abdul Khalil et al., 2018; Seglina et al., 2013). One of the most important packaging material properties are gas barrier (oxygen and carbon dioxide). The good oxygen barrier properties are critical in ensuring the long shelf life for the packaged produce since excess of oxygen can lead to oxidation causing an irreversible reaction to quality attributes like flavors, colors, etc. (Abdul Khalil et al., 2018; Kantola & Helen, 2001; Khwaldia, Arab-Tehrany, & Desobry, 2010). However, lack of oxygen can lead to anaerobic respiration which is also deleterious to the quality attributes of the fresh produce (Kantola & Helen, 2001). Siracusa, Rocculi, Romani, and Dalla Rosa (2008) mentioned that generally bio-based packaging materials have better oxygen barrier properties which, in turn, helps in extending the shelf-life of the fresh produce. In the experiment conducted by Peano et al. (2014), it was observed that the gas barrier properties of the bio-based materials enabled the internal atmosphere of the packed produce to reach the equilibrium state that is, amount of oxygen consumed and carbon dioxide generated were equivalent to the amount of oxygen entering the package and carbon dioxide permeating out of the package. Moreover, Choklob, Gupta, and Kajorncheappunngam (2019) recommended that, PLA blends/Rice Husk Ash (RHA) with varying water vapor and O2 permeability properties can be used as a fruit packaging material and thus can help in extending shelf life of fresh fruits. Furthermore, the carton boxes inserted in biodegradable packages had more acceptable CO2 concentration (Dukalska et al., 2008)

The moisture barrier property of the packaging material is also considered as an important factor for the fresh produce because it assures the stability and safety during distribution and storage (Abdul Khalil et al., 2018; Khwaldia et al., 2010). Due to lower water vapor barrier in the bio-based packaging material, higher weight loss was observed in the blackberries and tomatoes packed in these materials as compared to the conventional packaging material (Joo, Lewandowski, Auras, Harte, & Almenar, 2011; Kantola & Helen, 2001). Moreover, it leads to decrease in the titrable acidity (TA) along with the decrease in soluble solid contents (SSC)

which causes the generation of off-flavors, palatable taste, etc. (Joo et al., 2011). Similar results were obtained in the experiment conducted by Srinivasa, Baskaran, Ramesh, Prashanth, and Tharanathan (2002), where the fruits in carton boxes covered with chitosan film underwent more weight loss (7.5%) as compared to the LDPE film (3.5%). The water vapor permeability of bio-based packaging material (starch-based films and PLA) is 3-6 times higher than the conventional packaging material (PET, LDPE, HDPE, OPP and OPS) (Mistriotis et al., 2016; Muratore, Del Nobile, Buonocore, Lanza, & Asmundo, 2005; Robertson, 2008). Therefore, bio-based packaging material affected the quality attributes like appearance, texture and flavor. On the other hand, in the study conducted by Tengrang et al. (2017), it was observed that Polybutylene succinate (PBS) showed the lowest weight loss of the Rambutan fruit when compared with the LDPE bags. It was concluded that the bio-based packaging material (PBS) preserved the quality better than the conventional packaging material (LDPE). This was also supported by Srinivasa, Revathy, Ramesh, Prashanth, and Tharanathan (2002) since the chitosan film was effective in delaying the ripening process which was visible by the retention of chlorophyll and lower value of total soluble solids (TSS).

It was observed that the temperature fluctuations had non-significant effect on the permeability of gas and moisture, but condensation occurred when the temperature was decreased during the storage in both bio-based and conventional packaged fruits. As a result, appearance was deteriorated due to the microbial growth (Mallia, Linke, Gottschalk, & Cerruto, 2010). Moreover, the fungal growth was observed in the LDPE bags due to condensation (Srinivasa, Revathy, et al., 2002). Also, it was observed that increasing temperature increases the respiration rate (Kantola & Helen, 2001). This resulted in the low O2 and high CO2 and hence helped in improving the storability of raspberries at the highest temperature for around 96 hours (Giuggioli et al., 2015). The temperature abuse can also occur when the packed fresh produce is transported by road without refrigeration (James, 2006; McLauchlan & Bagshaw, 2001). Therefore, the maintenance of temperature in storage and distribution is critical for the fresh produce's final quality (James, 2006).

The bananas packed in the bio-based packaging material (PLA blends) were preserved for 14 days as compared to the bananas packed in the conventional packaging for 8 days (Choklob et al., 2019). The similar results were obtained when Srinivasa, Baskaran, et al. (2002) conducted the comparative study between LDPE and chitosan film used for covering mangoes. The fruits covered in LDPE showed off-flavor and fungal growth after 12 days whereas the fruits covered in chitosan film did not show any spoilage in the entire storage period for up to 18 days. In the study conducted by Muratore et al. (2005) on plum tomatoes, the bio-based packaging material was able to successfully maintain the shelf life of produce similar to the unpacked produce and also prevented the microbial decay and insect infestation. Thus, indicating the antimicrobial property of the bio-based packaging material. On the contrary, Kantola and Helen (2001) stated that although storage time can significantly influence the quality attributes like firmness, color and flavor of tomatoes but packaging type has no significant influence.

Identified managerial factors

On conducting an extensive literature search, the results obtained for managerial factors were less as compared to the technological factors. The managerial factors obtained were irrespective of the packaging material used and were more generic.

Table 6 Managerial factors influencing the quality attributes of packed fruits and vegetables in bio-based materials

Managerial Factors	Affected Quality Attributes
Maintenance of equipment and facilities	Appearance, safety
Employee hygiene	Appearance, safety
Training and knowledge of food-handlers	Appearance, safety
Pest and waste control	Appearance, safety

The 4 managerial factors were obtained from the literature search strategy as mentioned in the Table 6. Kenny (2002) stated that equipment and facilities should be maintained in a clean condition to avoid contamination in the fresh produce. This is especially important at the packing facilities, where the harmful microorganisms can be introduced to the product if they are not cleaned and well maintained (James, 2006). Moreover, the display counters and shelves in the retail store can also be a source of cross-contamination and should be cleaned regularly (James, 2006). A proper cleaning schedule should be in place including the frequency, method of cleaning and other details.

The food handlers work in the proximity of the fresh produce and are responsible for the product's safety (James, 2006). Therefore, they are responsible to prevent contamination directly or through cross-contamination by adopting to best hygienic practices (Araujo et al., 2018; Gil et al., 2015). This can be done by making the hygiene facilities like toilet and handwashing facilities accessible (Kenny, 2002).

Another managerial factor important for the packed fresh produce's safety and quality is the adequate training and knowledge of food-handlers along the entire food chain (Gil et al., 2015). To ensure the correct handling practices like proper temperature control, cross-contamination prevention and verification of processing and packaging requirements (Araujo et al., 2018; Kenny, 2002). They should also be trained on the proper use of toilets, hand-washing procedures and use of protective clothing (Araujo et al., 2018; Gil et al., 2015; James, 2006).

Pest infestations and poor waste management can also pose a risk on the safety and quality of the fresh produce. Hence, the waste should be disposed of properly to prevent pest infestations. Also, the control measures should be taken to prevent or minimize pest access. Moreover, the adequate

records should be readily available including the type of infestation and possible treatments (Kenny, 2002). In fact, pest control programs are essential at any storage facilities (James, 2006).

Moreover, the packhouse manager should estimate the amount of prevention required by assessing the risks in the plant. This can be done by screening windows and air vents. Monitoring and documenting the pest control management program to protect the product (James, 2006). Due to the complex nature of the entire food chain, there are managerial intervention of experts which are required to be taken to control hazards at each step of the food handling process (Gil et al., 2015).

3.1.4 Identified CQPs (Steps 3 and 4)

In reference to the QACCP tool (Figure 2), Sections 3.1.1, 3.1.2, and 3.1.3; the following technological (T) and managerial (M) factors are enlisted in Table 7 as the quality points (QPs). It was observed in the previous sections that these QPs influence the desirable quality attributes of the final product to an irreversible or unacceptable quality by the consumers. Therefore, these QPs were identified as CQPs because if these QPs are controlled, it can prevent or reduce the quality loss of the final product to an acceptable level.

Table 7 Identified CQPs

Quality points	T/M	Unacceptable to consumers	Irreversible	CQP?
Packaging material properties: - Gas barrier (CO_2 and O_2) - Moisture barrier	T	✓	✓	Yes
Temperature	T	✓	✓	Yes
Time	T	✓	✓	Yes
Maintenance of equipment and facilities	M	✓	✓	Yes
Employee hygiene	M	✓	✓	Yes
Training and knowledge of food-handlers	M	✓	✓	Yes
Pest and waste control	M	✓	✓	Yes

3.1.5. Conceptual framework based on the literature review

By analysing the relevant publications which are coherent with the specific research questions, the following conceptual framework was developed.

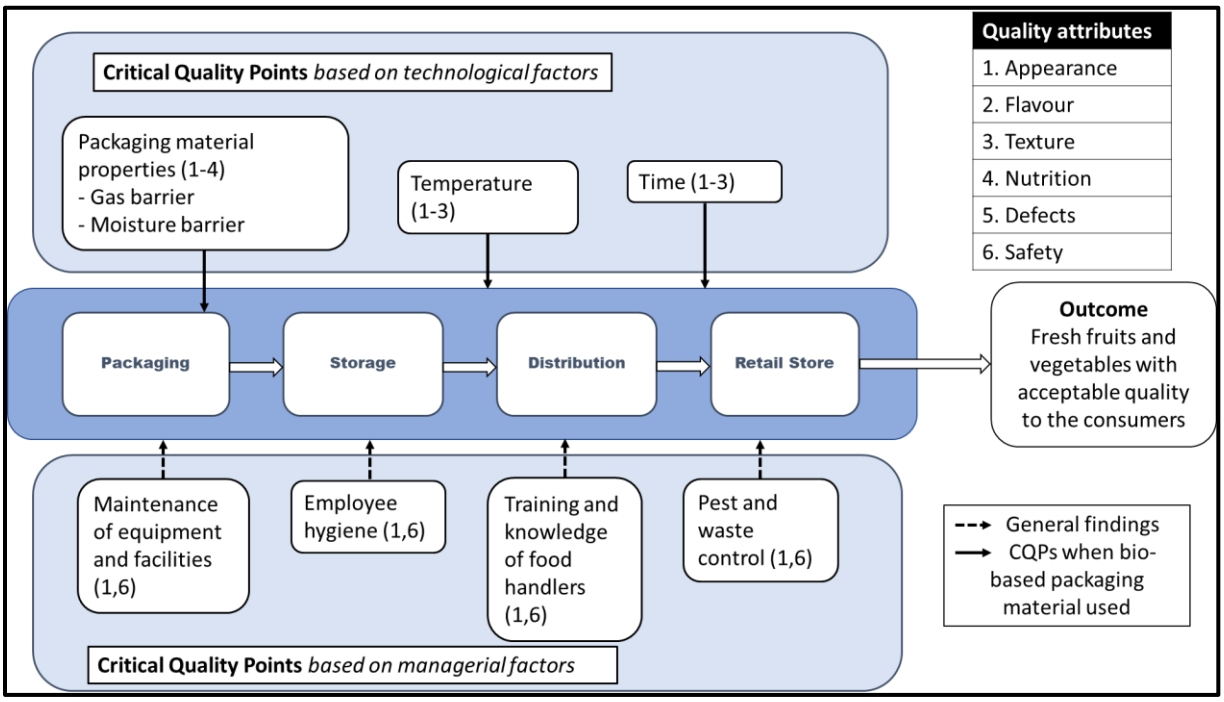

Figure 3 CQPs identified from literature review potentially influencing quality attributes

As shown in Figure 3, the four stages of the supply chain that is packaging, storage, distribution and retail were demarcated. Therefore, the other stages are out of scope of this thesis and will not be discussed further.

It was observed that there were two types of identified CQPs from the literature findings. The technological factors which were enlisted as potential CQPs were obtained from the publications referring to the possible quality deviations when conventional packaging material is altered with the bio-based one. On the other hand, the publications indicating the managerial factors as CQPs were not specifically related to the implications of using the bio-based packaging material for fresh produce. Therefore, these two different sets of CQPs were highlighted in the Figure 3 through different arrows.

3.2 Expert interviews

The professionals/companies in fresh fruits and vegetables supply chain were approached through different methods like LinkedIn, webpages, emails or via telephonic call. Due to lower responses, the search for the experts was then broadened to the packaging consultants and scientific researchers on packaging materials.

In total 40 professionals/companies were contacted where only 4 agreed for an interview. Out of these 4 experts, 2 were from the fresh fruits and vegetables supply chain and the rest 2 were the packaging consultant and researcher. Out of 4 interviews, 2 telephonic interviews were conducted and the rest 2 were conducted in person. These interviews were conducted to verify the findings from the literature review as well as to gain some additional insights. The information obtained from these interviews were then transcribed.

The Table 8 depicts the processed data obtained from the expert interviews. These interviews helped in revealing the perspectives of the officials working in/for the fresh fruits and vegetables supply chain.

General overview about the experts on bio-based packaging materials

In terms of experiences of the experts, 3 out of 4 had an experience of about 15-25 years whereas one expert had experience of about 2.5 years. The Expert 3 did not have a working experience with the bio-based packaging material but had few examples from the food companies. He was able to share the dilemmas the food companies go through when they decide to alternate the conventional packaging material with the biobased/biodegradable packaging material. Experts 1, 2 and 4 were able to discuss on this topic due to their experience in experimenting. It was observed during the interview that all experts have the same dilemma of alternating the packaging material with the more sustainable packaging material.

Experts 1 & 2 alternated the packaging with the biobased packaging material but had to switch back to the conventional materials. One of the reasons was the availability of the packaging material and the financial implications. The same reasons were inflicted by the experts' 3 & 4. Expert 4 also mentioned that due to lack of the established recycling structure for biobased/biodegradable packaging material, the companies are hesitating to alternate their packaging material.

The analysis of the results based on the expert interviews are explained in detail in the following Sections 3.2.1, 3.2.2, 3.2.3 and 3.2.4.

Additional insights from the expert interviews

The aim of the expert interviews was also to obtain the additional insights on the challenges faced by the market when alternating the packaging materials. Also, their point of view in combating the environmental impacts caused by conventional packaging materials. The inputs given by these experts were not solely based on the quality but also the sustainability factor of using the packaging material. The expert 1 stated that "*According to the current market, the more sustainable choice would be to remove Polystyrene based packaging material*". He supported his statement by mentioning the lack of recyclability of this type of packaging material. Furthermore, he added "*the lack of strictness in the law regarding the type of packaging material used in the food industry also makes the food companies to make choices for*

cheaper rather than sustainable packaging materials". In his concluding remarks he indicated his interest in switching back to the improved bio-based packaging materials with comparable cheaper rates like the conventional packaging materials.

The expert 2 decided to switch to the bio-based packaging material especially derived from the banana peels. He stated "*Bananas are abundant in the part where our company is located. Since, bananas are highly processed, and the peels were thrown away. We decided to use the peels in producing the bio-based packaging materials".* Also, that the high availability will lower down the packaging material costs was also one of the deciding factors. In his concluding remarks, he mentioned that "*The aim should be to develop a packaging material which should be resilient enough to take care of itself*".

The expert 3 being the packaging consultant had a lot of informative insights. In order to make the packaging material more sustainable with lower environmental impacts, he suggested that *"The companies should start using bio-based mono materials. Otherwise, it will face the same sustainability issues as the conventional packaging materials"*. He also mentioned "*Packaging materials like PLA is not recognized by most of The Netherlands market because it is not suitable for recycling process. Instead it interferes and pollutes the streams of the other recycled materials*". He highlighted the high price of bio-based packaging material which makes the companies to stick to the cheaper conventional packaging materials. He stated that "*The big companies should start using and create higher demands of bio-based packaging materials. The small companies will also start to switch from the conventional packaging materials*". In his concluding remarks he said that "*As long as the bio-based packaging material can withstand the best before date, I see no problem*". Furthermore, he added "*In order to attract consumers, the marketing team should have a good story to sell the product. It is always helpful to focus on the people engaged in sustainability and introduce bioplastics when the small part of price is in the packaging costing"*.

The expert 4 focused more on the reduction of the packaging material rather than the solution. He stated that "*The superfluous convenience package is rubbish when the original skin is the good packaging. Like for an example a pineapple has a hard skin protecting the fruit. The fruit should not be peeled and sold in the market as it increases the use of packaging materials*". He also mentioned that "*The benefits of the plastics are not understood very well but harms are understood*". He recommended to increase the recyclability of the conventional packaging material rather than introducing the bio-based packaging materials. This is so because the biobased packaging materials cannot be recycled. Thus, currently do not fit into the circular economy and is not a sustainable option. He also highlighted the challenges the companies face when they try to introduce sustainable option, but the poor consumers acceptance leads to the drop-in sales. In his concluding remarks, he stated that "*There is no problem when the shelf life of packaging material exceeds the shelf life of the fresh produce*".

Table 8 Overview of expert interviews

	Expert 1	Expert 2	Expert 3	Expert 4
Activities carried out	Overlooking entire production chain	Business owner, sourcing raw materials	Packaging and packaging processes	Contractor researcher
Stages of supply chain worked in	Accepting raw materials, packaging, storage, distribution	Product development, transportation, training of employees, getting customer feedback	Procurement, packaging, warehousing, storage, improving packaging processes	Research and development of protective packaging solutions for perishable products
Work experience	2.5 years	25 years	15 years	25 years
Worked with bio-based/biodegradable packaging	6 months (in 2019)	5-6 months (in 2015)	-	5 months (in 2019)
Decision to alternate the conventional packaging material	Due to changes in Indian laws	Large amount of banana peels was thrown away	-	Growing concern of consumers on the environmental impact caused by fossil-based packaging materials
Type of bio-based packaging used	Made up of sugarcane residues and banana leaves	Made up of 80-90% of soft pulp of the peel + cellulose	-	Cardboard based or fiber-based + PE lining (sometimes)
Challenges experienced	- Poor tensile strength - Expensive - Less availability - Softness in fruits due to condensation during storage - Extra handling - Less attractive from sensory/marketing point of view	- Couldn't increase pack size because of poor tensile strength - Less attractive from sensory/marketing point of view - Financial implications - Leakage due to poor material properties	- Migration of organic molecules from packaging - Expensive - Less availability - Leakage due to poor material properties	- Less attractive from sensory/marketing point of view - Drop in sales by 30% due to opaque packaging - Migration of organic molecules from packaging - Low life cycle analysis (LCA) and recyclability due to mixture with

	Expert 1	Expert 2	Expert 3	Expert 4
				plastics
Different points to control the quality in supply chain	- Temperature during storage (condensation) - Handling in the entire supply chain - Employee hygiene	- Temperature during storage (thick packaging material) - Transportation (poor tensile strength)	- Product of sealing and labelling - Temperature - Transportation - Packaging material integrity (thickness if decreased can cause leakage)	-
How to control at these spots	- Educating the food handlers to handle the packed produce carefully	- Quality check (QC) before dispatch - QC during transportation [F/V damage each other] - Smell and sampling aspect very rigid. Smell should not leach out of container, needs to be checked at every moment - Intensive training programs for the food handlers	- Train the food handlers - Conducting rigorous checks on the material's integrity	-
Additional inputs	- Ready to change if costs and delivered quality is comparable	- Consumer awareness will lead to acceptance of alternative packaging	- The packaging material should be a monomer to be more sustainable - PLA is a good alternative to fossil-based plastics but not recyclable (hence not that sustainable)	- Biobased or biodegradable do not fit into circular economy currently so not a sustainable option - Companies ready to switch to sustainable options but poor consumers acceptance

3.2.1 Quality deviations in fresh fruits and vegetables (Step 2)

After careful analysis, the following quality deviations in Table 9 were mentioned by the experts. These quality deviations were drawn when the conventional packaging materials were replaced by the bio-based packaging materials.

Table 9 Quality deviations in fresh fruits and vegetables

Types of quality deviation	Processes	Quality attributes affected	Expert(s)
Physiological	Softening	Appearance, texture, flavor	1
Physical	Leaching out of aroma	Flavor	2,3

Expert 4 stated that there will be no quality deviations in fresh fruits and vegetables until the shelf life of the packaging material exceeds the shelf life of the fresh product. Since, in biobased packaging material there are higher chances of the packaging material disintegration.

Expert 1 noticed that the fruits and vegetables were becoming soft during the storage. This made the final packed produce unacceptable to the consumers. Moreover, Expert 2 stated that there are high chances of the leaching out of aroma from the fruits and vegetables. This was specially observed when the biobased packaging material was used to pack the produce. He also stated that due to leaching out of aroma, the consumers perceive that the fruits and vegetables has lost its freshness. The Expert 3 also stated the similar concern when the alternative packaging material was used.

3.2.2 Identifications of technological and managerial factors (Step 2)

The following Table 10 was developed to summarize the technological and managerial factors obtained from the expert interviews.

Table 10 Technological and managerial factors influencing the quality attributes of packed fruits and vegetables in bio-based materials

Factors	T/M	Affected quality attributes	Expert(s)
Packaging material properties:	T		
• Tensile strength		Appearance	1,2
• Migration of material into the product		Safety	3,4
• No product visibility (Opaque material)		None	1,2,4
• Thick packaging material		Texture	2,3
• Low sealability		Flavor	3
Temperature	T	Appearance, texture,	1,2,3

Factors	T/M	Affected quality attributes	Expert(s)
		flavor	
Product handling	M	Appearance, safety, defects	1,2,3
Employee hygiene	M	Safety	1
Training and knowledge of food-handlers	M	Appearance, safety	1,2,3
Manufacturing costs	M	None	1,2,3,4

Technological factors

As mentioned in the Table 10, different types of packaging material properties were highlighted by the experts. These properties can affect the quality attributes of the fresh produce. The poor tensile strength of the biobased packaging material was experienced by the Experts 1 and 2. Expert 2 mentioned that they tried to add cellulose to give strength to the material. This was successful in small packages but were unable to create bigger packages to store various fruits and vegetables.

Expert 3 and 4 highlighted the possibility of the organic molecules from the packaging material to migrate into the product. For example, the migration limits are not clearly set for the packages like the cardboard. The presence of these molecules could create a safety issue. Expert 4 also gave additional insights on the product visibility in the packaging. He mentioned that the biobased/biodegradable (cardboard) material is generally opaque. This makes the packaging material look unattractive to the consumers. When the company tried to alternate the packaging material, they observed for about 30% drop in the sales. The similar point of unattractiveness to the consumers was also mentioned by the Experts 1 and 2, even though the quality of the fresh produce was not compromised. Also, the companies had to switch back to the conventional packaging material due to financial implications.

The Experts 2 and 3 also commented on the thickness of the packaging material as the possible reason to affect the quality attributes of the fresh produce. Expert 2 stated that due to poor tensile strength, the thickness of the biobased packaging was increased which leads to extra refrigeration costs in storage. Whereas, Expert 3 commented on decreasing the thickness of the packaging material can lead to the leakage of gases/odour. Furthermore, Expert 3 also took the example of PLA to state that they have poor sealing properties which can also lead to quality deviations in fresh produce.

The temperature was considered another important technological factor which can lead to quality deviations in fresh produce by Experts 1, 2 and 3. Expert 1 stated that the temperature if not controlled, can lead to condensation in the packed produce which in turn affects the appearance, texture and flavour. The Expert 2 and 3 highlighted the importance of temperature control especially when the thickness of the material is varied.

Managerial factors

Product handling was considered as one of the important managerial factors by Experts 1, 2 and 3. Expert 1 explained that when the biobased packaging material was used to pack produce, extra care was required due to the degradable nature of the material. He also gave an example of the packaging material if it comes into contact with water, degrades exponentially. Thus, rendering the produce unacceptable to the consumers in terms of appearance, safety and defects. Experts 2 and 3 also stated the importance of handling the packed produce in transportation. Extra care should be taken in placing the packed produce so that the packaging is not tampered, and fresh produce is not bruised during this process.

The employee hygiene was only highlighted by Expert 1. He stated that the good hygienic conditions of the food handlers should be practiced in the entire supply chain. This can avoid the contamination in the final packed produce.

The food handlers were educated and trained when the alternate packaging material was introduced by Experts 1 and 2. Moreover, Expert 3 also stated the importance of training the food handlers. This was done to educate them with the fragile nature of the packaging material, and that it required extra handling as compared to the produce packed in conventional packaging material. Rigorous quality checks were performed by the food handlers to avoid any quality deviations in the final product.

All 4 Experts agreed on the increased manufacturing costs by introducing expensive biobased packaging material. This was due to increased handling, additional refrigeration costs due to increased thickness and the costs involved to train the food handlers. Even though manufacturing costs don't induce the quality deviations, but it was considered as an important factor in terms of alternating the packaging material.

3.2.3 Identified CQPs (Steps 3 and 4)

In reference to the QACCP tool (Figure 2), Sections 3.2.1 and 3.2.2; the following technological (T) and managerial (M) factors are enlisted in Table 11 as the quality points (QPs). It was observed in the previous sections that most of these QPs influence the desirable quality attributes of the final product to an irreversible or unacceptable quality by the consumers. Therefore, these QPs were identified as CQPs because if these QPs are controlled, it can prevent or reduce the quality loss of the final product to an acceptable level.

Table 11 Identified CQPs based on expert interviews

Quality points	T/M	Unacceptable to consumers	Irreversible	CQP?
Packaging material properties:	T			
• Tensile strength		✓	✓	Yes
• Migration of material into the product		✓	✓	Yes

Quality points	T/M	Unacceptable to consumers	Irreversible	CQP?
• No product visibility (Opaque material)		✗	✗	No
• Thick packaging material		✓	✓	Yes
• Low sealability		✓	✓	Yes
Temperature	T	✓	✓	Yes
Product handling	M	✓	✓	Yes
Employee hygiene	M	✓	✓	Yes
Training and knowledge of food-handlers	M	✓	✓	Yes
Manufacturing costs	M	✗	✗	No

3.2.4 Conceptual framework based on expert interviews

The following conceptual framework was developed after scrutinizing the expert interviews.

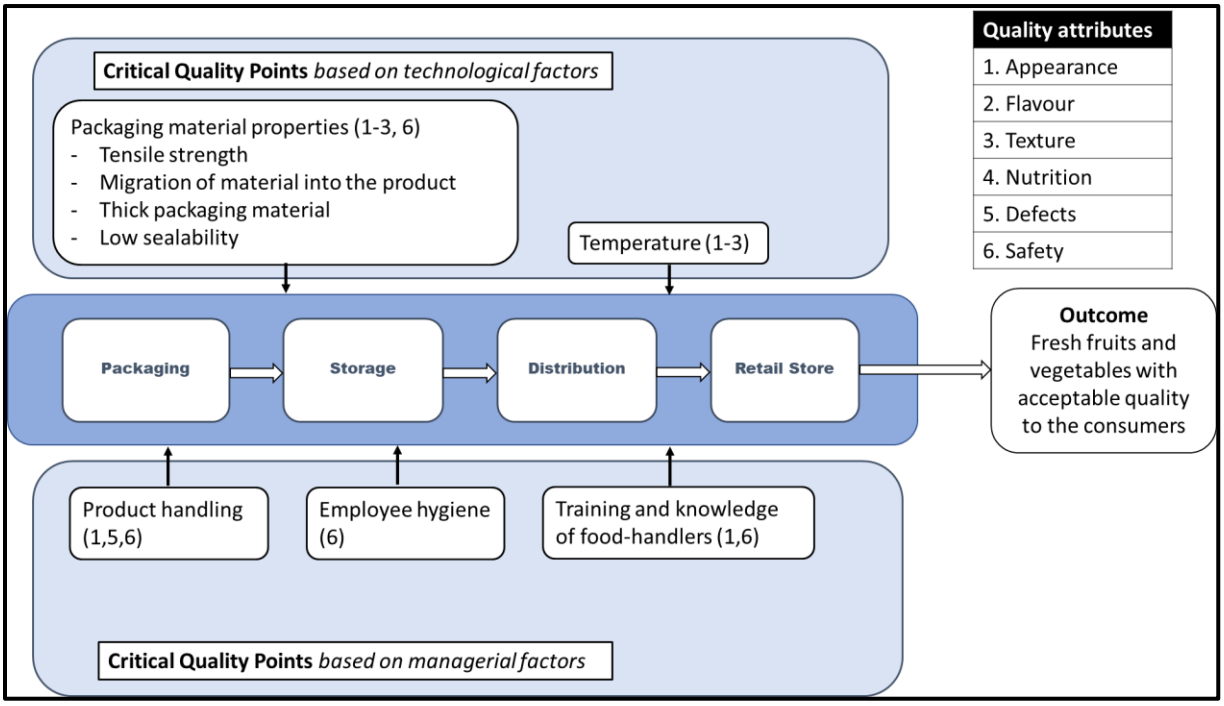

Figure 4 CQPs identified based on expert interviews potentially influencing quality attributes

The Figure 4 represents the CQPs mentioned by the experts. It was observed that all the experts agreed on the packaging material properties as one of the critical quality points which can affect the quality attributes of the final packed produce. The temperature was another CQP from the technological factors which can vary depending on the packaging material integrity.

As discussed in the Section 3.1.5, the managerial factors enlisted from the literature search were not specifically related to the implications of using the bio-based packaging material for fresh produce. Whereas the managerial factors mentioned in the Figure 4 as the CQPs are verified by the experts.

3.3 Result analysis

The results obtained from the literature review and expert interviews were integrated and analyzed under the following section. The analysis is presented corresponding to the SRQs in the study.

3.3.1 Quality deviations using the petrochemical based packaging materials (SRQ 2)

Table 12 depicts the quality deviations observed in the packed fruits and vegetables using the petrochemical based packaging materials.

Table 12 Quality deviations using petrochemical based packaging materials from literature review

Packaging material	Possible quality deviations	Processes	Affected quality attributes
Perforated fruit boxes and wax-lined cartons sealed with LDPE films	Physical, physiological	Weight loss, ripening	Appearance, texture
OPP	Physical, microbial	Weight loss, pathogen growth	Appearance, texture, flavor, safety

There was a total of 10 findings in the literature review. The quality deviations like physical, physiological and microbial were observed in 2 out of 10 findings when the conventional packaging material was used to pack fresh fruits and vegetables as stated in Table 12. These deviations affected the quality attributes like appearance, texture, flavor and safety. Whereas in the other 8 findings, the conventional packaging material had a positive effect on the quality attributes of the fresh produce (Table 4). According to the expert interviews, no quality deviations were highlighted when the petrochemical based packaging materials are used.

The results obtained from the literature review involved varied forms of conventional packaging materials like LDPE and OPP films. Moreover, the fruits and vegetables packed in these packaging materials also varied. This might be the reason of the varied results between the two approaches. The gap between the results can be reduced by increasing the number of expert respondents. Additionally, the results based on the similar fruits and vegetables and packaging materials will help in drawing up better conclusions. Thus, the findings suggest that the physical quality deviations can lead to the irreversible changes in the final quality attributes of the fresh produce.

3.3.2 Quality deviations using the bio-based packaging materials (SRQ 3)

Table 13 depicts the quality deviations observed in the packed fruits and vegetables using the bio-based packaging materials.

Table 13 Quality deviations using bio-based packaging materials from literature review and expert interviews

Packaging material	Types of quality deviations	Processes	Affected quality attributes
Based on literature review			
Wheat gluten-paper	Physical	Weight loss	Appearance, flavor
PHB-coated paperboard trays overwrapped with perforated starch bags; PLA- coated paperboard trays overwrapped with perforated starch bags	Physical	Weight loss	Appearance, flavor
Based on expert interviews			
Sugarcane residues+banana peels	Physiological	Softening	Appearance, texture, flavor
80-90% of soft pulp of the banana peel + cellulose	Physical	Leaching out of aroma	Flavor

There was a total of 12 findings in the literature review. The physical quality deviations were observed in 2 out of 12 findings when the bio-based packaging material was used to pack fresh fruits and vegetables as stated in Table 13. These deviations affected the quality attributes like appearance and flavor. Whereas 6 out of 12 findings had positive effects on the quality attributes of the fresh produce (Table 4). The rest finding had no effects on the quality deviations (Table 4).

According to the expert interviews, the physiological and physical deviations were observed in fresh produce packed in bio-based packaging materials. These deviations affect the quality attributes like appearance, texture and flavor.

The results obtained from the literature review mainly involved the wheat gluten paper, PLA PHB paperboard trays wrapped with starch bags as the bio-based packaging materials. On the other hand, it was observed that the banana peel was mainly used as a bio-based packaging material. Moreover, the fruits and vegetables packed in these packaging materials also varied. This might be the reason of the varied results of the quality deviations in the packed produce. The gap between the results can be reduced by increasing the number of expert respondents. Additionally, the results based on the similar fruits and vegetables and packaging materials will help in drawing up better conclusions. Based on both results, the physical and physiological quality deviations can lead to the irreversible changes in the final quality attributes of the fresh produce.

3.3.3 CQPs using the bio-based packaging materials (SRQs 4 & 5)

Table 14 states the comparison between the CQPs obtained from the literature review and the expert interviews using the bio-based packaging materials.

Table 14 CQPs based on literature review and the expert interviews

	Factors (Literature review)	T/M	CQP?	Factors (Expert interviews)	T/M	CQP?
Similarities	Temperature	T	Yes	Temperature	T	Yes
	Employee hygiene	M	Yes	Employee hygiene	M	Yes
	Training and knowledge of food-handlers	M	Yes	Training and knowledge of food-handlers	M	Yes
Differences	Packaging material properties:	T		Packaging material properties:	T	
	• Gas barrier (CO_2 and O_2)		Yes	• Tensile strength		Yes
	• Moisture barrier		Yes	• Migration of material into the product		Yes
	Time	T	Yes	• No product visibility (Opaque material)		No
	Maintenance of equipment and facilities	M	Yes	• Thick packaging material		Yes
	Pest and waste control	M	Yes	• Low sealability		Yes
				Product handling	M	Yes
				Manufacturing costs	M	No

As shown in Table 14, it was observed that the temperature was identified as a CQP in both literature review and the expert interviews. Also, the managerial factors like employee hygiene and training & knowledge of food handlers were found to be similar in both forms of the study. However, the factors such as packaging material properties identified in the literature review varied from the packaging material properties found via expert interviews. The different causal properties for the same technological factor were identified. This might be because the verification questions were not asked in line with literature findings. The interview conducted with the experts consisted of open-ended questions. This was done to obtain the additional insights on the study. This is also to find the degree of importance the different properties hold according to experts when the fresh produce is packed and sold to the consumers. Managerial factors such as maintenance of equipment and facilities; pest and waste control were not mentioned in the expert interviews as the presence of control measures for these factors pre-exist in the company. Product handling was considered as the CQP by 3 experts due to the poor packaging material properties of the bio based as compared to the conventional packaging

material. Even though manufacturing costs was the cause of concern for all the experts, it does not affect the quality attributes of the fresh produce. Hence, it was not considered as the CQP.

Based on both results, it indicates that the total of 8 CQPs if not controlled, can cause an irreversible change to the final packed produce. Thus, making it unacceptable to the consumers.

4 Conclusions, limitations and recommendations

This chapter will discuss about the final conclusions of the research project. It will also address the limitations and the recommendations for further study.

4.1 Conclusions

The aim of the research was to identify the possible quality deviations by establishing the CQPs in fresh fruits and vegetables when petrochemical (conventional) based packaging material is replaced by bio-based packaging material. The QACCP tool was applied to systematically answer research questions.

Based on the results, the attributes such as appearance (size, shape, colour, defects), flavour, texture, nutritive value, defects and safety were identified as the main quality attributes of fresh fruits and vegetables according to consumers. When the conventional packaging material is used, the physical, physiological and microbial quality deviations like weight loss, ripening and pathogen growth causes an irreversible change in the final quality attributes like appearance, texture, flavour and safety. On the other hand, bio-based packaging materials causes physical as well as physiological quality deviations like weight loss, softening and leaching out of aroma. Thus, leading to an irreversible change in the final quality attributes like appearance, texture and flavour.

The total of 9 factors were identified in the study. The 3 of them were technological factors like temperature, time and packaging material properties (gas barrier, moisture barrier, tensile strength, migration of material into products, no product visibility, thick packaging material and low sealability). The rest 6 were the managerial factors like employee hygiene, training and knowledge of food handlers, maintenance of equipment and facilities, pest and waste control, product handling and manufacturing costs. The managerial factor like the manufacturing costs and the one of the packaging material properties like no product visibility did not affect the quality attributes of the fresh produce. Therefore, the total of 8 out of 9 factors were responsible to affect the quality attributes of the final products (appearance, texture, flavor, safety, defects, nutritive value). These factors were identified as the CQPs. These CQPs if controlled, can prevent or reduce the quality loss of the final product to an acceptable level.

The varying results were observed from both the approaches (literature review and expert interviews). The different results were however taken into consideration to cover all the aspects affecting the quality attributes of the final products when packed in bio-based packaging materials.

4.2 Limitations

1. There was lack of enough literature explaining the managerial factors specifically causing the quality deviations in the fresh produce packed in the bio-based materials. The results were rather more generic. Moreover, the data obtained from the literature review were not directly implying to the different stages of the supply chain.

2. The questionnaire designed for the expert interviews consisted of open-ended questions. This was done to obtain additional insights from the experts due to the recent introduction of the bio-based packaging material into the market. Hence, there is a possibility of missing out the important factors as potential CQPs since verification questions were not asked during the interview.

3. The initial idea was to interview the experts having a working experience in the fresh produce supply chain network which is in transition of alternating the conventional packaging material of the fresh produce with the bio-based material or working in the bio-based packaging material manufacturing company for fresh produce. Due to shortage of time and poor responses, the experts from the packaging consultancy and scientific researches were also interviewed. As a result, the focus of these experts was inclined more towards the packaging as compared to the quality of the fresh produce.

4. The interviews were designed only for the experts but not for the consumers. The consumers perspective can also be valuable to gain insights on the importance of quality attributes of the final packed produce. This can help in verifying the SRQ 1. Also, to get additional insights on the quality deviations experienced when consumers buy packed produce in alternative packaging material.

5. It was also observed that the experts were a bit reluctant to reveal all the information about their work. This can also lead to less accurate or reliable data obtained via expert interviews.

6. None of the experts interviewed were currently working with the bio-based packaging material. This was due to the lack of availability of the packaging material and higher costs which led the companies to switch back to the conventional packaging materials. The other reason was due to lack of the established recycling system for the bio-based packaging material as compared to the conventional packaging materials.

4.3 Recommendations

1. It would be recommended to find more of the managerial data from various other sources not used in the current study. This will help in making the data more reliable to the study aim.

2. It would be advisable to consider the recycled conventional packaging material as a sustainable alternative solution. This was recommended by the experts as recycled packaging materials are comparatively more sustainable then the bio-based packaging material. Also, that it falls into the circular economy.

3. To approach the companies successfully implementing the bio-based packaging material to pack the fresh produce. This will further help to validate the study.

4. In order to make the complete understanding of the empirical data, the consumers perspective should also be included in the study.

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Appendix 1: Function of Boolean operators

Boolean operator	Function
AND	Narrows a search, making it more specific
OR	Broadens a search, making it more general
NOT	Narrows a search, do not take the term following it

Appendix 2: Search strategies

Table 15 Literature search strategy for SRQ 1

Database	Research keywords	Hits	Relevant
Web of science	TITLE: (Fresh fruit* OR Fresh Vegetable* OR Petrochemical* packag* OR Conventional packag*) AND TOPIC: (Quality attribute*) AND TOPIC: (Packag* OR Storage* OR Distribut* OR Retail* OR Supply chain*)	44	3
	TOPIC: ((Quality OR attribute* OR Parameter* OR Internal OR External) AND (Fresh "Fruits" OR Fresh "Vegetables")) NOT TOPIC: (cut OR Smoothies OR Juices OR Organic OR Insecurit*) AND TOPIC: ((Consumer* OR Customer*) AND (Perception* OR Wish* OR Demand* OR Preference*) AND (Purchase* OR Buy*))	39	5
WUR Library	kw:("quality" OR attribute* OR parameter*) AND (perception* OR wish* OR demand* OR preference*) AND (purchase* OR buy*) AND ti:(Fruit* OR Vegetable*) AND ti:(Consumer) NOT ti:(Cut AND Organic)	46	1
Scopus	(TITLE-ABS-KEY (fresh AND fruit* OR fresh AND vegetable* AND "Packag*" OR petrochemical OR conventional AND quality AND attribute*) AND TITLE-ABS-KEY (supply AND chain* OR retail* OR distribut* OR storag* OR post AND harvest*) AND NOT TITLE-ABS-KEY (cut)) AND PUBYEAR > 1999	5	0
	(TITLE-ABS-KEY ((quality OR attribute* OR parameter* OR internal OR external) AND (fresh "Fruits" OR fresh "Vegetables")) AND TITLE-ABS-KEY ((consumer* OR customer*) AND (perception* OR wish* OR demand* OR preference*) AND (purchase* OR buy*)) AND NOT TITLE-ABS-KEY ((cut OR smoothies OR juices OR	47	1

	organic OR insecurit*))) AND PUBYEAR > 1999		

Table 16 Literature search strategy for SRQ 2 & 3

Database	Research keywords	Hits	Relevant
Web of science	TOPIC: ((Plastic* OR Convention* OR Petrochemica*) AND (Packag*)) AND TOPIC: ((Fresh Fruit* OR Fresh Vegetabl*)) AND TOPIC: (Retail* OR Storag* OR Distribut* OR Packag*) NOT TITLE: (Cut)	143	3
	TOPIC: (Plastic* OR Petrochemical* OR Conventional*) AND TOPIC: (Qualit* OR Deviat* OR Chang* OR Deteriorat*) AND TITLE: ((Fruit* OR Vegetabl*) AND (Packag*)) AND TOPIC: (Retail* OR Storag* OR Distribut* OR Packag)	20	1
	TITLE: (Fruit* OR Vegetable*) AND TITLE: (Qualit*) AND TOPIC: (deviat* OR deteriorat* OR defect*) AND TOPIC: (retail* OR distribut* OR packag* OR storag* OR postharvest*)	116	0
	TOPIC: (Bio?based OR Sustainab* OR biodegradab* OR Bio?polymer*) AND TOPIC: (Retail* OR Storag* OR Distribut* OR Packag) AND TITLE: ((Fruit* OR Vegetabl*) AND (Packag*)) AND TOPIC: (Qualit* OR Deviat* OR Chang* OR Deteriorat*)	5	0
CAB Abstract	((Fruit* or Vegetabl*) and Qualit*).ti. and (deviat* or deteriorat* or defect*).ab. and (retail* or distribut* or packag* or storag* or postharvest*).ab.	147	4
	(bio?based or sustainab* or biodegradabl* or bio?polymer*).ti. and (retail* or storag* or distribut* or packag).ab. and ((fruit* or vegetabl*) and packag*).ab. and (qualit* or deviat* or chang* or deteriorat*).ab.	22	5
Scopus	(TITLE-ABS-KEY ((plastic* OR convention* OR petrochemical*) AND (packag*)) AND TITLE-ABS-KEY ((fresh AND fruit* OR fresh AND vegetable*)) AND KEY ((retail* OR storag* OR distribut* OR packag* OR postharvest*)) AND NOT TITLE (cut)) AND PUBYEAR > 1999 AND (LIMIT-TO (LANGUAGE , "English"))	71	2
	(TITLE-ABS-KEY (plastic* OR petrochemical* OR convention*) AND TITLE ((fruit* OR vegetable*) AND (packag*)) AND TITLE-ABS-KEY (quality OR deviat* OR change* OR deteriorat*) AND TITLE-ABS-KEY (retail* OR storag* OR distribut* OR packag*)) AND PUBYEAR > 1999 AND (LIMIT-TO (LANGUAGE , "English"))	48	4

	(TITLE (fruit* OR vegetable*) AND TITLE (qualit*) AND TITLE-ABS-KEY (deviat* OR deteriorat* OR defect*) AND TITLE-ABS-KEY (retail* OR distribut* OR packag* OR storag* OR postharvest*)) AND PUBYEAR > 1999 AND (LIMIT-TO (LANGUAGE , "English"))	170	2
	(TITLE-ABS-KEY (bio?based OR sustainab* OR biodegradabl* OR bio?polymer*) AND TITLE-ABS-KEY (retail* OR storag* OR distribut* OR packag) AND TITLE ((fruit* OR vegetabl*) AND (packag*)) AND TITLE-ABS-KEY (qualit* OR deviat* OR chang* OR deteriorat*)) AND PUBYEAR > 1999	7	3

Table 17 Literature search strategy for SRQ 4 & 5

Database	**Research keywords**	**Hits**	**Relevant**
Web of science	TITLE: (fruit* OR vegetabl*) AND TOPIC: (bio?base* OR Bio* OR Bio?polymer*) AND TOPIC: (packag*) NOT TITLE: (cut) AND TOPIC: (influenc* OR Effect* OR Affect* OR Factor*)	117	3
	TOPIC: (Bio?based OR Sustainab* OR biodegradab* OR Bio?polymer*) AND TOPIC: (Retail* OR Storag* OR Distribut* OR Packag) AND TITLE: ((Fruit* OR Vegetabl*) AND (Packag*)) AND TOPIC: (Qualit* OR Deviat* OR Chang* OR Deteriorat*)	5	0
	TITLE: (Bio?based OR biodegradab* OR Bio?polymer*) AND TOPIC: (food OR Fresh produc*) AND TOPIC: (packag*)	276	2
	TOPIC: (manager* OR handler* OR worker* OR people*) AND TITLE: (fresh AND fruit* OR fresh AND vegetable*) AND TOPIC: (packag* OR retail* OR distribut* OR storag*)	13	1
CAB Abstract	((Fruit* or Vegetabl*).ti. and (bio?base* or bio* or bio?polymer*).af. and packag*.ti. and (influenc* or effect* or affect* or factor*).af.) not cut.ti.	167	1
	(bio?based or sustainab* or biodegradabl* or bio?polymer*).ti. and (retail* or storag* or distribut* or packag).ab. and ((fruit* or vegetabl*) and packag*).ab. and (qualit* or deviat* or chang* or deteriorat*).ab.	22	3

	(Bio?based or biodegradab* or Bio?polymer*).ti. and (food or fresh produc*).ab. and packag*.ab. (manager* or handler* or worker* or people*).af. and (((fresh and fruit*) or fresh) and vegetable*).ti. and (packag* or retail* or distribut* or storag*).af.	156 36	2 3
Scopus	(TITLE (fruit* OR vegetable*) AND TITLE-ABS-KEY (bio?base* OR bio* OR bio?polymer*) AND TITLE (packag*) AND TITLE-ABS-KEY (influenc* OR effect* OR affect* OR factor*) AND NOT TITLE (cut)) AND PUBYEAR > 1999 (TITLE-ABS-KEY (bio?based OR sustainab* OR biodegradabl* OR bio?polymer*) AND TITLE-ABS-KEY (retail* OR storag* OR distribut* OR packag) AND TITLE ((fruit* OR vegetabl*) AND (packag*)) AND TITLE-ABS-KEY (qualit* OR deviat* OR chang* OR deteriorat*)) AND PUBYEAR > 1999 (TITLE (bio?based OR biodegradab* OR bio?polymer*) AND TITLE-ABS-KEY (food OR fresh AND produc*) AND TITLE-ABS-KEY (packag*)) AND PUBYEAR > 1999 AND (LIMIT-TO (LANGUAGE , "English")) (TITLE-ABS-KEY (manager* OR handler* OR worker* OR people*) AND TITLE (fresh AND fruit* OR fresh AND vegetable*) AND TITLE-ABS-KEY (packag* OR retail* OR distribut* OR storag*)) AND PUBYEAR > 1999	57 7 201 18	1 0 4 2

Appendix 3: Critically appraised SRQs

Table 18 Critical appraisal of relevant publications for SRQ 1

Source	Aim	Category (Fruit/Vegetable)	Quality Attributes (Extracted sentences from the publications)	Are they measurable
Barrett, D. M., Beaulieu, J.	"Desirable and undesirable quality attributes of fresh-cut fruit and	Combined	**"1) color and appearance, 2) flavor (taste and aroma), 3) texture and 4) nutritional value**. As consumers, these four	Yes

Source	Aim	Category (Fruit/Vegetable)	Quality Attributes (Extracted sentences from the publications)	Are they measurable
C., & Shewfelt, R. (2010)	vegetable products are reviewed. Both instrumental and sensory measurements for determining these critical quality attributes are discussed. The advantages and disadvantages ofsensory and instrumental quality measurements are described"		attributes typically affect us in the order specified above, for example we evaluate the visual appearance and color first, followed by the taste, aroma, and texture." "Nutritional value is a hidden characteristic that affects our bodies in ways that we cannot perceive, but this quality attribute is becoming increasingly valued by consumers, scientists, and the medical profession."	
Belay, Z. A., Caleb, O. J., & Opara, U. L. (2019)	"Influence of initial gas modification on physicochemical quality attributes and molecular changes in fresh and fresh-cut fruit during modified atmosphere packaging"	Fruit	**"Physical quality attributes** are the most important criterion that consumers use to evaluate quality of fruit and vegetables. These quality attributes **includes firmness, colour, antioxidants, sugars and others**."	-
Omar, A. F., & MatJafri, M. Z. (2013)	"This paper is designed to contribute by collecting the principles that have been defined for fruits quality perceptively and scientifically and methodologies and technologies that have been used to determine and quantify the defined principles."	Fruit	"Different quality attributes from different group of customers (Huyskens-Keil and Schreiner, 2004). **External Qualities: Size, Shape, Colour, Defect. Internal Qualities: Flavour, Texture, Nutrition, Defect, Safety"** Quality can be categorized into an external and internal component. Six quality factors which are normally defined for fruits and vegetables are appearance, flavour, texture, nutritive value, defect factors and safety.	Yes
Chamhuri, N., & Batt, P. J.	"To gain an understanding of the quality cues that consumers look for in purchasing fresh meat and	Combined	**"Freshness (**intrinsic cue), was the most frequently cited variable when respondents thought about the quality of both product categories. Other variables included price and	-

Source	Aim	Category (Fruit/Vegetable)	Quality Attributes (Extracted sentences from the publications)	Are they measurable
(2015).	fresh fruit and vegetables in Malaysia."		cleanliness (extrinsic cues). Quality was associated with **freshness, food safety, nutrition and value**. Exploratory factor analysis identified food safety (implicit cue) as the most important construct in the respondents' evaluation of quality. Even in the fresh produce category, the indicators of freshness varied across the different types of fruit and vegetables. In the case of potatoes and apples, the freshness of the produce was described by the skin colour, freedom from blemishes and bruises, texture and firmness. For spinach, freshness was visually assessed by the colour, freedom from wilting and the appearance of the leaves."	
del Carmen, D. R., Esguerra, E. B., Absulio, W. L., Maunahan, M. V., & Masilungan, G. D. (2012)	"Understanding Consumer's Preference For Fresh Table-Ripe Papaya"	Fruit	"The **external attributes** consumers looked for in papaya are: medium **sized**-fruits, full yellow peel **color**, and **blemish- and disease-free**. For **internal attributes**, most prefer papaya with yellow orange **pulp color** and average **sweetness and texture**. Overall, respondents indicated that absence of decay and damage, sweetness, maturity, texture and price are the topmost considerations in purchasing."	-
Martinez-Carrasco, L., Brugarolas, M., Martinez-Poveda, A.,	"To further progress in research on perceived quality of fresh fruit and vegetables. It seeks to develop and discuss two models for perceived quality of tomato, including the	Combined	"From our viewpoint, the most important attributes when explaining perceived quality in tomato are **firmness, colour, and flavour**. Therefore, these experiences should be provided to consumers at the place of purchase."	-

Source	Aim	Category (Fruit/Vegetable)	Quality Attributes (Extracted sentences from the publications)	Are they measurable
Ruiz, J. J., & Garcia-Martinez, S. (2012)	price variable as an indicator for perceived quality of tomato"			
Opara, L. U., Al-Said, F. A., & Al-Abri, A. (2007)	"Understanding consumer perceptions and attitudes towards fruit quality is important in setting quality specifications for marketing as well as providing a useful guide for postharvest research aimed at quality improvement of fresh produce"	Fruits	"Among the five types of fruit examined in the study, the most influential quality attributes affecting consumer purchase were **flavour, sweetness, and colour** for banana (Musa acuminata) and date (Phoenix dactylifera), and flavour, sweetness, and **firmness** for apple (Malus domestica), mango (Magnifera indica), and orange (Citrus sinensis)."	-
Saba, A., Moneta, E., Peparaio, M., Sinesio, F., Vassallo, M., & Paoletti, F. (2018)	"The objective of this research was to gain insight into consumers' conceptualization of vegetables freshness, by analyzing the underlying variables that summarize various consumers' beliefs and expectations on sensory and non-sensory attributes of vegetables"	Vegetables	"This study contributes to research about freshness, that is an important attribute of the perceived quality of foods from the consumers' perspective. In particular, a broader concept of vegetables freshness was identified by consumers' opinions mainly associated with visual and other sensory attributes, such as **texture, taste, odor and aroma."**	-
Anne, N., Magnus, R. d., & Karin, W.	"This research aims to evaluate how combinations of color, shape and damages influence consumer liking and perceived sensory	Fruit	"It can be concluded that visual appearance **of color, shape and damage has a significant impact on consumer liking**."	-

Source	Aim	Category (Fruit/Vegetable)	Quality Attributes (Extracted sentences from the publications)	Are they measurable
(2019)	attributes"			
Orth, U. R. (2018)	To test this hypothesis that vegetable and fruit consumers perceive product quality forming an opinion about intrinsic quality attributes from extrinsic attributes and hence to understand how consumers form expectations towards vegetable quality a causal model has been developed."	Combined	"Lacking immediate insight in intrinsic product quality attributes, consumers' perception of vegetable or fruit quality instead is most often based on **extrinsic** product attributes, for example **price, labeling** (indicating cultivation method, quality grade or origin), **appearance** (eye-appeal), **brand or store name**."	-

Table 19 Critical appraisal of relevant publications for SRQ 2

Source	**Aim**	**Category (Fruit/Vegetable)**	**Type of Quality deterioration**	**Possible quality deviations**	**Quality deviations when conventional/petrochemical packaging material used** *(Extracted sentences from the publications)*
Aked, J. (2002)	Focuses on maintaining fresh produce quality prior to its processing.	Combined	Physiological - Respiration Ethylene	Water loss, bacterial and fungal infections Water loss, physical damage pathogenic attack	"Polymeric films have been used to package fresh produce for over 35 years, with a number of benefits, including **control of water loss, protection from skin abrasion and reduced contamination of the produce during handling.** These films will also affect the movement of respiratory gases depending on the relative permeability of the film. This can lead to the development of lowered O2 and raised CO2 levels within the package and, as with CA storage, this can **reduce the respiration** of the produce and potentially extend shelf-life."
			Physical	Water loss Injury	
			Microbiological	Fungal and bacterial pathogens	
Nunes, M. C. N., Emond, J. P., & Brecht, J. K. (2006)	To show the relationships between weight lost during controlled temperature and humidity storage, from fourteen freshly harvested fruits and vegetables, and the major visual symptoms of loss of quality associated with moisture loss, such as changes in general appearance, color, and texture.	Combined	Physical	Water loss	-
Zerbini, P. E. (2002)	The recent findings as regards the effects of harvesting time, storage and ripening conditions on eating quality of pears are	Fruit	Physiological	Ripening	-

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when conventional/petrochemical packaging material used *(Extracted sentences from the publications)*
	reviewed and the relations between chemical and sensory properties are discussed.				
Jomngam, P., Chen, K. Y., Chumpookam, J., & Shiesh, C. C. (2017)	The objective of this study was to evaluate the optimal ripening temperature and management temperature during storage to maintain good fruit quality of atemoya.	Fruit	Physiological	Ripening	-
Siddiqui, M. W. (2015)	To discuss about how the postharvest quality of fresh horticultural produce gets influenced by both preharvest and postharvest factors.	Combined	Physiological	Ripening	-
Bouzo 2012	The aim of this study was to investigate the effect of different wrappers in fresh fig fruits during postharvest.	Fresh fig fruit	Physical	Weight loss	"Auto-modifying gas atmosphere using wrappers with selective permeability (MAP) produces a **decrease in the respiration** rate and thus further extends the storage life and **quality appearance**. In the **MAP treatment, the weight loss was 5.9%, while T had the highest weight loss (18%). Firmness decreased as weight loss increased in each treatment.** Finally, the MAP treatment resulted in better internal and external appearance and the fruits of the unwrapped T treatment had a significant loss of quality."
Chandra, D., Lee, J. S., Choi, H.	To decipher the effects of modified atmosphere	Vegetables	-	-	"The use of micro perforated HDPE film as a packaging material for whole radish roots contributed largely to **maintaining the quality parameters and extended a considerable period of**

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when conventional/petrochemical packaging material used *(Extracted sentences from the publications)*
J., & Kim, J. G. (2018).	packaging with or without curing on the quality attributes of Korean radish roots during storage at 0∘C for an extended period.				**postharvest life**. Results obtained from this study clearly depicted the better ability of packaging film in **reducing weight loss and maintaining color and firmness traits as well as better maintenance of several sensory qualities that jointly** resulted in an increased marketable period of radishes. Therefore**, the use of HDPE film could be a better option** for packaging radishes in order to ensure an extended shelf life during storage at low temperature."
Chandran, S. (2010)	In this study, plastic film was used to investigate the effects on shelf life and fruit quality attributes of dragon fruit.	Fruit	-	-	"As the fruit respire, oxygen level decreases and the carbon dioxide level increases within the sealed bag. This will ensure the **respiration rate of the fruit is reduced and the consumption of respiration substrates is retarded.** Ultimately, postharvest fruit quality can be maintained with simple modified atmosphere storage." "The **mature green fruit remained firm and did not show any change in colour to indicate that ripening had not commenced while in storage** while the unripe and ripe fruit also remained as they were on the first day of storage. In order to maintain quality and at the same time prolong shelf life, packaging has been introduced for perishable products such as fresh fruit." **"An important consequence of film packaging is it effect on fruit appearance.** Results indicated that, all fruits packed **maintained peel colour up to two weeks** when stored at low temperature. In this study**, pulp firmness decreased regardless of fruit packaging. Reduction in pulp firmness is directly correlated with fruit softening** which are contributed by enzymatic degradation of pectin turning a fruit to soft edible fruit."
D'Aquino, S., Palma, A., Schirra, M.,	To assess the effectiveness of individual film packaging, applied as	Fruit	Physical	Weight loss, scald and browning	"As expected, no typical symptom of chilling injury developed both in control and wrapped fruit, **while excessive weight loss, extensive scald and browning of the peel associated with a high incidence of decay, strongly altered the visual appearance**

Source	**Aim**	**Category (Fruit/Vegetable)**	**Type of Quality deterioration**	**Possible quality deviations**	**Quality deviations when conventional/petrochemical packaging material used** *(Extracted sentences from the publications)*
Continella, A., Tribulato, E., & La Malfa, S. (2010).	a standalone treatment or in combination with fludioxonil, on reducing the occurrence of husk scald, weight loss and decay.				**and reduced the percentage of salable fruit in control fruit.** MA achieved with film wrapping had a striking effect on transpiration, in inhibiting husk scald and maintaining freshness for all the storage periods and the following shelf-life."
Fernandez-Leon, M. F., Fernandez-Leon, A. M., Lozano, M., Ayuso, M. C., Amodio, M. L., Colelli, G., & Gonzalez-Gomez, D. (2013).	To identify, quantify and compare the main quality parameters and functional compounds of 'Parthenon' broccoli florets stored at two different conditions.	Vegetable	Physical	Weight loss	"The results indicated that the loss of quality was lower in MAP than in Control samples when comparing with Fresh sample. In addition, **the weight loss in MAP samples was 0.75% while in the Control samples was 3.36%** at the end of storage. Besides, the losses of external attributes were also more pronounced in Control than in the MAP samples."
Somboonkaew, N., & Terry, L. A. (2011).	To detail the physiological and biochemical changes in non-adulterated and commercially-treated litchi fruit stored in different	Fruit	Physical	Weight loss, lower pericarp moisture content	"Unwrapped fruit had a **greater fruit weight loss than those wrapped with PP** or PropaFresh™ PFAM films. The reduced fruit weight loss in PropaFresh™PFAM film regimes could be due mainly to the low moisture vapour permeability of this film resulting in slight difference of vapour pressure between fruit and atmosphere in the packages. Unwrapped fruit at both storage temperatures had significantly lower pericarp moisture content

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when conventional/petrochemical packaging material used *(Extracted sentences from the publications)*
	packaging films under different storage temperatures.				than those wrapped with PP or PropaFresh™ PFAM."
Sahoo, N. R., Bal, L. M., Pal, U. S., & Sahoo, D. (2014).	To study the effect of packaging material and storage environment on shelf life of fresh bell-pepper.	Vegetable	-	-	"The major changes taking place during **its senescence include loss in weight due to moisture loss, degradation of chlorophyll thus change in colour, loss of turgidity and change in texture, loss of nutritional value and reduction in marketability**. Polymeric film packaging in combination with cool storage has been successful in **delaying senescence, maintenance of physico-chemical constituents and extending shelf life**. However, the selection of an appropriate packaging film and packaging techniques are the important criteria for its storage life. The PLW% in case of bell pepper storage was maximum in the ambient control which was 21.60 (±2.57) %. A decrease in the peak force required to puncture the bell pepper samples was observed in all the packaging types both under ambient and refrigerated storage conditions. Marketability quality of fruits and vegetables was subjectively assessed by observing the level of visible mould growth, rotting, shriveling or discoloring."

Table 20 Critical appraisal of relevant publications for SRQ 3

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
Del Nobile, M. A., Baiano, A., Benedetto, A., &	A comparative study on the influence of films with different water and gas permeability on the	Vegetable	-	-	"Results showed that over the period of observation the lowest respiration activity was found for lettuces packed with PF1, whereas lettuces packed using PF2and BF films showed a similar respiration activity. On the other hand, no substantial differences in the color variation kinetics due to the packaging with the three

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
Massignan, L. (2006).	quality decay of fresh processed lettuce is presented				investigated films were detected. Results pointed out that the two commercially available polyolefinic films and the investigated biodegradable one have similar gas barrier properties. Results suggest that using biodegradable films with appropriate barrier properties, performances similar to that of commercially available poliolefinic films, in terms of senescence level and color variation, can be obtained."
Briassoulis, D., Mistriotis, A., Giannoulis, A., & Giannopoulos, D. (2013)	To validate the optimal design of the innovative equilibrium modified atmosphere (EMA) biodegradable bio-based film package.	Combined	-	-	"Results from lab experiments show improved efficiency of the optimized PLA based EMAP system in **prolonging the shelf-life time** of horticultural commodities as compared to non-packed commodities and commodities packed with conventional oriented polypropylene (OPP) film. Comparisons with non-packed commodities and commodities packed with conventional oriented polypropylene (OPP) show improved shelf-life time of peach and cherry tomatoes packed in the PLA and PLA/Mater-Bi based EMAP systems." "Improving the quality characteristics and controlling better fungal decay of these fruits, as compared to conventional BOPP EMAP systems."
Briano, R., Giuggioli, N. R., & Girgenti, V. (2016).	To evaluate the performances of three biodegradable and non-commercial films from starch corn to storage in the warehouse some experimental units (minibag) of 'Himbo Top®' raspberry fruits up to 12 days at +1°C and 95% RH.	Fruits	-	-	"From the fruit packing (0 day) as expected, a decrease in the headspace O2 concentration, as well as an increase in the headspace CO2 concentration was observed during storage for each wrapping film. All films instead showed good performances in terms on **maintenance fruits aroma and turgidity and no fungal decay was observed on fruits**. In a warehouse, the management of the fruits using new materials such as biodegradable and compostable films could represent an important opportunity to develop a sustainable policy."

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
Briano, R., Giuggioli, N. R., Girgenti, V., & Peano, C. (2015).	The objectives of this study were as follows: (1) to evaluate the performance in terms of gas transfer of the noncommercial biodegradable and compostable films under different temperature conditions; (2) to evaluate the capacity of the new films to manage a passive MAP to store a new everbearing variety of red raspberry, the cv. Grandeur, for up to 12 days at a cool storage temperature (1 ± 1C) and at the most common temperature at European retail points (20 ± 1C); and (3) to evaluate the impact of the resulting gas conditions on the quality and nutraceutical	Fruits	Physical	Weight loss	"The **lower weight loss in fruits packed with the biodegradable and compostable films** compared with unpacked fruits (control) stemmed from the low rates of water loss in the MAP fruits, which occurred because the atmosphere of the packed fruits was limited; however, for the macroperforated film (F1), the reduction of weight loss was due to protection from mechanical damage. The F2 and F3 films were the only films suitable for storing fruits for up to 12 days because they limited weight loss at high temperature (20 ± 1C) due a good barrier to humidity. The data showed that weight loss was not a limiting factor for the quality of the cv. Grandeur fruits during storage, even when the berries were subjected to metabolic stress due to the change of temperature." "Biodegradable and compostable films (F2, F3 and F4) showed a positive effect on the **retention of external color** of the cv. Grandeur compared with the macroperforated film (F1) and unwrapped fruits (control) due to the modification of the atmosphere inside each package. "This study indicated that the new films used to wrap the packages are good substitutes for traditional plastic film (polypropylene macroperforated film) and could be used throughout the supply chain of the cv. Grandeur. The new tested films minimized changes in weight loss and color of the raspberries, showing the best performance at a lower temperature (1 ± 1C) and changed the initial atmospheric composition inside the packages due to the good permeability properties of films to the gas and the respiration of cv. Grandeur."

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
	compounds of raspberry fruits at various storage times.				
Dukalska, L., Muizniece-Brasava, S., Kampuse, S., Seglina, D., Straumite, E., Galoburda, R., & Levkane, V. (2008).	To check the published data of biodegradable PLA packaging film special suitability to provide longer shelf life of fresh fruits and vegetables, some in Latvia cultivated fruit storage were tested.	Fruits	-	-	"The **highest CO2 content 18% have been observed in the PP trays sealed with OPP film** after 25 storage days. PLA pouches thickness of 40 µm (MaaG company) – 11 to 12% and O2 – 4%, which could be assessed as adequate to equilibrium modified atmosphere (EMAP) for minimal breathing of fruits at the storage time." "Suitability of biodegradable packaging materials for food application, for all that the experiment should be followed up."
Giacalone, G., & Chiabrando , V. (2013).	To evaluate the effect of MAP with biodegradable films on preserving sweet cherry fruit quality during cold storage (15 days).	Fruit	-	-	"Biodegradable films was useful to preserve quality of cherries through a **delay in the changes in colour and the losses of firmness and acidity**. Film 2, characterized by a high permeability to CO2 barrier to O2 and high provided the best results in terms of colour, acidity and firmness"
Giuggioli, N. R., Briano, R., Baudino, C., & Peano, C.	To evaluate the most important qualitative traits and volatile compounds of red raspberry variety cv. Himbo Top after	Fruit	-	-	"Considering all the qualitative parameters and aroma compounds measured, non-commercial biodegradable and compostable film showed the best results for storing fruits over a period of 96 h (48 h at 1°C followed by 48 h at 18°C). Among all aromatic components, terpenes and ketones underwent the greatest change during storage. The non-commercial

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
(2015).	wrapping the fruits in a non-commercial biodegradable compostable film and a PP film under passive and active MAP conditions for 96 h (48 h at 1°C followed by 48 h at 18°C).				biodegradable film used in this work can be proposed as a suitable packaging for raspberry fruits under both passive and active MAP conditions, due the **more attractive colour of the berries and the similarity of aroma profiles**, mainly dominated by terpenes. Packaging using film made from a renewable source such as that used in this work represents a promising solution to improving the marketability of these fruits."
Guillaume, C., Schwab, I., Gastaldi, E., & Gontard, N. (2010).	To evaluate the ability of such composite wheat gluten-paper material to improve preservation of fresh products at ambient temperature (20 °C) as often encountered in European market and home storage, and 80% RH to simulate RH conditions used in the assessment of materials gas permeation.	Vegetable	-	-	"By maintaining **firmness, fair whiteness, and unbroken veils of mushrooms**, only MAP with WG-paper would satisfy consumer acceptance after 4 days of storage at 20 °Cand80%RH. However, slight yellowing of the cut part of stem appeared after 3 days of storage probably due to an excessive content in CO2 (9.5 kPa)." "It should be pointed out that the WG-paper exhibited **high water vapor permeability and consequently led to an important weight loss** on day 3 compared to the commercial film. However, it did not affect the overall quality of mushrooms within the storage duration."
Kantola, M., & Helen, H. (2001).	To find out if certain prospective biodegradable packaging materials are suitable for	Vegetable	-	-	"The weight loss of the tomatoes after three weeks of storage was from 1.7-2.7%, depending on the type of package used, being 1.7% for LDPE-bags and over 2.5% for bags made of biodegradable materials. The **water vapor barrier of biodegradable films is much poorer than that of LDPE film**."

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
	packaging of organic tomatoes.				"Respiration rate increases when storage temperature is increased, or relative humidity is decreased. The quality of organic tomatoes in biodegradable packages remained as good as the quality of tomatoes stored in LDPE bags for three weeks. For preserving tomato quality, it is essential that tomato packages are perforated and that the storage conditions are optimal for tomatoes, a too high temperature (over 14C) and a too low relative humidity (under 80% RH) increases fruit respiration and shortens shelf-life."
Peano, C., Giuggioli, N. R., & Girgenti, V. (2014).	To evaluate the effects of MAP on the storage of apricot fruits (cv. Tom Cot®) by evaluating the performance of different films used in unit flowpacks that yielded "ready-to-eat" fruit.	Fruit	-	-	"The biodegradable film was the only treatment that was **able to reach and maintain the equilibrium state; the amount of O2 entering the package and the amount of CO2 permeating out of the package were equal to the amount of O2 consumed and the amount of CO2 evolved by the packaged fruit.** Among all of the quality parameters, the fruit flesh firmness was the most affected by the storage process in modified atmosphere packaging. All films used were able to modify the initial headspace gas composition; the two multilayer films and the biodegradable film changed the internal atmosphere of packages containing apricots for up to 21 days of storage. An equilibrium was reached when the gas concentration inside the package stabilised, and this condition was observed only for the biodegradable film; it was maintained until the end of storage. identifies biodegradable film as a new flexible packaging material for storing apricots in modified atmosphere packaging."
Srinivasa, P. C., Susheelamma, N. S., Ravi, R., & Tharanathan, R. N.	Comparative studies on 'Alphonso' mango fruits packaged in perforated fruit boxes and wax-lined cartons sealed with	Fruit	-	-	"Mango fruits undergo both physical and biological changes during ripening. The **weight loss (WL) during storage was higher for fruits stored in perforated plastic box followed by those kept in cartons sealed with chitosan films**." "The **force required for piercing was lowest for the fruits stored in perforated plastic boxes,** followed by those stored in cartons sealed with LDPE films, **while those stored in cartons**

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
(2004)	either LDPE films or chitosan films have been carried out for both physical and sensory quality attributes during storage and the results are reported in this paper.				**sealed with chitosan films required highest force**, indicating retention of desirable firmness for a longer period." "The relatively high a negative values were indicating the greenness of fruits sealed with LDPE or chitosan films even after 10days, which decreased rapidly during further storage, but the a values were positive for the fruits packaged in the perforated plastic box indicating redness of color by 10 days of storage and this parameter showed little change after 12 and **the relative changes in L, a and b values indicated that ripening was delayed in the fruits packaged with chitosan films**." "In the LDPE film-sealed cartons, **condensation of water droplets on the inner film surface was noticed and fruits were also moist on the surface**, but this type of **condensation was absent in the cartons sealed with chitosan films**." "The higher level of carbon dioxide and lower level of oxygen or lower rate of oxygen transmission associated with chitosan films **delays ripening**, and the **higher water vapor transmission rate minimizes the rate of transpiration and prevents condensation** of water droplets on the film, thus helping to establish the equilibrium moisture content of mangoes in the cartons which, in turn, **extend the shelf life of fruits for a longer period**."
Mistriotis, A., Briassoulis, D., Giannoulis, A., & D'Aquino, S. (2016)	The development of a one-dimensional steady state analytical model of the in-package atmosphere assuming that WV transport process through the permeable packaging film obeys Fick's	Combined	Physical	Weight loss	"Weight losses of unwrapped fruit after the eleven days of storage were 7.7%, with an average weight loss per day of 6.9 g /kg. Fruit sealed in PLA80 and PLA90 bags at the end of storage lost 5.09% and 4.66% of their initial weight respectively, which is equivalent to 4.6 and 4.2 g/kg per day. This measured transpiration rate is within the range of 35–70 mg/kg/s. The weight loss in OPP bags were only 3.3%, equivalent to 3 g/kg per day. The results also show that the standard deviation of **weight losses is much smaller in both PLA and OPP packages compared to unwrapped fruits**. This indicates that the PLA

Source	Aim	Category (Fruit/Vegetable)	Type of Quality deterioration	Possible quality deviations	Quality deviations when bio-based/biodegradable packaging used (Extracted sentences from the publications)
	law. Using this analytical model, packaging bags made of PLA have been optimally designed and developed for two selected horticultural produce: cherry tomatoes and peach, as typical high value vegetables and fruits respectively.				packaging generated a stable in-package atmosphere offering a predictable control." "No rotten fruits were detected over the 11 days of storage when they were kept unpackaged. In contrast in packaged fruit decay developed from day 8 and further increased after 11 days of storage. Decay incidence was affected by the type of the package: for **fruits sealed in PLA80 packages there was no decay after 8 days and only 4% of rotten fruit were detected after 11 days**. Slightly higher levels of decay developed in PLA 90 packages, while **considerably higher losses occurred in OPP packages**. The stem end scar is generally the starting site of decay in cherry tomatoes, however if the scar is dry it is difficult for pathogens to start the infection. As a result, in unpackaged fruit no decay occurred over the storage time. In contrast, the **higher humidity inside the packages enhanced pathogen growth**, and the effect was **more pronounced in OPP packages due to the higher humidity and the presence of condensation**. The presence of condensed water prevented the drying process of the stem end scar, but also caused cracks of the peel starting from the end scar, thus increasing fruit susceptibility to decay." "It was shown that the relatively high water vapour (WV) permeability of PLA films compared to conventional OPP films allows the development of an optimised biodegradable bio-based EMA packaging system for the specific applications PLA was shown to be a versatile material which allows through a proper design, for a better control of the in-package atmosphere than conventional materials due to its higher permeability to water vapour combined with its barrier properties with respect to CO2 and O2."

Table 21 Critical appraisal of relevant publications for technological factors of SRQ 4

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
Peano, C., Giuggioli, N. R., & Girgenti, V. (2014)	To evaluate the effects of MAP on the storage of apricot fruits (cv. Tom Cot®) by evaluating the performance of different films used in unit flowpacks that yielded "ready-to-eat" fruit.	Fruit	Packaging material properties – Gas barrier	Storage	-	The temperature, the fruit weight and the exchange area through the film were kept constant during the entire storage time, so the evolution of the internal atmosphere inside each basket was influenced and controlled by the **interaction between the fruits' respiration and the film's permeability.** The biodegradable film was the only treatment that was able to reach and maintain the equilibrium state; **the amount of O2 entering the package and the amount of CO2 permeating out of the package were equal to the amount of O2 consumed and the amount of CO2 evolved by the packaged fruit.** Gas film permeability greatly influenced the composition of the internal atmosphere.
Mallia, I., Linke, M., Gottschalk, K., & Cerruto, E. (2010)	To examine dynamic changes of the permeability of different plastic films and the occurrence of condensation processes of closed packaging units depending on modified atmosphere under changing external climatic conditions.	Fruit	Temperature	Storage	Appearance (Microbial)	**Temperature has only little effect on permeability for CO2 and water vapor**, while **condensation can occur during decreasing transients** of periodic fluctuations of storage temperature. The **coefficient of permeability for water vapour is quite similar for all the films**, while some differences could be appreciated as regards the CO2.
Joo, M., Lewandowski, N., Auras, R., Harte, J., & Almenar, E. (2011)	This study compares the blackberry retail shelf life performance of different packaging materials, bio-based versus petroleum-based using the same	Fruit	Packaging material properties – gas & moisture barrier	Storage	Appearance, texture, flavor	In this study, despite the lower barrier to water vapor of the OPLA in front of that of the OPS, no significant differences in fungal growth were observed during storage. **Higher weight losses were observed in the OPLA packages than in the OPS** ones, 5.59% vs. 3.75%, and 4.28% vs. 3.62%, for 'Cancaska' and 'Chester', respectively, at the end of storage. The higher weight

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
	packaging design.					loss of the fruit in the OPLA container was due to the **higher permeability of the material to water vapor**. A decrease of TA accompanied by a decrease in SSC, as observed in this study, has been attributed to fruit with off-flavor, palatable taste, and others. Blackberries in the OPLA containers showed a **higher SSC to TA ratio** than that of the blackberries in the OPS containers possibly due to the **higher decrease in TA observed in the berries of the OPLA containers during storage**.
Giuggioli, N. R., Briano, R., Baudino, C., & Peano, C. (2015)	To evaluate the most important qualitative traits and volatile compounds of red raspberry variety cv. Himbo Top after wrapping the fruits in a non-commercial biodegradable compostable film and a PP film under passive and active MAP conditions for 96 h (48 h at 1°C followed by 48 h at 18°C).	Fruit	Temperature Time	Storage	-	After 48 h the biodegradable film-maintained fruit colour parameters near to harvest value (L 26.9 and 27.6, respectively for passive and active atmospheres) and, **as the temperature increased, it was the only film used that facilitated storage of fruit for up to 96 h**. *Headspace gas composition:* The increase in storage temperature after 48 h caused an increase in fruit respiration rate. The **lowest O2 and highest CO2 partial pressures were achieved gradually with the biodegradable and compostable film**, which also **improved the storability of raspberries at the highest temperature (96 h)**. Raspberries wrapped in the biodegradable and compostable film in active MAP maintained higher CO2 levels at all time points than the produce undergoing corresponding passive MAP.
Choklob, W., Gupta, R. K., & Kajorncheappunngam, S. (2019)	In this study, we want to explore the possibility of broadening the gas permeability range of permeable PLA blend based film by varying the rice husk ash (RHA) content and film stretching configuration.	Fruit	Time Packaging material properties – gas and moisture barrier	Storage		Bananas preserved for up to **14 days** whereas the **conventional LLDPE film was able to keep the freshness of bananas for only up to 8 days.** Moreover, a variety of **water vapor and oxygen permeability results indicated that PLA blend /RHA composite films could be used for various kinds of fruit as a green packaging material for extending the shelf-life** of fresh fruits.

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
Tengrang, S., Leabwan, N., Loylerd, K., Enmak, P., Changpraser t, S., & Korppiboon, A. (2017)	Effect of bio-packaging materials on postharvest life of rambutan fruit was investigated in this study.	Fruit	Packaging material properties – moisture barrier	Storage	-	Table 1. Properties of bioplastic bags.:  **PBS bags showed the lowest weight loss, of about 8.54%,** followed by LDPE bags (15.29%) and Mater-Bi® bags (24.97%) at the 18th day of storage. However, rambutan TA values in bioplastic bags were significantly different when compared with fruit packed in **LDPE bags**, where **TA decreases sharply by 3rd day of storage**. This result shows that PBS bags preserved the quality of fresh rambutan best and better than LDPE bags. This result is **consistent with the outer appearance of fruits**. Rambutan kept in PBS bags could have a shelf-life of 15 days at **13±2°C and 78% RH.** In addition, the bioplastic bags were environment-friendly and are considerably degraded after 100 days
Srinivasa, P. C., Baskaran, R., Ramesh, M. N., Prashanth, K. V. H., & Tharanathan, R. N. (2002).	The main objectives of the present study were to extend the shelf-life of mangoes using biodegradable chitosan films, which have higher water vapor transmission rate (WVTR) at room temperature, and to assess the physicochemical and physiological characteristics of the fruits during the storage period.	Fruit	Packaging material properties – moisture barrier Time	Storage	Appearance, texture, flavor	The fruits were kept in carton boxes whose top surface was covered with either chitosan film or with low-density polyethylene (positive control) or kept as such (control) and stored at room temperature (27±1 °C at 65% RH). The fruits stored as such had a shelf-life of 9±1 day, whereas **those stored in low-density polyethylene showed off-flavor due to fermentation and fungal growth on the stalk and around the fruits** and were partially spoiled. On the other hand, fruits stored in chitosan-covered boxes **showed an extension of shelf-life of up to 18 days** and **without any microbial growth and off flavor**. chitosan film1 (MAP1) or LDPE film (MAP2). **PLW was less in MAP1 in comparison to control fruits** because of reduction of transpiration loss and respiration rate in the former. PLW in MAP1 and control fruits was comparable up to 10 days, but on the 11th day, the control fruits showed small black patches due to microbial growth and on day 12 all the fruits were spoiled, whereas MAP1 fruits continued to remain green and fresh until day 18. **MAP2 fruits showed less**

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						weight loss (3.5%) compared to MAP1 (7.5%), probably due to **reduction in transpiration of water vapour in LDPE films**. The latter was observed as condensed water vapour droplets adhering to the inner surface of the LDPE films inside the boxes. The control fruits started spoiling from the 11th day onwards, **MAP2 fruits showed off-flavour and fungal growth after 12 days, but MAP1 fruits did not show any spoilage during the entire storage period of over 18 days,** which also **indicated the antimicrobial property of chitosan films in extending the shelf-life of the fruit**. It is also possible that this activity is related to the lower relative humidity in the chitosan-covered boxes. This is of importance in the transportation of produce to far-off places. No significant changes in color were observed in MAP1 and MAP2 stored fruits. After 5 days, the hue angle value of the control fruits shifted to the first quadrant, concomitant with the change in color of the fruit from green to yellow. The **retention of chlorophyll by MAP1 packaging indicates the effect of chitosan films in retarding the ripening process** and thus allowing extension of shelf-life. The **TSS increased with the storage period but MAP1 packed fruits showed a lower value throughout, compared to MAP2 and control fruits.** Lower TSS values (means a lower ripening rate) in MAP1 are probably due to its higher WVTR as compared with MAP2. The formation of TSS takes place due to the breakdown of complex carbohydrates into water-soluble sugars. **Condensation of water inside the pack resulted in higher humidity leading to fungal growth in fruits packed with LDPE**.
Siracusa, V., Rocculi, P., Romani, S., & Dalla	The aim of this review was to offer a complete view of the state of the art on	Combined	Packaging material properties – gas and	-	-	Barrier properties: Generally, plastics are relatively permeable to small molecules such as gases, water vapor, organic vapors and liquids and they provide a broad range of mass transfer characteristics, ranging

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
Rosa, M. (2008).	biodegradable polymer packages for food application.		moisture barrier; mechanical			from excellent to low barrier value, which is important in the case of food products. Carbon dioxide is now important for the packaging in modified atmosphere (MAP technology) because it can potentially reduce the problems associated with processed fresh product, leading a significantly longer shelf-life. For example, for fresh product respiration rate is of a great importance in MAP design so **identify the best packaging is a crucial factor**. The most important barrier properties of polymer films used in packaging application are described. Oxygen transmission rate (OTR): The **oxygen barrier property of a food packaging container for fresh product** (e.g. fruits, salad, ready-to-eat meals) plays an important role on its preservation. The oxygen barrier is quantified by the **oxygen permeability coefficients** (OPC)which indicate the amount of oxygen that permeates per unit of area and time in a packaging material [kgmm 2 s 1 Pa 1]. So, when a polymer film packaging has a **low oxygen permeability coefficient, the oxygen pressure inside the container drops to the point where the oxidation is retarded**, extending the shelf life of the product. Generally, **the biodegradable polymers present a value one or more order of magnitude below the synthetic polymer used in the same field as PET and OPS**. Water vapor transmission rate (WVTR): The water vapor barrier properties for the packaged product whose physical or chemical deterioration is related to its equilibrium moisture content, are of great importance for maintaining or extending its shelf-life. The water vapor barrier is quantified by the water vapor permeability coefficients (WVPC) which indicate the amount of water vapor that permeates per unit of area and time in a packaging material [kg mm 2 s 1 Pa 1]. For fresh food products it is important to avoid dehydration.

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						Carbon dioxide transmission rate (CO2TR): Like the oxygen and water vapor barrier properties, also, the carbon dioxide barrier property is of particular importance on food packaging application. The carbon dioxide barrier is quantified by the carbon dioxide permeability coefficients (CO2PC) which indicates the amount of carbon dioxide that permeates per unit of area and time in a packaging material [kg mm 2 s 1 Pa 1]. Mechanical properties: In addition, many packaging containers are commercially used below room temperature, so it is important to assess the mechanical performance under these conditions (Auras et al., 2005). Chemical resistance properties: The interaction and absorption between chemical compounds and polymer may affect the final mechanical properties of a polymer (Auras et al., 2005). PLA is becoming a growing alternative as a green food packaging material because it was found that in many situations it performs better than synthetic ones, like oriented polystyrene (OPS) and PET materials (Auras et al., 2005).
Robertson, G. (2008).	To discuss about bio-based packaging, the food industry and the environment	Combined	Packaging material properties – moisture and gas barrier	-	-	Properties of bio-based food packaging materials - Barrier properties: **WVTRs of starch-based films are 4–6 times greater than those of conventional films made from synthetic polymers**. PLA has WVTRs 3–5 times higher than PET, LDPE, HDPE and OPS; PHAs have WVTRs similar to those of petroleum-derived polymers. **PLA has better O2 barrier properties than PS but not as good as PET**; PHB has better barrier properties than PET and polypropylene (PP). The high CO2:O2 permeability ratio of certain bio-based packaging materials suggests that they could find application in the packaging of respiring foods such as fruits and vegetables.
Muratore, G., Del Nobile, M.	A comparative study on the influence of water and gas	Fruit	Packaging material properties	Storage	Appearance, texture, flavour	Package A was a high permeability polyolefinic film Package B was a ternary biodegradable mixture of three biodegradable polyesters, kindly Package C was a

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
A., Buonocore, G. G., Lanza, C. M., & Asmundo, C. N. (2005).	(oxygen and carbon dioxide) permeability of the packaging film on the quality decay kinetics of plum tomato is presented.		– gas & moisture barrier			binary biodegradable mixture of two biodegradable polyesters of natural origin, kindly provided by Novamont (Novara, Italy). The samples stored in direct contact with air (i.e., without using a polymeric film as package) will be referred to as the Reference sample. Film barrier properties: water permeability of the three investigated films did not depend on water activity. Moreover, it has been observed that the **water permeability coefficient of the two biodegradable films investigated in this work was much higher than that of the polyolefinic** one Sensorial descriptors: As shown in the above figures, brightness, juiciness, toughness and firmness show a similar trend. In fact, they remained practically constant over the entire period of observation for Package A, whereas in the case of the Reference and **Package B and C a continuous decrease in the value of the sensorial descriptors was observed.** Packed plum tomatoes for storage time longer than 12 days. In fact, the **lower water permeability of Package A could slow down the dehydration process**, whereas, the **lower carbon dioxide permeability** of Package A could promote a higher concentration of carbon dioxide in the package head space, which in turn **slows down the produce respiration rate**. **vitamin C content initially showed a slight increase** with storage time for the Reference, Package A, and **Package B**, whereas for Package C there was a marked decrease in vitamin C content. Results showed that films with higher oxygen permeability and lower water and carbon dioxide permeability, such as the film used for Package A, slowed down the detrimental phenomena responsible for the unacceptability of the investigated produce by **reducing the dehydration rate, ensuring that the**

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						oxygen concentration in the package head space did not go down to the threshold level required for aerobic respiration, and enhancing the accumulation of carbon dioxide in package head space, which slowed down the produce respiration rate. On the other hand, film with **low oxygen permeability**, such as Package C, speed up the quality decay kinetic. Results also showed that the **biodegradable film used for Package B had quality decay kinetics similar to that of Reference sample**, indicating that this type of film can be advantageously used to **prevent contamination from both microorganisms and insects, without reducing the shelf life of the packed produce**.
Mistriotis, A., Briassoulis, D., Giannoulis, A., & D'Aquino, S. (2016).	The main objective of the present work was the development of a one-dimensional steady state analytical model of the in-package atmosphere assuming that WV transport process through the permeable packaging film obeys Fick's law	Combined	Packaging material properties – moisture and gas barrier	Storage	-	Gas transport properties of PLA film offer selective permeability with respect to the three gases which are important in fresh produce packaging, **namely O2, CO2 and H2O** (WV). The CO2 and O2 molar fractions are controlled independently through the micro-perforation design. It was shown that the relatively high water vapour (WV) permeability of PLA films compared to conventional OPP films allows the development of an optimised biodegradable bio-based EMA packaging system for the specific applications. PLA was shown to be a versatile material which allows through a proper design, for a better control of the in-package atmosphere than conventional materials due to its **higher permeability to water vapour combined with its barrier properties with respect to CO2 and O2**. This PLA property in combination with the laser microperforation technology makes possible the

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						development of optimal EMAP systems fitting the **exact needs of specific high value horticultural products**. In this way, their **quality and safety is preserved for a longer shelf life period by using a bio-based and compostable material.**
Khwaldia, K., Arab-Tehrany, E., & Desobry, S. (2010).	The main objectives of this study were to review the different types of renewable biopolymers investigated as paper coating materials, to summarize the barrier, mechanical, and other properties possessed by biopolymer-coated paper, and finally to discuss existing and potential applications for bioactive coatings on paper coating materials.	Combined	Packaging material properties – gas and moisture barrier	Distribution, Storage	-	Barrier properties: To **avoid the moisture transfer that can affect food quality, WVP control is important to assure stability and safety during distribution and storage**. The ingress of oxygen, which is strongly and irreversibly reacted with food components such as lipids, vitamins, flavors, and colors, leads to permanent change in the nature of food products (rancidity, vitamin loss, and microbial contamination). **Good oxygen barrier properties are critical for achieving a long shelf life for the packaged product.** Other important gases to which food packaging should be less permeable are carbon dioxide and nitrogen
Abdul Khalil, H. P. S., Banerjee, A., Saurabh, C. K., Tye, Y. Y., Suriani, A. B., Mohamed, A., . . . Paridah, M. T. (2018).	The main aim of this review is to effectively summarize different types of biopolymer-based packaging which have been studied to increase the shelf life of freshcut agricultural products.	Fruits	Packaging material properties – gas and moisture barrier	Storage	-	Headspace gaseous composition is one of the important aspects of storage of minimally processed agricultural produce. An elevated O2 percentage inside the packaging usually leads to unfavorable reactions like oxidation and browning while a lower O2 percentage may facilitate the growth of anaerobic bacteria. Thus, **maintenance of an optimum ratio of O2 and CO2 percentage is vital in food packaging**. Barrier properties of a packaging film are the main factor in determining the headspace gas composition of a packed sample. Generally, polymers are moderately permeable to small molecules like O2, CO2, water, and organic vapors. The O2 barrier is calculated by the oxygen

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						permeability coefficients (OPC) which signify the quantity of oxygen that infuse in a definite time and pressure through per unit of area of a packaging material (kg•mm−2s−1Pa−1). Thus, **packaging films with low OPC may extend the shelf life of a packed product by reducing the O2 percentage of a packet to the point that inhibits oxidation**. Generally, **biodegradable film has an OPC value of one or more order of magnitude below the OPC of synthetic films such as polyethylene terephthalate (PET) and polystyrene for same applications**. The CO2 barrier is measured by the CO2 permeability coefficients (CO2PC) which signify the quantity of CO2 that permeates during a definite time and pressure through per unit of area of packaging films (kg•mm−2s−1Pa−1). **Equilibrium moisture content is one of the important factors responsible for the physical and/or chemical deterioration and dehydration of packed fresh agricultural produce.** Thus, the water vapor barrier characteristic of food packaging films is of great importance for maintaining or extending the shelf life of fruits and vegetables.
Seglina, D., Krasnova, I., Strautina, S., Kalnina, I., Gailite, I., & Dukalska, L.	The objective of this work is to evaluate the potential of biodegradable packaging materials for	Fruit	Packaging material properties – gas and moisture barrier	Storage, Retail	Appearance, texture flavor, nutritive value	An appropriate atmospheric composition in the package headspace is required to avoid the deteriorative processes limiting product shelf-life. The more acceptable gas composition after 6 days established in the sample A1 (CO2 17% and O2 10%), made from BIO PLA 121 (□=30 μm) film and stored at

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
(2013).	preserving the quality parameters of Latvia grown and harvested strawberries 'Polka' and to determine the quality parameters during storage at various temperature conditions.		Temperature			temperature +2±0.5□C. Part of berries already after **3 days of storage in control packaging turned soft;** especially it was observed in packs stored at **+12□C**. The **aroma and appearance of berries packed in VC999 PLA lidding film pouches was still acceptable after 6 days of storage.** Mass losses of strawberries were dependent on the **water vapour permeation of a packaging material** ($p<0.05$) and disparated. Higher mass losses after 3 and 6 day storage had strawberry samples in the control packaging, accordingly 6.3% and 11.0% (stored at +12°C) and 9.0% and 12.8% (stored at +2□C). The mass losses of berries in packs with selective gas permeability were less, from 0.1% to 2.4%. The **dynamics of vitamin C during storage was dependent on the degree of ripeness.** Decrease of vitamin C content (on average 8.8-19.5%) was observed in all examined samples stored for 6 days at temperature +12□C, while in samples stored at +2□C the decrease of vitamin was less (on average 3.5-11.7%). Biodegradable PLA 121 and VC999 PLA packaging materials could be used for quality maintenance of Latvia grown and harvested strawberries during cold storage along 6 days. The more acceptable gas composition (CO2 17% and O2 10%) during storage was established in berry sample packed in BIO PLA 121 film and stored at temperature +2±0.5□C. **Vitamin C losses during storage were influenced by elevated storage temperature +12□0.5□C in warehouse.**
Kantola, M., & Helen, H. (2001).	To find out if certain prospective biodegradable packaging materials are suitable for packaging of organic tomatoes.	Vegetable	Packaging material properties – gas and moisture barrier Time	Storage	Appearance, texture, flavour	The weight loss of the tomatoes after three weeks of storage was from 1.7-2.7%, depending on the type of package used, being **1.7% for LDPE-bags and over 2.5% for bags made of biodegradable materials.** The **water vapor barrier of biodegradable films is much poorer than that of LDPE film**, which explains the differences in weight losses. To avoid anaerobic

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
			Temperature Relative humidity			respiration and to preserve tomato quality the availability of Oxygen, is critical. The access of Oxygen was guaranteed by perforating the packages. Changes in fruit respiration can also be caused by changes in storage conditions. **Respiration rate increases when storage temperature is increased**, or **relative humidity is decreased.** However, in this experiment the tomatoes' skin and optimal storage conditions kept the tomatoes' respiration rate and moisture content relatively stable. The moisture content of tomatoes during storage varied somewhat, but all within the 94% range. **Storage time** significantly ($p < 0.05$) influenced the tomatoes' **firmness, color and flavor**, whereas the package type or their interaction had no significant influence. For preserving tomato quality, it is essential that tomato packages are perforated and that the storage conditions are optimal for tomatoes, a too **high temperature (over 14C) and a too low relative humidity (under 80% RH)** increases fruit respiration and shortens shelf-life. **Lack of oxygen changes the fruits' respiration from aerobic to anaerobic, which is deleterious to tomato quality.**
Dukalska, L., Muizniece-Brasava, S., Kampuse, S., Seglina, D., Straumite, E., Galoburda, R., & Levkane, V. (2008)	To check the published data of biodegradable PLA packaging film special suitability to provide longer shelf life of fresh fruits and vegetables, some in Latvia cultivated fruit storage were tested.	Fruits	Packaging material properties – gas and moisture barrier	Storage	-	As the sealing of packages was performed at atmospheric ear ambiance, the initial content of CO2 was presumed closely to zero and O2 according as in atmosphere – 21%. The gas composition in packages established at the storage time depends from the barrier properties of films used for packaging. As a result of berry's breathing the CO2 content in the head space of packages has been raised accordingly O2 content – decreased. The **highest CO2 content 18% have been observed in the PP trays sealed with OPP film after 25 storage days**. It could be explained by **low CO2 permeability of OPP film**, which promotes CO2 accumulation in the packages. The more acceptable concentration of **CO2 for storage of berries has been**

Source	Aim	Category (Fruit/Vegetable)	Technological factors	Process stage	Affected quality attributes	Mechanism
						observed in the carton boxes inserted in PLA pouches thickness of 40 µm (MaaG company) – 11 to 12% and O2 – 4%, which could be assessed as adequate to equilibrium modified atmosphere (EMAP) for minimal breathing of fruits at the storage time. In the PP trays enclosed into pouches made from biodegradable PLA films thickness of 25 µm (Treofan company) the content of CO2 was acceptable, whereas O2 content decreased close to zero, **the oxygen free ambiance could not provide the fruit quality at the storage time.** The mass of berries packed in PP trays and sealed with OPP film accordingly to OPP inherent **moisture barrier properties does not changes for 21–25 storage days.**
McLauchlan, R., & Bagshaw, J. (2001)	The paper will deal with the postharvest problems encountered in agricultural products, especially fruits and vegetables.	Combined	Temperature	Transportation	Appearance	Most fruits and vegetables are **transported by road without refrigeration**. Owing to the poor transportation system, the total **losses in transit can amount to more than 15–35%. Mechanical injury of fruits and vegetables is serious with the packages**. Now cartons, and wooden and plastic boxes are used more commonly in storage and transportation in large cities.

Table 22 Critical appraisal of relevant publications for managerial factors of SRQ 4

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
Kenny, M. (2002)	This article focuses on the quality and safety aspects of producing fresh fruits and vegetables, as an integrated	Combined	Maintenance of equipment and facilities	All	Appearance, Safety	Facilities and equipment, packinghouses: **Adequate facilities**, suitable to the type of process, **should be made available**. **Equipment should be maintained in a clean condition and not provide a source of contamination**. Cleaning facilities: Adequate facilities should be provided to maintain the premises and **equipment in a**
			Employee hygiene			

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
	component in the production chain.		Training and knowledge Pest and waste control			**hygienic condition**. **Chemical agents in contact with fruits and vegetables should not contaminate the product**. A **cleaning schedule setting out frequency, method of cleaning and other details should be maintained.** Employee hygiene: As above, **food handlers should adopt best practices to prevent contamination of produce, directly or through cross-contamination**. Appropriate **hygiene facilities should be made available** for employees, including **toilet and hand-washing facilities**. **Correct handling practices should be implemented to ensure proper temperature control, prevent cross-contamination, and verify process and packaging requirements**. Storage facilities: Adequate storage facilities should be provided and **should not be a source of contamination**. These include facilities used during the transportation of the produce, e.g. open trucks or refrigerated containers. When in storage, produce **should be stored in suitable packaging to maintain quality and safety**. Pest control and waste: The premises should be **maintained clean, and waste should be properly disposed of to prevent pest infestations**. When necessary, measures taken to control pests should be safe, and adequate records maintained of treatment and type of infestation. The premises should be properly secured to prevent or minimize pest access.
James, J. (2006)	A comprehensive look at both microbial hazards and available measures for their prevention, this book is an essential reference for the fresh fruit and	Combined	Maintenance of equipment and facilities Employee hygiene Training and	All	Safety, Appearance	Packhouses: **Packing facilities should be cleaned and well maintained to reduce the introduction of harmful microorganisms to product**. No matter what method of packing is used, care must be taken with product. **Rigs and utensils** used for packing should be **cleaned and monitored daily**. Packhouses, whether open or enclosed, should be **cleaned and protected to deter pest entry and possible product contamination**. Good sanitation practices enhance a

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
	vegetable industry as well as a practical text for the education and training of scientists, professionals, and staff involved in managing food safety		knowledge Pest and waste control			company's food-safety program. In daily sanitation programs, seven steps could be followed to ensure clean equipment: 1. **Dry cleaning** to remove gross debris from equipment and floors; 2. **Prerinsing** to remove debris from surfaces; 3. **Using soap and scrubbing equipment** on surfaces and floors; 4. **Postrinsing to remove soap**; 5. Removing standing water and reassembling equipment if necessary; 6. **Inspecting cleaned area and recleaning** with detergent if necessary; 7. **Sanitizing equipment and floors in high-care facilities**. Pest management could prevent product contamination, recall, and other loss of productivity. **The packhouse manager should assess the risk in the plant to determine the level of prevention needed**. Windows and air vents should be screened, and facilities kept free of debris. Any pest-control program implemented should be monitored and documented regularly to protect product. **Employees.** Packhouse employees should **be trained in safe food-handling practices**. Product safety of final consumer packs is directly influenced by the handling practices in the packhouse. **Employees should receive training on the proper use of toilets, hand-washing procedures, use of protective clothing, and headgear to avoid product contamination.** **Storage and Distribution Refrigeration** temperatures in storage and distribution are crucial to maintaining product quality. **These temperatures also reduce the proliferation of human pathogens if they are present on produce items.** Refrigeration units are thought to spread mold throughout warehouses, and routine **servicing of air filters and refrigeration systems is required**. As cold air systems blow mold spores into the air, there is also the risk that pathogens

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
						may be spread along with the spores from one pallet to the other. Pest control programs are necessary at any storage facility. A basic rodent control program would reduce the presence of pests that harbor harmful microorganisms forming a potential hazard to food. **Vehicles and containers used to transport fresh produce could also be sources of potential contamination**. Vehicles used to transport fresh produce should be clean and free of odors, dirt, and debris before loading. **Good hygienic and cleaning practices ensure product safety when loading or during inspections**. The temperature of transport would also determine the potential for growth of pathogens. Thus, refrigeration temperatures are used to transport many produce items. The cold temperature helps to preserve product quality as well as safety. **Retail: Consumers could be a source of fresh produce contamination** in retail outlets. Consumers touch fruit and vegetables as they make a decision on whether to purchase product. If a person's hands are contaminated because of improper hygiene, this product could be affected. **Food contact surfaces in food-preparation areas should be cleaned and sanitized regularly**. Display counters and shelves should be cleaned regularly to prevent cross contamination. All **employees in a retail operation should thus have a basic knowledge of food safety and their responsibility of protecting the public**.
Gil, M. I., Selma, M. V., Suslow, T., Jacxsens, L.,	The purpose of this review was to collect the key consensus preventive measures	Vegetables	Employee hygiene Training and knowledge	All	Safety, Appearance	To minimize the risk associated with microbial hazards of leafy vegetables, producers, and processors have at their disposal several detailed schemes or codes of practice and regulations. (1) **managerial interventions, which refer to building an**

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
Uyttendaele, M., & Allende, A. (2015)	and intervention strategies to exclude or, potentially, eliminate pathogens in fresh leafy vegetables along the farm to fork chain including primary production, postharvest handling, processing practices, distribution, and consumer handling.		Maintenance of equipment and facilities			**operational culture of food safety and commitment to excellence in implementing the preventive control strategies.** Retail establishments typically does not involve application of a treatment designed to inactivate microorganisms, food worker hygienic practice can be expected to have a direct influence on the microbiological characteristics of fresh produce items. **Retailers should have receipt procedures to identify and accept only fresh produce that meets their specifications.** On the sales floor, **produce racks and wet racks should hold food at the ideal temperature and moisture conditions**. In wet markets, a typical scenario is the **lack of refrigeration facilities.** Among the preventive measures and intervention strategies, one of the most important is the **training and education of the growers and handlers along the entire food chain**. These training programs include **information related to the safe growing and handling practices such as clean handling procedures, control of cross-contamination, and personal hygiene**. The **persistence of existing habits and attitudes may influence compliance to procedures**. Numerous intervention strategies to control microbial hazards exit, however, there is no uniquely effective or singular control point. Given the complexity and differences of the primary production, processing, packing, and distribution systems, there are intervention strategies that need to be taken at all these steps to control hazards. More information may be needed on the logistics during distribution and retail sale operations, particularly in relation to time and temperature of storage and distribution of fresh-cut products. **Managerial interventions of experts from the food chain including agronomists, food microbiologists, and food science experts are needed.**

Source	Aim	Category (Fruit/Vegetable)	Managerial factors	Process stage	Affected quality attributes	Mechanism
Araujo, J. A. M., Esmerino, E. A., Alvarenga, V. O., Cappato, L. P., Hora, I. C., Silva, M. C., . . . Cruz, A. G. (2018)	This study aimed to develop a checklist for good hygiene practices (GHP) for raw material of vegetable origin using the focus groups (FGs) approach (n= 4).	Combined	Employee hygiene Training and knowledge	All	Appearance, Safety	Hygiene, health, and training of workers in the pavilion: **Supervision of health status**, performance and registration of periodic examinations. **Removal in case of injuries or diseases** that contaminate marketed foods. **Correct hand washing after using toilets or touching contaminated surfaces** and deteriorated food. **Avoiding habits and attitudes** that could contaminate food. **Use of clean uniforms compatible with activities**. Existence of periodic training program in Good Hygiene Practices (GHP). Precarious hygiene conditions were associated with **lack of training and education of producers**. **Improper handling and exposure of food to inadequate temperatures, lack of identification of a product's origin, and lack of professionals for inspection**. The training program as an important task, due to the **lack of information about the adequate procedures**. The other participants emphasized the importance of **preventing the increase in microbial load in the marketing stage since there is no guarantee that sanitation will totally eliminate the biological hazards in the later stages**. This information provides evidence that **food safety knowledge and attitudes among food handlers are generally poor**. Training program involving this topic should be carried out in all handlers and managers of the food establishments as a potential approach to improve risk perceptions and their food safety knowledge. Packaging is very important for perishable products such as horticultural products, being attractive at the time of purchase, **adding value to food and protecting against contamination.**

Appendix 4: Interview procedure

Introduction

- Meet/greet and appreciate the expert for cooperating in the interviews from their busy schedule.
- Take permission from the expert for the recording the interview.
- Inform the expert about the research aim, the time duration for the interview and the maintenance of confidentiality of their identities.
- Inform the expert about the different sets of the interview: 1. General questions about the background of the interviewee and 2. Specific questions for the research.
- Starting the interview with their consent.

During the interview

- Summarizing the answers given by the experts.
- Verifying the summary of the interview by repeating their answers.

Appendix 5: Interview questions for the experts

S.No.	General questions
1.	Which activities are carried out by you in the company?
2.	Which stages of supply chain have you worked earlier/currently working?
3.	How many years do you have experience in bio-based packaging?
Specific questions	
4.	When did your company decide to alternate the conventional packaging material with the bio-based?
Could you please elaborate:	
5.	Which type of bio-based packaging is used to pack fresh produce?
6.	Is it made up of 100% bio-based material?

7.	If no, then why other materials are added?
8.	Could you please highlight one time when you were involved from conventional to bio-based packaging?
9.	What were the major changes made during the transition from conventional to bio-based packaging material?
10.	What were the challenges experienced during this period?
11.	Are there different points to control the quality of fresh fruits and vegetables in the supply chain?
12.	How do you control at these different spots?
13.	Were there any changes in the control points before and after the change of the packaging material?
14.	Are there any other quality aspects which consumers expects and needs to be controlled?

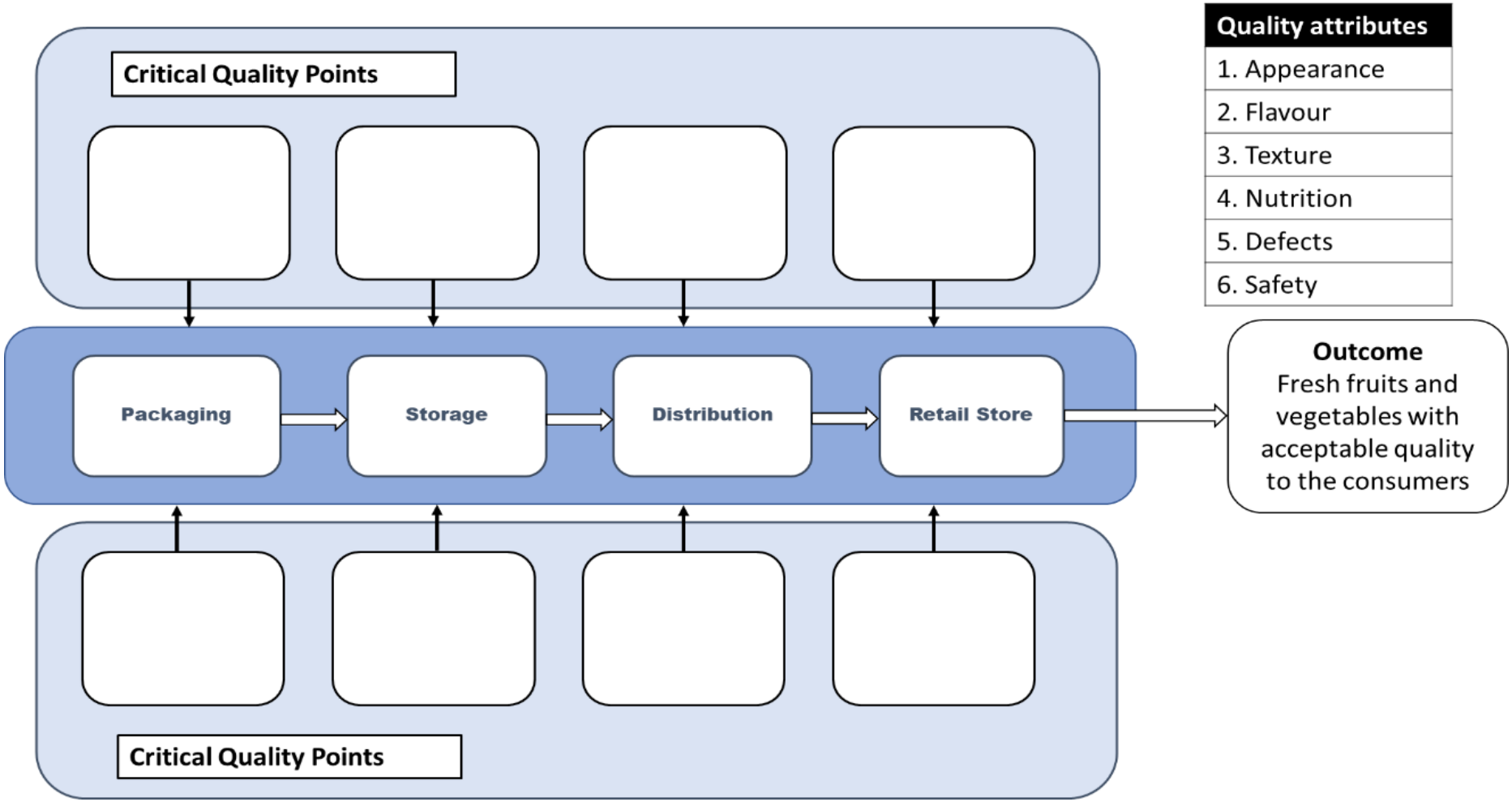

Figure 5 Blank framework to be summarized based on the quality points highlighted in the interview