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The present role and possible future of active and intelligent packaging

By

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1. Introduction

The roles of active and intelligent packaging is of increasing importance in the food and meat production industry. Global issues surrounding food packaging include waste and the incidence of food borne illness. Approximately 82.5 million metric tons per year of packaging waste was recorded in European households and all sectors of the producing industries in 2014 (B Geueke, 2018). The municipal solid waste in the US gathered 69.6 million metric tons of packaging waste (EPA, 2014). Revelations such as these have lead to the conclusion that it is necessary to explore a more scientific approach to meat conservation for the consumer. Nowadays consumers prioritize packaging that offers fresh and natural products with optimal nutritional value. The industry must strive to achieve consumer desires, while still providing safe products. Roughly 30% of people in industrialized countries will suffer from a foodborne disease annually, with a recorded minimum of two million people who die from diarrhoeal disease globally, therefore the growing concern for food safety within the public is understandable (WHO, 2007). Packaging now has additional actions which potentially increase product quality, longevity and influence consumer appeal. (B. Holman, 2018)

Active packaging can be defined as a system that interacts with the package contents and the food to increase shelf life, improve safety or sensory components of the food, while still preserving the food quality (Lacroix, 2011). With the goal to meet consumer demand for more natural, recyclable, and biodegradable products (Lopez-Rubio et al., 2004) came the development of renewable resource based active packaging material which degrade naturally and have less ramifications on the environment. Active packaging extends food storage life and increases food safety through modifying the food status (N. deKruiif, 2002)

The goal of this paper is to research literature exploring packaging methods used in the past, the problems associated, and compare these to novel approaches. I intend to research antioxidant and antimicrobial agents incorporated into active packaging, bioactive and biodegradable edible films, biopolymers as an alternate for synthetic polymers, and other exciting prospects such as Nanotechnology-assisted processing and packaging.

2. Literature Review

The idea behind active packaging, is the process of integrating active agents into the packaging material which will control or react with what is inside. In other words, packets that do more than solely prevent it coming in contact with the rest of your shopping items. For example antioxidant active packaging, traps pro-oxidant compounds or releases antioxidant compounds thereby decreasing the breakdown by lipid oxidation (R Dominguez, 2018).

Intelligent packaging methods vary greatly with several different goals such as extending shelf life, monitoring freshness, displaying information on quality, improving safety, health of the consumer, and improving convenience. These goals go hand in hand with the underlying function of displaying information to the buyer about the condition of the product. Currently less intelligent packaging systems exist than active packaging due to legal constraints. In this study I will research and compare some novel ideas in both active and intelligent packaging with the above mentioned underlying goals in sight.

Active Antioxidant packaging entails substances which emit antioxidants into the food and its surrounding environment or scavengers which consume unwanted molecules (for example oxygen, food-derived chemicals and radical oxidative species) and can potentially slow down the detrimental process of lipid oxidation (I Ahmed, 2017)

Some of the primary issues with meat and products during processing and storage are lipid oxidation and deterioration, as a result of microorganism growth. In some select food types the shelf life may significantly decline without the presence of chemical additives. Therefore the meat industry can be viewed as an accurate portrayal of perishable products being manufactured with differing fat contents and an elevated number of unsaturated fatty acids. Considering this, it is clear that lipid oxidation could be the primary factor in quality degradation of meat and meat products (JM Lorenzo, 2018) and hence a major target for Active and Intelligent packaging manufacturers. Lipid oxidation reactions will result in the development of undesirable flavours, smells, texture and discolouration arising from the myoglobin oxidation. All of these factors impact heavily on customer preference and approval.

Active components are integrated into the package material or in independant devices such as a sachet, pad or label. (M Andrade, 2018). Currently the most popular are oxygen scavengers, produced as separate devices (A Lopez-Rubio, 2008) where the active component is added to a typical ‘passive’ package (Estaca, 2014). However these independent devices can pose problems with safety by accidental swallowing or contamination, hence the interest in new research for methods of integrating antioxidant in the walls of the package such as coating, which will be discussed later.

Further studies have been carried out where active Edible Films have additional functions such as containing antioxidants (C. LeTien, 2001) antimicrobial agents and other components, which again are aimed to contribute to the collective goals of extended shelf life, product quality and associated health increases, and these will be elaborated on in the discussion.

While Antioxidant packaging is of great importance, Anti-microbial packaging is also an area of great interest, so another area I would like to discuss is packaging in reference to *Listeria monocytogenes* which is one of the most virulent foodborne pathogens with 20 to 30% of foodborne listeriosis infections in high-risk individuals being life threatening (V Ramaswamy, 2007) *Listerias'* ability to grow at temperatures as low as 0 °C allows rapid growth in refrigerated foods. As refrigeration is one of the most common methods of protecting food quality, the pervasiveness and psychrotrophy of *L.monocytogenes* means poses a higher risk than other bacteria (M. Ghandi, 2007) Because chemical preservatives are disliked by consumers and restricted legally, the use of natural antimicrobials such as bacteriocins from lactic acid bacteria (LAB) are now a substitute to dated approaches to food preservation. Amongst other bacteriocins, Nisin is a small heat–stable bacteriocin also known as a lantibiotic (W. Holzapfel, 1995). The anti-listerial activity of nisin has been well studied and applied in a variety of vegetables, meat and dairy products (Irkin, 2015).

Another form of Intelligent packaging can be seen for example in some supermarkets where a chemical is incorporated into the packaging label which can go from lighter to darker colour in the case of a reaction. This is a slow process if kept chilled but will be faster with higher temperature, and so can indicate increased level of bacterial growth with temperature rise. This informs the buyer whether they can be certain the product is fresh or not (M Ghaani, 2016).

There is great variation in the world of Active and Intelligent packaging and I will discuss a few key methods further in the discussion.

3. Materials and methods

Tools used for this literature based thesis include ScienceDirect, Scopus and Pubmed. I used a combination of searches such as "active and intelligent packaging", "Food Hygiene awareness and standards", as well as "food production and manufacturing". As the world of active and intelligent packaging is relatively novel and still being established I aimed to keep my searches as recent as possible and dated mostly from the year 2000 and on. I also visited several Irish chain supermarkets such as Dunnes and Supervalue to look for examples of active or intelligent packaging, and get an idea of what type of packaging is most common.

4. Results and Discussion

4.1 Active packaging

As described in the Literature review, active packaging carries out more purposes than protecting the product from coming in contact with the rest of your shopping items.

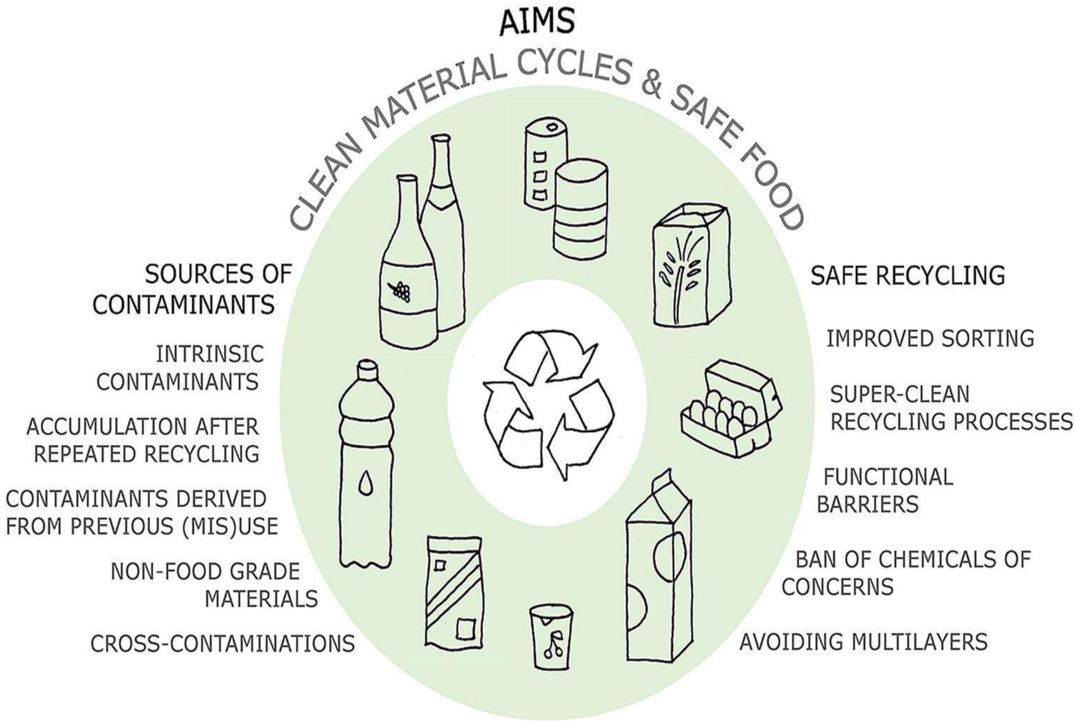

Fig. 1 Aims and requirements for more economically friendly and safe food packaging. Also could be viewed as the motivations behind the research into novel approaches in Active and Intelligent packaging**.** (B Geueke, 2018)

4.1.1 Present roles in food industry

Prior to Active and Intelligent packaging being well established, advances began with ideas such as electrically driven packaging machinery, metallic cans, aseptic packaging, flexible packaging, aluminum foils and flexographic printing. Materials such as, viz. polyester, polypropylene, and ethylene vinyl alcohol polymers quickly initiated the deviation from traditional metal, paperboard and glass packaging to plastic and flexible packaging. In the 20th century further achievements in packaging technology began with intelligent and active packaging (oxygen scavengers, antimicrobial agents, respiration controllers, and aroma/odor absorbers) (AL Brody, 2008)

Active packaging is an alternative for original food processing techniques such as high thermal treatments, brining, acidification, dehydration and additive preservation (Lopez-De-Dicastello, 2011). The theory is based on adding specific components inside the polymer and intrinsic characteristics of the polymer itself used as packaging agent (Gontard, 2000) and more recently exploring the use of active packaging adding polymer materials with components that impart antimicrobial properties (P. Suppakul, 2003) which can release active ingredients (antioxidants and antimicrobials), and retain compounds (ethylene, oxygen and water) or undesirable food components (S Flores, 2007). The market for food and beverages has become a worldwide multi trillion dollar enterprise and so manufacturers and modern companies should be keen to evolve their products with the advancing technologies becoming available in order to stay current on the market.

Active packaging is used in several food products as well as meat packaging, for example fruit and vegetables, powdered products, and even in pasta and biscuits. While a lot of this paper refers to meat packaging it is important also to note the significant advances being made in all aspects of the food industry worldwide.

Fig 2: Image of popular consumer products from Irish supermarkets which are packed in the conventional method of Vacuum Packaging, which we will compare to novel approaches (Supervalue, 2019)

Fig 3: Image of popular consumer products from Irish supermarkets which are packed in the conventional method of Vacuum Packaging, which we will compare to novel approaches (Supervalue, 2019)

Fig 4: The roles of Active and Intelligent Packaging (S Mihindukulasuriya, 2014)

4. 2 Criteria for success

Due to the world of Active and Intelligent packaging being still relatively new, with further advances being made all the time, it is important to look at what aspects to focus on as underlying goals for effective products. While active and intelligent packaging are slightly different fields they share desired outcomes of food quality and safety, and so some of the parameters which can be viewed as relevant to both fields were outlined well in the journal "Meat Science" (BWB Holman, 2018) however this article puts a lot of focus on "Smart" packaging which is a combination of both active and intelligent elements. This article also focuses on meat packaging alone, whereas active and intelligent packaging extends to many other food types, examples of which will be reviewed later.

4.2.1 Dark, firm and dry red meat.

Off-colored red meat with dark, firm and dry properties, also known as “dry cutting”, is damaging to both presentation and organoleptic appeal. It is thought to be due to inadequate glycogen stores to drive post-mortem acidification throughout the change from muscle to meat, thereby disturbing its myoglobin's power to oxidise and develop standard water-holding properties (E Ponampalam, 2017). DC is graded before carcass deconstruction, therefore processors and manufacturers end up carrying the financial stress. However parties from all stages are affected costwise by lost opportunity leading to the need to find package alternatives to restore or save DC meat, and improve retail-value. An example of this is the investigation into different modified atmospheric packaging (MAP) gaseous profiles, thought to give a biochemical groundwork for the salvation of colour (M Abril, 2001)

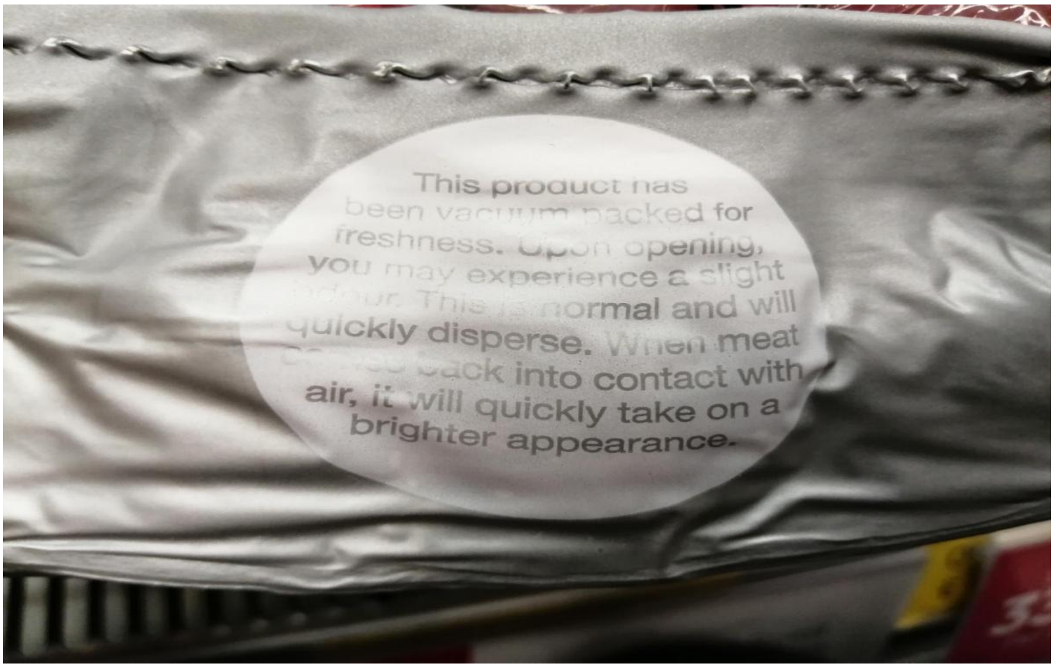

Fig 5: This product shows a packaging label on conventionally vacuum packaged meat in Irish supermarket outlining change of colour in red meat on contact with air (Supervalue, 2019)

4.2.2 Water loss, Traceability and durability

Purge losses are another parameter to be noted during package manufacturing, as a high amount of red meat is water, which can be expelled during post-mortem, decreasing carcass yield and meat quality.

Customers have classically depended on on-pack identifiers for product traceability, consisting of standard labels, barcodes and other individual brandings. The consequence of incorrect information in this area should not be undervalued, as not presenting nutritional or religious-based guarantee to the consumer can lead to lost profits and customer loyalty. Therefore we have begun to explore novel packaging options with the aim of reinforcing product traceability.

Durability is another important parameter, while we cannot view packaging as the primary defence against meat product damage, contamination and deterioration, rather it can be seen as back-up if initial protection is lacking.

much effort has been dedicated to improving the durability of meat packaging and identifying when its barrier function has been compromised.

Novel packaging materials and films are being brought forward with their durability being the major point of emphasis.

An example was seen where (S Karnet, 2005) altered biodegradable gelatin film with differing amounts of stearic acid, with results that showed an 8 h reaction time with a 15% concentration and advanced the tensile strength (60 MPa2) of a previously very breakable pure gelatin film.

4.2.3 Product spoilage and colour protection

Microbial spoilage and food safety are of a key element of concern with packaging due to the fact that red meat processing does not take place in sterile conditions and so some amount of microbial contamination is to be expected.

Intelligent packaging methods aim to prevent and estimate microbial loads, and alert if dangerous bacteria are discovered. Examples of relevant microbes in this area which lead to food spoilage are lactic acid bacterium, *Brochothrix thermosphacta*, *Enterobacteriaceae* and *Pseudomonas* species, other threatening microbes include *Listeria monocytogenes, Salmonella,* and ***E.coli.***

Colour stability of red meat as well as other food products such as fish, fruit and vegetables is an essential parameter to consider when testing packaging as consumer buying is influenced heavily by the degree freshness presented to customers, which in turn will influence money made from these products. Therefore smart packaging options should aim to sustain colour of otherwise unfavourable coloured meat in order to make it more attractive to the consumer. For example packaging film can be coated with antioxidants using essential oils in order to conserve myoglobin redox status. (D Djenane, 2016) manufactured a film incorporating 4% oregano extract with HiO2-Modified Atmospheric Packaging or Vacuum Packaging. Results showed this enhanced the overall redness of beef put on retail display, in comparison to those that were not coated, on the condition that meat is initially VP and next repackaged in MAP, this lead to the prediction of an increased shelf life of 3 to 10 days (D Djenane, 2016).

4.2.4 Environmental impacts

Intelligent packaging should allow for better protection from environmental consequences of waste disposal, by decreasing, and substituting the material once disposed are directly linked to harming the environment. Innovation methods in this area with a goal of improved recycling, should combat pressing issues such as pollution, landfill encroachment, and exploiting unsustainable resources (Licciardello, 2017)

One example of decreasing packaging material disposal in the environment is by enabling it to be consumed, and therefore destroyed simultaneously, along with the product. (GP Cardoso, 2016) manufactured edible films consisting of a chitosan and gelatin. Results showed an efficient blockade to oxygen and inhibited oxidation better than uncoated packaging.

4.3 Intelligent Packaging

4.3.1 Types of Intelligent Packaging

Intelligent packaging methods vary greatly but can be basically divided into three main sections, Interactive, Sensors, and Indicators. Interactive packages contain individual details about the products (eg. Storage and origin) and so can also be referred to as automatic identifiers, which come in the form of packaging labels for example in 2D codes and Radio frequency identification which will be discussed further in a later section.

Sensors can obtain information by monitoring details such as temperature, CO2 levels or pH. They can quantify chemical properties of the food using receptors and then relays the information through signals from a transducer. Indications give qualitative information on the product usually by an alteration in colour.

Fig.6 : Image of Intelligent Packaging method in supermarkets whereby freshness is indicated by the duration of time the product has been contained in the package, conveyed to the consumer via colour changing label. (Nanopack, 2018)

Fig 7: Image of intelligent packaging for informing on temperature changes (Harington, 2011)

4.3.2 Time- temperature Indicators

Temperature is another integral parameter in terms of keeping track of freshness. “Time temperature indicators” (TTIs) have been developed to display to consumers in a clear manner any permanent alterations with the product as a result of past exposure to temperatures. This information is paramount in deciding if the food remains safe to ingest. They can be found on the outside of the packaging material, and convey the necessary information via adjustment in consistency or colour alteration or progression. The reason for these changes revolves around sensing some form of chemical, mechanical, permanent alteration in the product such as an acid-base reaction or melting. It can also be due to some biological process for example enzyme or microorganism reaction to thermal conditions. Overall TTIs are another highly useful method of Intelligent Packaging for ensuring consumer safety. (Pavelkova, 2012)

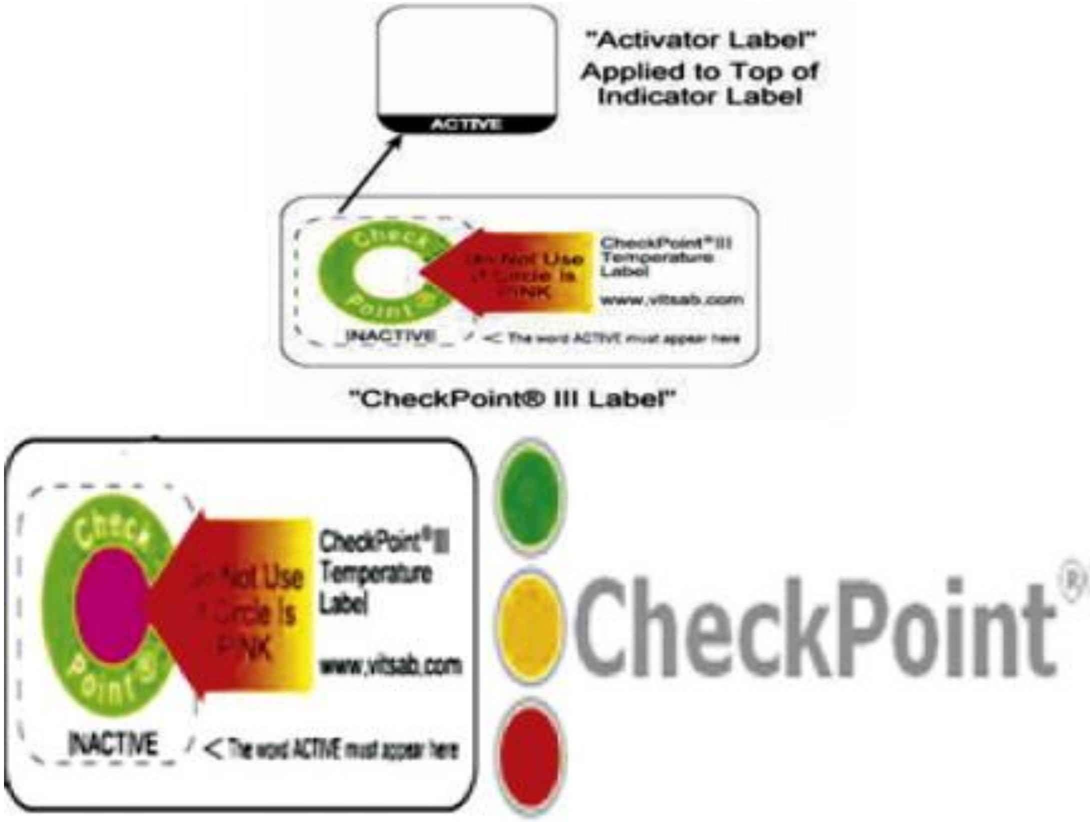

Fig 8: Depiction of the movement of colour portrayed on the label in order to convey information to the consumer on whether this product is fit for consumption or not based on sensing thermal exposures. (S JuLee, 2014)

4.3.3 Intelligent packaging for traceability

Intelligent packaging appliances have been manufactured with the ability to confirm the origin of packaged meat, separate to pre-packaging rules. For example the production of nanoparticle biosensors which can detect quality. A biosensor which incorporated a zinc oxide (ZnO) based thin-film and gold nanoparticles was invented by Foo, Hashim, Voon, Kashif, and Ali (2016) to make a connecting surface for a thiol-modified probe DNA, which recognizes the presence of pork and ensures halal approval. (K Foo, 2016)

Another example, a radio-frequency identification (RFID) system employed to differentiate between grass fed beef through their plant could then be used for tracing product movement as far as the retail division. RFID potential to convey real time data of packaged meat products has shown promise and supported further operation in the area (A Townsend, 2008). As a result, RFID could be compared to an electrical version of conventional packaging identifiers, when used for guarantee of origin can be imprinted straight on to a packaged material.

Additionally, Mohammed, Al-Khateeb, Haider, Rahim, and Hashim (2017) used altered multi-wall carbon nanotubes and silicon dioxide ($SiO2$) in order to recognize and chemically deactivate DNA. Their ability to detect relies on the reference or probe DNA involved, and so potentially may give red meat shareholders methods to exploit origin, breed and/or brand genetic irregularities for proof of packaged content. (A Mohammed, 2017)

The efficacy of these methods will be somewhat dependant on the resemblance of red meat product genomes and level of DNA breakdown during ageing, which is seen to via mini-DNA references (127bp) which are comparible to full-DNA references (658bp) in showing the difference between packaged meats (RS Helberg, 2017).

however they did not use aged products in their comparison, or meat which came from genetic backgrounds which were much the same. Regardless, it provides an optimistic insight for what is to come for the expanding progression in genetic tools.

4.4. Different types of Active packaging

4.4.1 Antioxidant Active Packaging

Lipid oxidation could be viewed as the main cause of quality deterioration in meat and meat products, and one of the most standard approaches to avoiding this process is by decreasing the oxygen in contact with meat by packaging the products under vacuum or nitrogen (Y Chu, 2002) (P Putnik, 2017) but low O2 (0.05% residual O2) can lead to the oxidation of pigments and lipids and affect the colour of the meat.

Antioxidant active packaging is a more favourable method as it encompasses antioxidant compounds which interact with the headspace and meat to inhibit lipid oxidation (Z Adilah, 2016); (J Martucci, 2015) and so decreases the need to directly add chemicals.

Studies carried out on meats using a range of natural antioxidants with different biopolymers and plasticizers concluded that samples packaged with active films displayed a higher maintenance in the red colour with prevention of lipid oxidation. The decrease was more significant with the films containing more active agent. Similarly it was found that incorporation of active films lead to decreased lipid oxidation and discoloration. (Vargas, 2015)

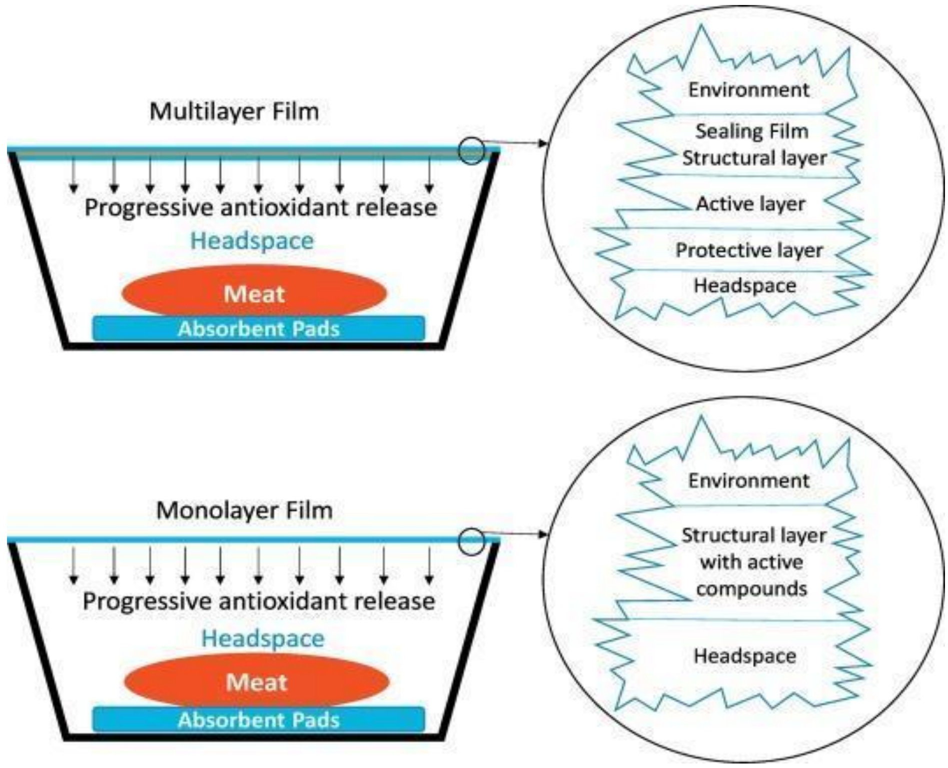

Fig 9: Standard "Monolayer" film compared to active "Multilayer"film (R Dominguez, 2018)

4.4.2 Oxygen Scavengers

Currently the most commonly utilized antioxidant active packaging would be oxygen scavengers, designed as a separate component which is usually in the form of a sachet or label which is packed alongside the traditional packaging (A Lopez-Rubio, 2008). The sachets usually contain Iron which absorbs the oxygen within the package as it oxidizes. However as buyers generally don't enjoy seeing with their food which say "Don't eat!" alternative ideas have been investigated such as Sealed Air, a company in New Jersey who are developing a food wrap which acts as an oxygen scavenger, comprising of an inside coating of a polymer which acts similarly to Iron by oxidizing and consuming the oxygen. (New Scientist, 24 April 2004)

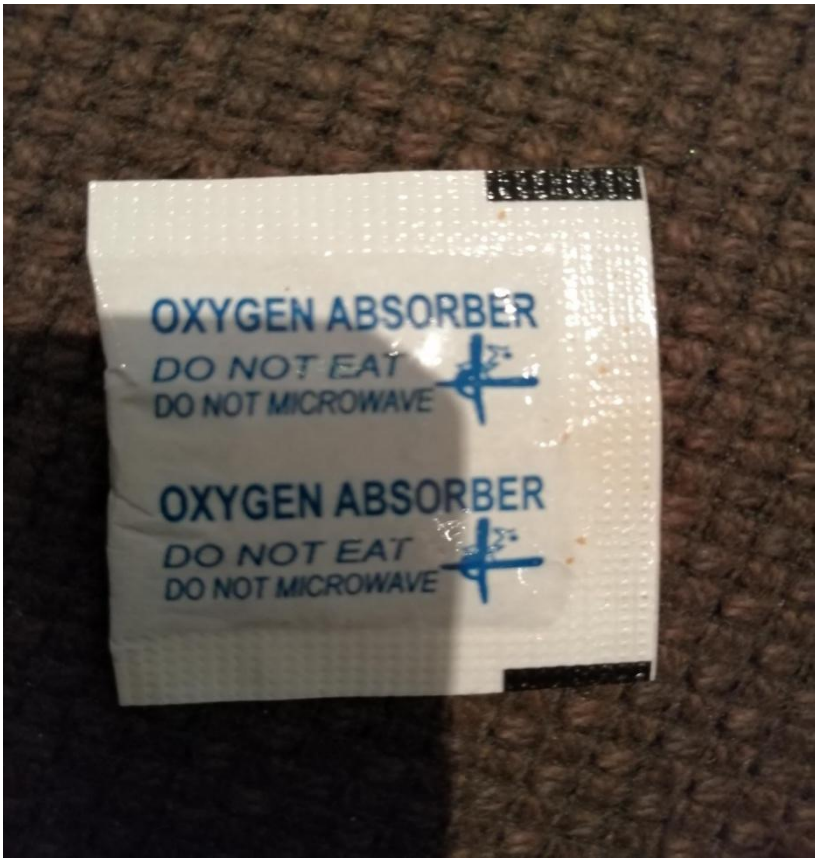

Fig. 10: Oxygen scavenger from inside packaging of dried meat product.

4.4.3 Moisture absorbers

The majority of food products available to the consumer will be affected by moisture and humidity levels. Storage of dry food products in particular can be notably affected by these parameters, causing differing levels of deterioration or spoiling dependant on the state of the product. This all has a knock on effect on cosmetics appearance of the product, consumer appeal undoubtedly duration of freshness.

In terms of meat, fish and vegetables some amount of moisture within the packaging is of an advantage in order to avoid the product becoming too dry, and is considered quite normal in foods with high water content. However "purge losses" as mentioned earlier are off-putting from a cosmetic point of view to buyers and will accumulate with prolonged duration of storage. (S Yildirim, 2017)

The measure of moisture within the packaging can be somewhat managed by using materials which have attributes that mean they can act as a blockade for liquids There are two primary categories of "Active moisture scavengers", the first act by absorbing the moisture in the environment inside the package and around the product, these are known as dessicants and are commonly in sachets or small bags with many tiny pores. Silica gel is an example of the materials used, as well humectants such as sodium chloride and magnesium chloride, and some clays in crystalline form such as zeolite, calcium or potassium which function as a molecule filter.

The second category is usually a pad which lies below the product and acts to directly absorb the liquid. Porous substances for example cellulose are teamed with highly absorbent polymers such as silicates among others make up these pads. While it has been debated whether this concept can be officially viewed as "active" packaging, it was stated that materials which "*are intentionally designed to absorb moisture from the food*" and can be considered as active packaging (EU, 2009) can also incorporate substances which have antimicrobial properties, manipulate pH, or can produce CO2 in order to improve food quality and avoid unattractive smells and liquid loss.

Fig 11: Image of meat product in local supermarket containing several obvious moisture scavengers within the packaging.

Fig 12: Image of meat product in local supermarket containing obvious moisture scavenger within the packaging (Supervalue, 2019)

Fig 13: Image of meat product in local supermarket containing obvious moisture scavenger within the packaging (Supervalue, 2019)

4.4.4 Equilibrium Modified Atmosphere

In the current economic state we live in worldwide shipping has now become a necessary measure for a lot of growing industries for raw meat and fish, fruit and vegetables and other such products which continue to respire during transport and storage. This can be more successfully carried out by influencing the environment for respiring via the temperature control. Therefore by aiming to govern the O2 content within a package with the goal of reaching the lowest possible amount of respiring needed, we can prolong the duration of time that the product remains in the highest quality state. Although there will be variations dependant on the product type, for fruit and vegetable produce some can be sustained at as low as 1% O2 without entering an anaerobic state.

Using certain types of packaging material with specific degrees of permeation, it is possible to cause increasing CO2 which acts to decrease the production of ethylene and also reduce the activity of microbes. Simply utilizing plastic packaging to create the correct O2 and CO2 harmony can be extrememly difficult, especially when taking into account certain unavoidable thermal variations. Studies have developed methods to establish the most appropriate type of material needed to package plant based products through recreating the attributes of both the product and packaging material. Through these studies it has been possible to appropriately quantify the necessary attributes required by each of the packaging designs. This development is the idea behind MAP or more correctly termed EMA packaging.

Confusion lies where MAP is not considered to be “active packaging” when we use it to describe simply filling a package with a combination of gas, in this situation it is technically seen as a “passive process”. However we can instead refer to Equilibrium Modified Atmosphere (EMA) when discussing active packaging technologies, as this method can be viewed as an interface between both concepts. The difference lies where EMA establishes the control of the level of O2/CO2 permeability and therefore controls the influence of natural/plant based components creating or not creating an environment conducive to respiration. Through the use of specific polymer materials in packaging, we can see that EMA is the middle ground for both active and passive packaging methods. (Muredzi, 2013)

4.4.5 Anti- Listeria Active Packaging coated films

Along with enterocins mentioned earlier, other methods against *Listeria monocytogens* were discussed such as the hydrophilic polymer Polyvinyl alcohol which can be swelled/dissolved by water, therefore allowing PVOH to create a welcoming environment for the microorganism and as a result has been utilised to capture live bacteria (L Liu, 2009).

Research was carried out on this active food packaging, with a thin coating on its surface holding living enterocin-producer bacteria, that was theorised to slow down or prevent the bacterial growth in the event of a cold chain break (R Iseppi, 2011). To measure the anti-listerial quality of these doped films they were compared with films doped with bacteriocins, nisin and enterocin 416K1 and for a negative control an undoped film. Results indicated that all the doped films had the capacity to liberate antibacterial materials to the surrounding culture substrate, as such, implying that they could also have the same effect when tested on food. Further testing was carried out using contaminated chicken food packaged in undoped and differently doped films and their antibacterial properties were measured under varied storage conditions.

This study concluded that it is possible to entrap live *Enterococcus casseliflavus* IM 416K1 bacteria in PVOH-based coatings. The entrapped cells can survive and eventually produce anti-listerial products therefore making this doped-film an effective and promising approach to food preservation.

The results of this study show that live-Enterococcus-doped film will act as a smart active food packaging, efficient in rapid *Listeria* growth due to cold chain break circumstances.

4.4.6 Edible Films

Edible films (EFs) formed with biodegradable biopolymers may beneficial substitute for the complications associated with disposal of the traditional packaging components (P Nayak, 2008). This study tested Alginate films because of their known resistance to oil and fats transfer. However as water-soluble polymers they are poor water barriers (L Wang, 2001).

The biggest advantage of alginates is the ability to yield a stable gel and insoluble polymer by reacting through their carboxylate groups with polyvalent metal cations, notably Ca^{2+} ions

Castor oil (CO) was tested as it is known as the most favourable vegetable oil because of biodegradability, renewability, low cost, and abundance. Once prepared the different films were tested on parameters such as water vapour permeability, colour and antibacterial properties.

An example of the positive effects were seen with the fusion of CO into alginate edible film which showed a clear obstruction to *S. aureus* and *B. subtilis* (Gram-positive bacteria) among others. Results of this study showed that because of enhanced antibacterial, thermal and mechanical effects, alginate/castor oil films would potentially be effective materials for use as edible films.

4.4.7 Future prospects of Active Packaging

While Edible Films as discussed above show very promising results for food packaging, they are also of interest for future methods which incorporate even more advanced approaches such as nanotechnology in order to further protect food quality. Examples of some nanomaterials which also function as being edible (ie. Not metal based) under research currently are quinoa protein, lemongrass essential oil and pectin from apples.

Quality and overall physical appearance of food declines significantly with transport and storage as most fresh food products continue to have active respiration and some microbial action, which are both greatly affected by thermal factors and relative humidity. To combat this issue studies have suggested that a slight coating of nano-edible films should perform as protection from gas and liquid, and so improves the rate of breakdown of food and maintains freshness for longer. (X He, 2019)

4.5 Future Prospects of Intelligent packaging

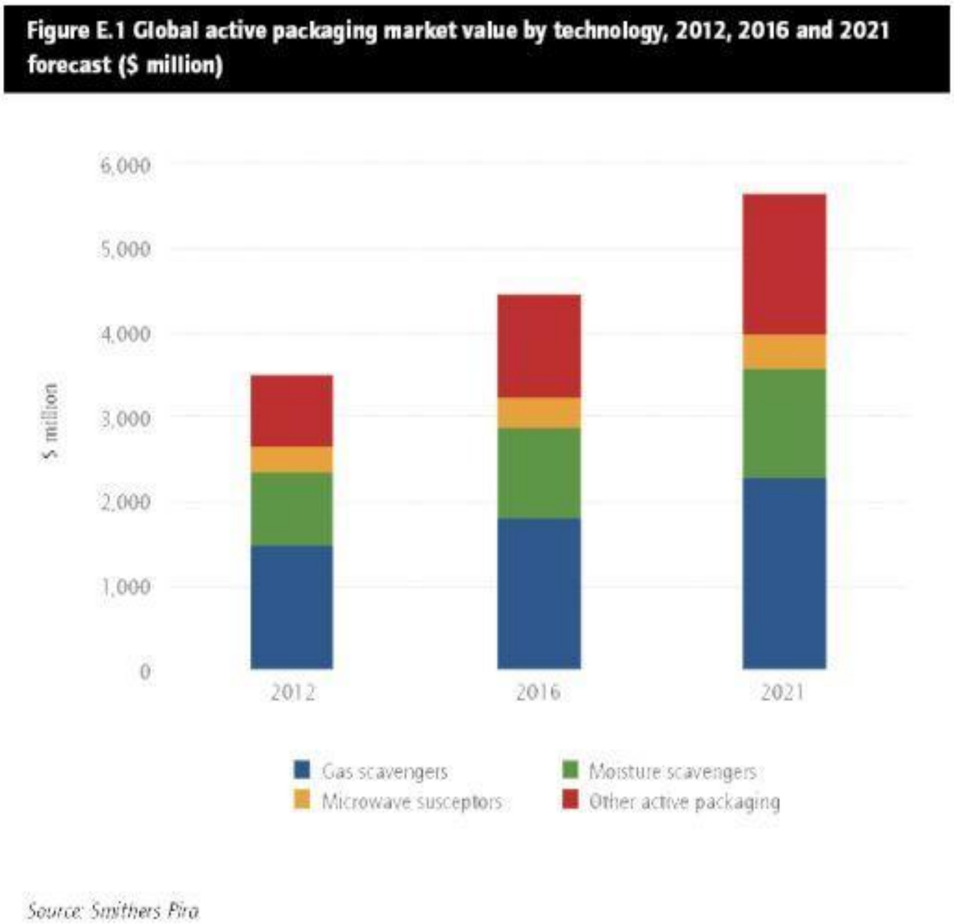

Fig 14: Packaging News' predicton of the industry value up to 2021. (MordorIntelligence)

4.5.1 The Future for food manufacturers

In terms of what the future of Smart Packaging holds for the manufacturer, according the the Smithers 2016 report for the future of smart packaging the worldwide market at present is approximately $5.3 billion with a forecast value of $7.8 billion by 2021.

in another article written by FutureBridge referring to companies which could gain from the move towards active packaging it was predicted that the worldwide market will grow to more 48 billion dollars by the year 2024. From this information modern brands have realised the notable advantages revolved around engaging with buyers and profit to be gained from getting on board. Popular brands are continuously striving to find improved and up to date approaches via marketing strategies in order to connect with buyers. Modern companies recognise the advantages associated with higher levels of interaction with the consumer and having more readily and expanded information showcased on the product. Additional to these predictions, companies have now also invested hugely in further development of novel packaging approaches, with a current calculation of approximately 3 trillion dollars minimum for the worldwide effect of nanotechnology by 2020, which may also provide jobs in the growing enterprise of approximately 6 million manufacturing positions. This obvious appeal to companies is a clear incentive to adapt and evolve their products to incorporate nanotechnology and enhance product quality (X He, 2019).

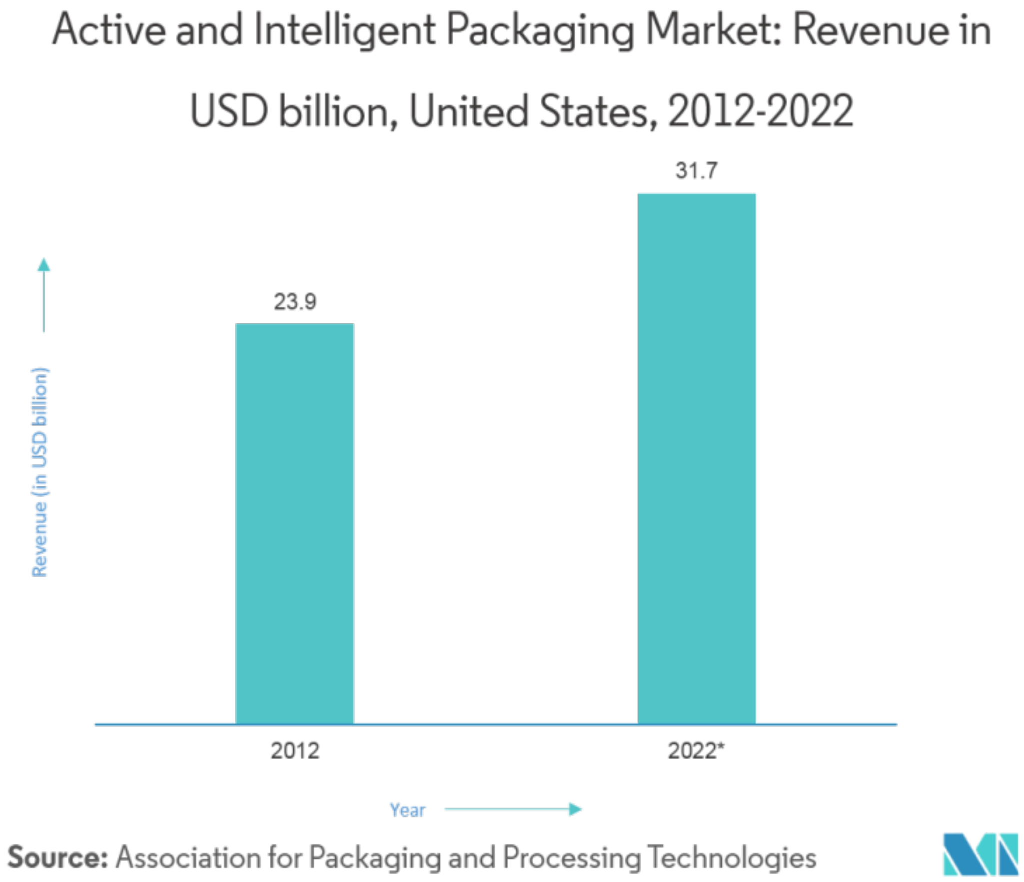

Fig 15: Mordor Intelligence Market trends for Active and intelligent Packaging in the USA

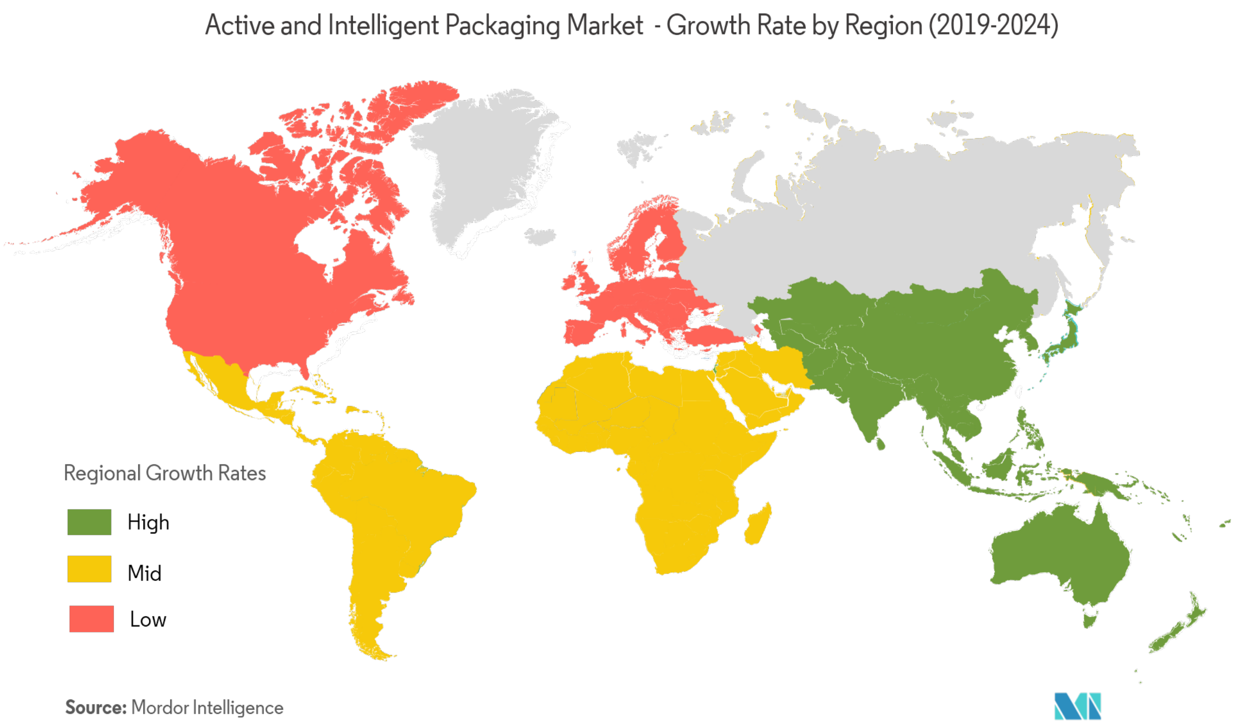

Fig 16: Depiction of global rates of increase in industry market. (MordorIntelligence)

4.5.2 Progression towards Nanotechnology

Food packaging incorporating nanotechnology is a new idea under development with little evidence of being actually put to use so far. It is more a case that advances are being made and will be applied to the meat packaging process when relevant and safe to do so. Ongoing studies are being carried out involving sensors for transmission of required information and stimulating subsequent alterations in packaging materials, environments or the products for preservation and safety (McMilllan, 2017).

Impressively there are already several existing products which have incorporated nanotechnology into their manufacturing in the last 10 years, most of which are "food contacting" however they are not ingested by humans. Thus far, predominantly due to strict legal regulations, there are no new nanomaterials being manufactured straight into the food products, bar titanium dioxide and also iron oxide which have functioned as pigment additives to food. (X He, 2019)

There are many challenges associated with the future potential success of nanotechnology in meat packaging, public approval, economics and control of food processed with nanomaterials which could build up and cause toxicity. While it's future looks bright in meat packaging, long standing consequences of the shift of nanomaterials over time on health and environment must be investigated further. There will also be a great dependence on the actions of governments, regulatory agencies and manufacturers in relation to the above mentioned challenges (K Ramachandraiah, 2015).

The use of bioactive substances with health benefits incorporated into foods to protect from disease is growing, but there are many obstacles with the manufacturing, storage and distribution of products with incorporated bioactive constituents, especially because of the vast range of conventional meat products. Notably there is an issue with low bioavailability of bioactive substances when incorporated into meat products, largely due to high proteins, fats, and minerals. To address this, studies were done to change formulations of meat products, unfortunately not to much success, causing decreased organoleptic quality, reduced water retaining capacity and less resistance to microbial infection (J Weiss, 2010). This highlights the requirement for a modified and novel approach such as nanotechnology to combat these issues and lead towards better quality for customers overall (DJ Troy, 2010).

Nanotechnology is primarily aimed at producing, characterization and maniplulation of nano-sized materials with innovative properties, although it is being investigated no worldwide approved definition currently is agreed on (G Lovenstam, 2010).

Key differences with nanomaterials and bulk materials are observed with the changes in physicochemical (for example porosity), optical, mechanical and catalytic components. Additional differences are seen with the strength, absorption, function, weight, and stabilization of materials (A Cockburn, 2012). These provide an optimistic future potential for nanotechnology in food packaging.

It must be taken into account that nanotechnology could also potentially change components and behaviour of food when applied (A Cockburn, 2012), still their use has shown less amounts of particular foods elements are required because of enhanced bioavailability of functional compounds (J Weiss P. T., 2006). This considered, nanomaterials could also allow us to potentially decrease the concentrations of salt, sugar and preservatives, while improving the overall customer appeal by showing favourable effects on color, flavor and texture. Additionally, an increase in the delivery and absorption of active ingredients and nutrients can be noted (Q Chaudry, 2011). Further advantages are delivery, improved absorption and stability of the bioactive compounds, with increased antimicrobial action against harmful microorganisms in food which have resistance to chemical antimicrobials (Duncan, 2011) (A Cockburn, 2012). The attention and approach towards the potential advantages and disadvantages may affect customer approval of nanotechnology (DJ Troy, 2010).

An example of current popular nanotechnology being investigated is a substance known as Nanoclay. There are a few different types classed according to physiochemical attributes, for example bentonite and montmorillonite. It of great interest to manufacturers because of it's relatively small cost, along with strong physical and temperature related barrier potential. Studies showed that membranes had significantly improved water permeance when nanomaterial bentonite clay/poly were incorporated into the membrane. Gabr et al.(2015) demonstrated enhanced interlaminar fracture durability with 3% nanoclay laden carbon fiber. Some results have shown there may be risk of migration of nanomaterials and so as this is still a very novel idea, ongoing studies are being done to assess this issue. There is also current studies being carried out for the potential use for

Nanomaterials in food packaging in terms of pathogen recognition , and exposure of harmful toxins and pesticides. (X He, 2019)

Overall, nanotechnology presents an exciting new prospect for the future of active and intelligent packaging.

5. Conclusion

To conclude this study I would like to focus on consumer impact of the technologies discussed. Active packaging has shown to be very beneficial to the consumer for concerns such as food safety, longevity, as mentioned in the discussion the organoleptic traits of importance to buyers are improved significantly by methods such as oxygen scavengers and antioxidant active packaging. By ensuring prolonged shelf life and being more physically attractive to the consumer for longer, buyers should be more inclined to trust in these products in relation to food safety and freshness. The reality of the world we live in currently is that it is becoming increasingly more apparent to the consumer that the environment itself is suffering and will continue to suffer at a growing rate due to build up of waste accumulated by humans. The duration of time that food remains “fresh” or “buyable” should mean that less products are being removed from shelves past their sell by date and so less food waste accumulating.

Edible films also provide an optimistic view of reducing packaging waste. This means less harm to the environment due to decreased waste build up and therefore less risk of disease and dangerous environmental effects. Overall the world of active packaging currently shows some very advantageous prospects for society in general in terms of food safety, consumer benefit and environmental health.

In terms of marketing and cost for distributors, it is clear that the modern consumer wants to know more information about their food, and in their view the option to engage more with the products they are buying is worth the extra cost, hence the growing popularity and the reason for more distributors getting on board and being willing to invest their time and money in alliance with the direction of the growing trends in the industry.

Intelligent packaging as stated previously is less established that Active packaging with a lot of its potential methods still in developmental stages. However it too provides a bright future for food safety. Having the advantage of being able to gauge freshness and levels of edibleness is a massive help to the consumer and will affect buyers choice of purchase. With the growing interest in food and animal safety, and resultant popularity of free-range and organic produce, factors such as traceability is of increased importance to consumers in terms of having the information readily available on the products origin and manufacturing. Therefore intelligent packaging for the purpose of traceability is a very exciting prospect for the future of the meat industry. It also paints a positive picture for years to come with the research into novel approaches such as nanotechnology. While these methods may involve a higher manufacturing cost one could hope that the function provided by these smarter methods would entice the modern consumer to see the benefits associated with paying the slightly higher cost for a more safe and sustainable future.

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