

Emerging of bio-nano composite gelatine-based film as bio-degradable food packaging: a review

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Abstract

The increase in production of Municipal Solid Waste (MSW) from various sectors of the industry should be taken seriously globally. Efficient waste management has been promoted for a great and clean environment. The industry's by-products waste such as fish and poultry waste have been gaining researchers interest to seriousness converted it to a valuable commodity like alternative gelatine. Therefore, the review on current waste from industry in Malaysia and its impacts, potentially used of fish and poultry wastes as gelatine-based film using bio-nanotechnology approaches and business opportunities was discussed. Application of nanoparticles in food packaging is growing rapidly worldwide especially the development and implementation of bio-degradable packaging system that works against moisture, gas and microbial barrier is a very useful approach to achieve the mentioned function. Replacement of petroleum-based non bio-degradable plastics by bio-degradable packaging material significantly useful for future application in order to protect human health. This is because the major risk associated with nano-sized components is their potential opposing health effects due to its migration into food.

1. Introduction

Various industries rapidly expanding with the utilization of latest technology globally. However, there has been a lot of waste produced including agricultural and livestock waste. Sahu *et al.* (2017) reported that million tonnes of fish and prawn waste throughout the food chain is produced by fish and prawn processing industries. The waste such as fish intestine, gills, muscles, fat and prawn could be reused for other beneficial purposes. The reused principle normally refers to the repeated use of products or components for their intended purpose and the targets of reduction principle are to minimize of raw material use, energy input, and waste production (Ghisellini *et al.*, 2016). Many studies have been conducted using this waste in the production of food packaging with the use of Nano-technology.

Recently, Nano-technology is the most recognized technology that shows the ability to synthesize new products with diverse applications and advantages. Application of nanoparticles in food packaging including nanoencapsulation, nanocomposite, nanoemulsions, edible nanocoatings and nano-coating materials (Sharma

and Dhanjal, 2016). Moreover, biotechnological aid is applied to synthesize nanoparticles that helping by living entities such as bacteria (Farhoodi, 2016). The function of this technology that involved in food packaging, therefore, to protect food from damage and contamination, and extends the shelf life of food products, thus potentially reducing wasted food (Heller, 2017).

Sharma and Dhanjal (2016) stated that bio-nanotechnology proposals advanced anticipation in food packaging which will deliver the longer shelf-life, secure packaging and recover the quality of food. An intelligent food packaging can attentive on spoilage food whereas, during the active packaging, antimicrobials is added as preservatives into the food during the initiation of the spoilage (Duncan, 2011). Gelatine and silver nanoparticles and organo-clay that exhibit a significant activity of antimicrobial towards pathogenic bacteria. In addition, gelatine based nanocomposite films will benefit in competing and eliminating the bacterial invaders that can prolong the shelf life and improve the quality of food (Sharma and Dhanjal, 2016).

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Therefore, this paper presents a contemporary review of potential value added product that can be produced from industrial waste especially by-products from fish and poultry processing industry. The introduction of gelatin alternative from fish and poultry by-products offer a potential biodegradable film packaging which benefit to the mentioned industry in order to manage their waste. Thus, indirectly solve the environmental problems.

2. Environmental impact

2.1 Solid waste generation in Malaysia Farm waste

Municipal solid waste (MSW) generation increases steadily in Malaysia - as a response to the growing population (Abushammala *et al.*, 2011). Based on 2017 estimation by CIA (2018), the country land area of 329,847 km² is home to 31.38 million. The relative amount of MSW generation is strongly linked to the respective population of the states (Manaf *et al.*, 2009). Among the 11 states in Peninsular Malaysia, the contribution of MSW is mainly from congested states like Selangor, Kuala Lumpur (capital of Malaysia) and Johor. Areas with fewer residents like Perlis, Melaka and Negeri Sembilan have the lowest figures.

The rate of MSW generation in 1990 for Malaysia was 0.7 kg/capita/day - slightly below that in developed countries like Singapore and the United Kingdom at 0.85 and 0.845 respectively (Eusuf *et al.*, 2011). However, it was much higher than other countries like the Philippines at 0.5. The Malaysia number soared to 1.5 in 2007 and is anticipated to increase further due to population growth and development (Periathamby *et al.*, 2009). Waste management comes with an excessively high cost, comprising up to 50% of the municipal operating budget. The waste collection alone constitutes 70% of the budget, albeit collecting only 70% of total MSW (Johari, 2014). The situation would reach a tipping point should it continues. In curbing the issue, long ago the federal government passed a bill in 2007 to allow privatization of solid waste management company. A list of Malaysia transformation of solid waste management policies and plans was summarized by Razali *et al.* (2019).

The main contribution of MSW is activities of daily living, street cleaning, industrial production, construction works, landscape conservation, institutional and commercial activities (Johari, 2014). The residential waste alone amounts to 48% of gross MSW.

The waste generally comprises of food, paper, plastic, glass, metal, textiles and wood (Budhiarta *et al.*, 2012; Fazeli *et al.*, 2016; Zainu, 2017). Food represents as high as 45% of the total waste. Wet food waste from households constitutes 38.32% of the total food waste

generated in Malaysia (Ministry of Housing and Local Government Malaysia, 2011). To minimise household food waste, Jereme *et al.* (2018) has identified a few solutions such as the formulation of households food wastes policies. The remainder of 60% of food waste originates from production to retailing (FAO, 2011). Due to high food waste percentage, MSW typically has high moisture content. For example, Kuala Lumpur waste contains 55% moisture content by weight (Kathirvale *et al.*, 2004). Other typical characteristics of the trash are high carbon and chlorine contents.

In the stages of agriculture, first is farming and husbandry activities, followed by food processing and manufacturing. The third stage is the retail at wet markets, grocers and supermarket. Lastly is at household, food service departments (restaurants, hospitality sector, cafe) and institutions such as education institutions, hospitals, prisons. As each point gives rise to food waste quantity, it is pertinent to consider revising the steps in bringing down the food waste.

At the present time in Malaysia, the majority of the waste is disposed and a minute portion recycled, composted, incinerated and used as landfill (Agamuthu, 2006). Landfill is generally categorized as inert, sanitary and unsanitary landfill (Agamuthu, 2006). Until 2002, 5% was subjected to recycling, 5% into sanitary landfills, and 90% as other disposal sites. Utilization of rubbish improved tremendously in 2006, with percentage increment of recycling to 5.5%, composting 1.0%, inert landfill 3.2%, sanitary landfills 30.9% other disposal sites 59.4%.

Albeit no latest statistics of waste reduction, it is believed that there is still a big gap before the achievement of the objectives of Malaysian Vision of 2020. Given the short span of one year before the deadline, it arduous to accomplish 22% recycling, 8% composting, increase incineration to 16.8%, the inert landfill to be increased to 9.1%, and aiming the sanitary landfill at 44.1% and a full closure of the unsanitary landfill. The most favoured options are to practice prevention, minimization, and reuse, rather than recycling, energy recovery, and land disposal (Lim *et al.*, 2019).

2.2 Environmental impacts of solid wastes

Through the study of the life cycle inventory of open dumping and sanitary landfill starting from MSW collection in the residential area, Saheri (2011) has identified the severe environmental impacts of waste production, either directly or indirectly due to energy consumption, air emissions, and water discharge. Production and release of atmospheric carbon dioxide in

energy consumption processes leads to global warming. Leachate - water discharged from unsanitary landfill has various toxicities and is harmful to the surrounding ecosystem. The high organic content of leachate has high biochemical oxygen demand that deprives oxygen from living organism. The lack of respiratory gas kills many lives. The absence of free oxygen also forces anaerobic reaction to occur and produces climate change by-products like methane. Electricity generation produces toxic air such as hydrogen chloride, hydrogen fluoride, ammonia, nitrous oxides, sulfur oxides, all of which could cause acidification of rain, and aquatic eutrophication nitrogen and phosphorus (Abdul Aziz, 2007; Tonini *et al.*, 2018). In energy utilization, heavy metals are emitted too (Abdul Aziz, 2007).

3. Type of waste

3.1 Fish waste

The fishing industries include any industry or activity that involves in taking, culturing, processing, preserving, storing, transporting, marketing or selling fish or fish products. Approximately 140 million tons of fish production, including aquaculture, are derived from a huge market share of international channels in which 110 million were for human consumption (Benhabiles *et al.*, 2012). In addition, Food Agriculture Organization (FAO) also reported that aquaculture's contribution to total fish food supply grew at an average annual rate of 3.2% from 1961 to 2013 (Ishak and Sarbon, 2018). This data showed that more than 60% of the industry's by-products are fish wastes including head, skin, trimmings, fins, frames, viscera, and roe. These fish waste, especially from fish processing industries, are an important environmental contamination source. An important waste reduction strategy for the industry is the recovery of marketable by-products from fish wastes (Ishak and Sarbon, 2018).

Consequently, in the last two decades, fish by-products have been gaining attention as a significant additional source of nutrition. For instance, a wide range of fish by-products is found such as oils, collagen, gelatine, hydrolysates, and bioactive peptides. Fish wastes, including frames, head, skin, scales, bone, and viscera, are used to produce protein hydrolysates (Ovissipour *et al.*, 2009; Ishak and Sarbon, 2017; Rasli and Sarbon, 2019), gelatine (Cheow *et al.*, 2007; Rosli and Sarbon, 2015; Rasli and Sarbon, 2019), bioactive peptides (Halim *et al.*, 2016; Ishak and Sarbon, 2017; Halim and Sarbon, 2017; Halim *et al.*, 2018) and collagen (Hamdan and Sarbon, 2019; Hadfi and Sarbon, 2019). Many studies have been reported on gelatine production from different part of fish by-products like from fish skin such as thornback ray (Lassoued *et al.*,

2014), shortfin scad (Rasli and Sarbon, 2018); from fish scales such as lizardfish (*Saurida* spp.) (Wangtueai and Noomhorm, 2008); from fishbone such as Freshwater Fish (*Cirrhinus mrigala*) (Chandra *et al.*, 2013), Tiger-toothed croaker (*Otolithes ruber*) and Pink perch (*Nemipterus japonicus*) (Koli *et al.*, 2012).

3.2 Poultry waste

Recently, poultry waste especially chicken skin has been gaining researchers interest in the efforts to obtain alternative gelatine as this commodity can be easily found due to its common consumption by consumers all over the world. This was proven throughout statistics data reported by The United States Department of Agriculture (USDA) where the global poultry production was 111,000 thousand metric tons in 2015 and predicted to increase by 24% over the next decades, reaching 131,255 thousand metric tons in 2025 ("Global Industry Statistics, Poultry Hub", 2018). Therefore numerous studies have been developed regarding this poultry by which almost all part of that animal has been exploited recently including feet part (Lee *et al.*, 2015), skin part (Sarbon *et al.*, 2015; Nor *et al.*, 2017; Soo and Sarbon, 2018) and also its meat residue (Rammaya *et al.*, 2012) despite the consumption of its meat and eggs.

Currently, rapid progress on the development of gelatine sources from skin and bones derived from poultry underway have been spotted as these sources never had a problem with health issue regarding mad cow diseases caused by bovine spongiform encephalopathy, BSE. Concerning the abundant amount of chicken waste linearly contributed by the high consumption number of chicken from time to time, chicken skin based gelatine have been highlighted and studied by Sarbon *et al.* (2013; 2015) before followed by Nazmi *et al.* (2017) and Nor *et al.* (2017) with further application in food packaging area. By examining the functionalities of this type of gelatine by Sarbon *et al.* (2013), it found that gel strength from chicken gelatine has significantly higher bloom value compared with bovine gelatine due to the intrinsic characteristic such as protein chain composition, molecular weight distribution, amino acid content and types of extraction treatment as well as the properties of collagen.

3.3 Potential of gelatine base film

The use of gelatine to form films or coatings was very well studied in the 1960's, which resulted in many patents being filed, mainly in the pharmaceutical area (Park *et al.*, 2008). However, gelatine has again attracted much attention from researchers in recent years as packaging films and coatings due to its natural abundance, renewable, relatively low cost,

biodegradability, film-forming ability and excellent functional properties (Jahit *et al.*, 2016). The α -, β -, γ -chains and other peptide fragments of gelatine enable it to be an ideal dispersing and film-forming agent by holding the native hydrophilic and hydrophobic domains in the structure (Ahmad *et al.*, 2015). Due to the existence of reactive functional groups include -NH₂, -COOH, and -OH along the backbone and side chains, gelatine can be further blended with other functional polymeric molecules to form composite film with better functional properties (Nur Hanani *et al.*, 2012; Ahmad *et al.*, 2015).

Properties of gelatine films vary depending on both the gelatine type and concentrations used. The functional properties of gelatine film are influenced by different types of gelatine (Nur Hanani *et al.*, 2012), as their physical and structural properties of gelatine are mainly influenced by the molecular weight distribution and amino acid composition (Gómez-Guillén *et al.*, 2009). The study of Nur Hanani *et al.* (2012) revealed that high concentration gelatine films had good mechanical properties as well as good gas barrier properties. Gelatine film also thin, flexible and possess high optical properties with higher degree of transparency (Jahit *et al.*, 2016; Nur Hazirah *et al.*, 2016). However, gelatine films have some major limitations due to their high moisture sensitivity, high brittleness as well as poor thermal stability (Arvanitoyannis *et al.*, 1998; Nur Hazirah *et al.*, 2016). However, gelatine film possesses poor water vapour barrier and water-resistant due to its high amount of hydrophilic amino acids with negligible or no sulfur containing amino acids (Hoque *et al.*, 2011). Therefore, several research studies have been conducted to improve the functionality of gelatine films by blending and/or mixing with other biopolymers, plasticizers, cross-linking agent, strengthening agents or additives with antimicrobial or antioxidant properties (Al-Hassan and Norziah, 2012; Nur Hanani *et al.*, 2012; Ramos *et al.*, 2016, Said and Sarbon, 2019).

3. Nanotechnology

Nanotechnology is a revolutionary field of micro manufacturing involving chemical and physical changes to produce nano-sized material. The word 'nano' is a Latin word meaning 'dwarf'. Currently, this technology has increasingly been considered an attractive field that has revolutionized in various industrial areas like agriculture, food, medicine and etc. It is a technology that involves designing, synthesis and characterization of material (molecule or atom) structure by controlling the sizes and shapes on the nanometre scale. Gupta *et al.* (2016) and Rai *et al.* (2009) state that these materials

have a unique properties, unlike their macroscale counterparts due to the changes in the high surface to volume ratio and other novel physicochemical properties like appearance, colour, optical, texture, strength, solubility, diffusivity, thermodynamic and etc. Therefore, nanotechnology offers a huge possibility and opportunity for the development and application for solving obstacles ranging from food packaging, pharmaceutical industry, medical, to electronics and energy industry or system with new and unique properties (Omanović-Miklićanin *et al.*, 2019). Nowadays, nanotechnology has carried new industrial revolution and both developed and developing countries are interested in participating more in this adaptable and sustainable technology (Qureshi *et al.*, 2012; Singh *et al.*, 2017).

3.1 Nanotechnology in food packaging

The food industry is growing rapidly in line with the increasing number of human in the world. Referring to the United Nation (2017) report, the world's population has reached 7.6 billion by mid-2017 and the world population is projected to increase by more than one billion people within the next 13 years, reaching 8.6 billion in 2030, and to increase further to 9.8 billion in 2050. Thus, the demand for food also increased and that's why researchers want a diversity of methods, technologies and innovations to meet the needs of huge populations demand. Currently, the food packaging sector became the most of nanotechnology applications in the food industry (Reig *et al.*, 2014). This is mainly due to the vast development of nanotechnology in this sector, to a higher acceptance by the consumer of the use of this technology in food packaging rather than in food as ingredients. Moreover, based on the requirements of regulations, application in packaging is less restrictive than for the enforced current food legislation. All of these contributes to the fact that there are many more applications in this area compared to the others food sector, together with the necessity of lighter, stronger, sustainable, efficient and intelligent packages. These packages would be able to provide safe products with superior quality and at the same time can maintaining the food products in the best possible conditions and with a longer shelf-life.

Generally, the functions of packaging are numerous and not only as protecting or preserving of raw or processed food against spoilage or pathogen microorganism, but it also provides as a barrier in controlling potentially damaging levels of light, oxygen and water. It facilitates ease of use, offers adequate storage, conveys information and provides evidence of possible product tampering. Currently, a desirable

packaging material must have gas and moisture permeability combined with light but have a good strength and biodegradability capabilities (Couch *et al.*, 2016). Thus, nano-based ‘smart’ or ‘intelligent’ and ‘active’ food packaging confer several advantages over conventional packaging methods from providing better packaging material with improved mechanical strength, barrier properties, antimicrobial films to nanosensing for spoilage or pathogen detection and alerting consumer to the safety status of foodstuff (Mihindukulasuriya and Lim, 2014).

A wide variety of nano-materials or nanocomposite from organic and inorganic such as protein, carbohydrate, chitosan, silver nanoparticle, titanium nitride nanoparticle, nano-zinc oxide and nanoclay are introduced as functional additives to food packaging system (Tager, 2014). Application of nanotechnology in food packaging system can be divided into three main categories as i). improve packaging: Nanoparticles are mixed with polymer chain to improve the gas barrier properties, as well as, humidity and temperature resistance of packaging; ii). Active packaging: The use of nanomaterials is helpful to interact directly with food or environment to allow better protection of the food product. Several nanomaterials such as nanosilver, carbon nanotubes and nano magnesium oxide can provide antimicrobial properties; iii). Intelligent/smart packaging: The use of nanoparticles is to design and help in sensing the biochemical or microbial changes in the food. It can detect specific pathogen developing in the food or specific gases from food spoiling. Some smart packaging has been developed to use as tracing devices for food safety (Pal, 2017).

The applications of nanoparticles are not limited to antimicrobial food packaging but have been actively used in food packaging to provide a barrier from mechanical shock or external hazards and protect from extreme thermal to extending shelf-life in the form of nanocomposite and nanolaminates. Application of nanotechnology also can be used in coatings or labels of packaging that providing information about the traceability and tracking of the outside as well as inside

food products conditions through the whole food chain. Some example of these application are: temperature variations (freeze-thaw-refreezing, monitoring of cold chain by means of silicon with nanopores structure); leak detection for food that packed under vacuum or modified atmosphere (some compounds change of colour, therefore warming to the consumers that air has come inside due to the leaking problem) (Mills and Hazafy, 2009); humidity changes or foodstuffs being deteriorate or spoil (unusual microbial presence). Liu *et al.* (2007) state that these sensors work producing a specific pattern of answer against each type of microorganism. In this way, the incorporation of nanoparticles into packaging materials contributes to the best quality foodstuff with longer shelf-life and solves environmental problems by reducing the necessity of using plastics that manage to aid the worldwide waste issue. With all the benefits provided, attempts should be made to develop low-cost packaging by using nanotechnology. The packaging applications along with the most commonly used type of nanomaterial in each situation are briefly described in Table 1.

4. Food safety

4.1 Gelatine based film with antimicrobial property

The rapid development in the food packaging industry is in line with the diversity of foods that have been created and produced. The use of food packaging is subject to the functionality of the wrapper itself in protecting foods from physical, chemical, or biological damage. Instead of the conventional packaging that offer the single layer with *Low-density polyethylene (LDPE)* or Ethylene vinyl alcohol (EVOH) and composite package (LDPE/EVOH), development of antimicrobial packaging system that works against moisture, gas and microbial barrier is very useful approach to achieve the mentioned function (Lu *et al.*, 2018).

Antimicrobial packaging is classified under active packaging that prevents surface growth of pathogenic microorganisms in food by the use of antimicrobial agents. The antimicrobial agents incorporated with the inner layer of the packaging will release into food

Table 1. Applications and characteristic of nanomaterial-based food packaging

| Application | Type of Nanomaterial | Characteristic |
|------------------------|--------------------------------------|---|
| Mechanical properties | Carbon nanotubes | A relatively low loading can improve polymer properties without impact on density, transparency and few other properties. |
| Barrier properties | Nano-clay | Improved gas-barrier and protect against visible and UV light. |
| Antimicrobial activity | Silver nanoparticles | Biocidal action based on size and shape-dependent interaction with microorganisms. |
| Active packaging | Inorganic nanoparticles such as iron | Oxidation of iron instead of food constituents such as myoglobin in meat products. |
| Intelligent packaging | Cellulosic nanomaterials | Monitoring of pH changes in foods and controlled release of bioac- |

Adapted from Tsagkaris *et al.* (2018)

surface during storage and distribution. It prevents the degradation of packaged food which providing protection against microorganisms and therefore, maintain the quality of the food products. According to Suppakul *et al.* (2003), the lag phase will be extended and the growth rate of microorganisms is reduced which then extending shelf life and maintaining product quality and safety. Table 2 shows the application of antimicrobial packaging done by a few researchers.

Normally, antimicrobial agents such as spices, chitosan, enzymes, bacteriocins and organic acids may be coated, incorporated, immobilized, or surface modified onto packaging materials has been tested with a different result (Gautam and Kumar, 2017). In a study carried out by Lopez-Carballo *et al.* (2008), an antimicrobial photo sensitizer-containing edible films and coatings based on gelatine as the polymer matrix, incorporating sodium magnesium chlorophyllin (E-140) and sodium copper chlorophyllin (E-141) showed the inhibiting effect towards *Staphylococcus aureus* and *Listeria monocytogenes* with reduction of 5 logs and 4 logs respectively. Fernández *et al.* (2009) found that silver nanoparticles in fluff pulp and nanostructured Lyocell fibres which are immersed in silver nitrate effective against *Escherichia coli* and *S. aureus*. Many researchers found that silver nanoparticles have antimicrobial activity towards Gram-negative and Gram-positive bacteria and fungi (Hoffmann *et al.*, 2019).

This revealed that silver-based nanotechnology is potentially used as antimicrobial packaging. According to Yadav *et al.* (2019), silver (Ag) usually incorporated with other materials and served as a nanofiller in food packaging to give antibacterial properties. Kim *et al.* (2011) investigated the utilization of antimicrobial nanoparticle incorporated into polymer matrix towards pathogenic bacteria as well as factor contributed to the

quality of food product such as odour. Chitosan biopolymer films (CBFs) with different viscosities of chitosans were used in this study. The researchers found that CBFs were more effective for inhibition of *L. monocytogenes* as compare to *Salmonella enterica* serovar Typhimurium and *E. coli* O157: H7. Li *et al.* (2012) reviewed on the effectiveness of antimicrobial activity of films which are PLA (polymer 4060D) +AIT (essential oil component of cruciferous plants) and Chitosan + AIT against *S. enterica serovar Stanley*. The microbial growth was reduced from 4.57 to 4.04 and from 4.35 to 4.15 log cycles for PLA +AIT and chitosan + AIT coatings, respectively. However, direct addition of AIT into foods may significantly decrease its antimicrobial activity. In addition, Aguirre *et al.* (2013) reported on carvacrol and thymol in biodegradable and edible packaging film that was plasticized with glycerol. The used of 1% (w/w) oregano EO including carvacrol and thymol effective in controlling gram-positive *S. aureus* compared to gram-negative such as *E. coli* and *Pseudomonas aeruginosa* that were tested in their study. In other findings, Singh *et al.* (2015) revealed that nisin and eugenol oil combination which incorporated into bioactive chitosan film (BAC) showed a potent antimicrobial additive for food applications.

4.2 Safety of Bio-nano composite

Replacement of petroleum-based non bio-degradable plastics with biodegradable packaging material sounds to be very important for future application in order to protect human health. The major risk linked with nano-sized components is their potential adverse health effects contributed by its migration into the food (Echegoyen and Nerin, 2013). In certain cases, nanoparticles indicated that vascular disease, intracellular damages and pulmonary inflammation can be induced. Since many nanomaterials are not fully discovered and understood,

Table 2. The application of antimicrobial packaging.

| Material used | Application | Reference |
|--|--|--------------------------------|
| Chlorophyllins incorporated into the gelatine film-forming solution | Inhibiting effect of the cast films that reduced the growth of <i>Staphylococcus aureus</i> and <i>Listeria monocytogenes</i> . | Carballo <i>et al.</i> (2008) |
| Silver nanoparticles in fluff pulp and nanostructured Lyocell fibres which were immersed in silver nitrate | Effective on <i>Escherichia coli</i> and <i>S. aureus</i> . | Fernández <i>et al.</i> (2009) |
| Chitosan biopolymer films (CBFs) | Effective inhibition towards <i>L. monocytogenes</i> rather than <i>Salmonella enterica</i> serovar Typhimurium and | Kim <i>et al.</i> (2011) |
| PLA(polymer 4060D) +AIT(allyl isothiocyanate) and Chitosan + AIT | Reduction effect on <i>S. enterica</i> serovar Stanley. | Li <i>et al.</i> (2012) |
| Carvacrol and thymol in biodegradable and edible packaging film that was plasticized with glycerol | Used of 1% (w/w) oregano EO including carvacrol and thymol effective in controlling gram-positive <i>S. aureus</i> compared to gram-negative (<i>E. coli</i> and <i>Pseudomonas aeruginosa</i>). | Aguirre <i>et al.</i> (2013) |
| Bioactive chitosan film (BAC) | Revealed that nisin and eugenol oil combination showed a potent antimicrobial additive for food | Singh <i>et al.</i> (2015) |

the toxicological study is required to clarify the risks involved and food regulation should be established (Mihindukulasuriya and Lim, 2014). Moreover, European act and FDA regulations are already setting the permitted levels of the nanoparticles in food (Chaudhry *et al.*, 2008). In line with that concern, lately, many researchers conducted a study on the effect of nano packaging especially related to food and the impact on regulations.

Li *et al.* (2008) reported that titanium dioxide (TiO₂) is not categorized as toxic mineral particles and widely used in drug, cosmetics and food. Nano-TiO₂ shows specific characteristics but with unknown risks on human health. It's showed that the erythrocytes treated with nanoTiO₂ underwent abnormal sedimentation, hemagglutination and dose-dependent hemolysis which were totally different from those treated with micro-TiO₂. Their findings suggest that nano-TiO₂ may toxic and effected human health. In the near future, about 10 and 100 times of nanosilver of sewage treatment plants are estimated to be released (Mueller and Nowack, 2008). Another few reports related to nanoparticles that show significant influences on aquatic microorganisms that impact to fish reported by Handy *et al.* (2008) who established evidence of toxicity. The Titanium dioxide nanoparticles are present in the viscera and gills of fish as reported by Zhang *et al.* (2007). In another study, Sawosz *et al.* (2007) found that 25 mg/kg of silver nanoparticles in drinking water exposed to quails affected gastrointestinal microflora.

de Abreu *et al.* (2010) simulated many types of food and highlighted on the migration of caprolactam, 5-chloro-2-(2,4-dichlorophenoxy)phenol (triclosan) and trans,trans-1,4-diphenyl-1,3-butadiene (DPBD) from polyamide and polyamide-nanoclays. Those substances were migrated from matrix polymer into food found to be slow down up to six times with the presence of polymer nanoparticles. Certain nanoparticles will affect some organ that was studied which indicated the spreading of nanoparticles into the reproductive system, testis and brain. The potential migration of nanoparticles also will be a specific concern of brain and unborn foetus (Silvestre *et al.*, 2011). The health effect on other particles incorporated or coated to food packaging is still under study such as ZnO nanoparticles (Lin and Xing, 2008) and fullerenes (Xia *et al.*, 2010).

5. Cost opportunity

5.1 Waste management in Malaysia

Waste management has become one of serious concern in Malaysia. The traditional approaches to reducing waste management which is reduce, recycle,

and reuse (3R) method are practised but at the low to moderate levels due to the lack of policy and participation from the public. Private sectors were encouraged to participate in green technology. The Ministry of Energy, Green Technology and Water has given serious concern towards minimizing waste management. The ministry determination in dealing the global environmental change has been carried out by promoting the more environmentally sound waste management (Sreenivasan *et al.*, 2012).

5.2 Economic perspective

Actions are necessary and urgent throughout food systems on producing more food, moderating demand, reducing waste and improving governance to move towards more sustainable food systems (Godfray and Garnett, 2014). Proper waste management and reduced food waste can save economic resources, lessen negative impacts of food leftover on waste management systems and contribute to food security. The large economic impact of food wastage affects all the individuals and organizations involved in the food supply chain. Saving money can be a driving factor to prevent food waste behaviours; therefore, people need to understand the economic costs of food wastage that can occur when they do so (Quested *et al.*, 2013; Graham-Rowe *et al.*, 2014; Waste Minz, 2014).

Research has shown that the higher the incomes of household, the more varied diet they will consume (Drewnowski, 1999; Pingali and Khwaja, 2004; French *et al.*, 2019). In developed countries, people eat more protein, energy-rich and convenience foods, and eat less rice. For example, western foods that have shorter shelf-life foods and more vulnerable may lead to greater food waste (Lundqvist *et al.*, 2008). Conrad *et al.* (2018) stated that the food will be less wasted in the more repetitive diet rather than a diversified diet. Hence in restaurants, spread menus will lead to more food waste since there are extra ingredients to manage.

5.3 Business opportunities for fishbone and poultry waste

Previously, seafood and poultry waste business is not popular among the entrepreneur. Due to low economic value, seafood and poultry waste were thrown out as waste or leftover as organic fertiliser. Moreover, there are only a few available proven processing technologies exhibited by industrial players that contribute to the underdevelopment of the seafood and poultry waste industry. In addition, financial institutions also have a low confidence level towards most seafood and poultry investor due to the lack of mature technologies that will lead to unsuccessful financing support.

Industrialization of food systems will affect the foods that people eat, contributes to increasing the types and quantities of food waste (Parfitt *et al.*, 2010). The food production and preparation has been shifted from home to factory and also from cooking to buying (Strasser, 1999). For example, in industrialized food systems, people will purchase pre-cut meats, such as chicken legs. Thus, there are no other parts of the chicken to be wasted because the other parts of the chicken are utilized by industry during the chicken processing. Therefore, these seafood and poultry waste can be good business opportunities for industry player and entrepreneur.

Waste to wealth should be applied among the consumer in order to reduce the global warming phenomenon from seafood and poultry waste toward sustainable waste management. For instance, the commercial fish processing industry generates a problem when only flesh is used to make a product and a huge number of unwanted parts will be dumped as waste. Fish waste has active ingredients that can produce a high value product. Collagens are among others the example of the product that can be extracted from seafood waste and widely used in the pharmaceutical field (Raghuraman *et al.*, 2013). Without proper utilization of waste, environmental problems might occur. The fish waste was testified as a good source of protein content and polyunsaturated lipid. Active ingredients that present in food waste can create natural product such as proteins, polysaccharides, fibres, flavour compounds, and phytochemicals have shown potential market (Baiano, 2014).

6. Conclusion

In conclusion, the recent development of nanocomposite technology has provided renewed opportunities for the use of gelatine-based nanocomposite films in the food packaging industry. Gelatine films composited with nanofillers, such as nanoclay, organic fillers, and nanometals (like AgNPs, CuNPs, ZnO NPs), and TiO₂ NPs, have shown not only improved film properties but also strong antimicrobial activity. However, the properties of gelatine-based nanocomposite films produced are depending on the type of gelatine used. Proper utilization of fish and poultry waste has been proved contributed to the economy through the introduction of high-value products besides generating a solved environmental problem. Thus, the waste to wealth concept applied to the fish and poultry waste can be achieved by focusing on integrating nanoparticles with biopolymers as antimicrobial packaging.

Conflict of Interest

The authors declare no conflict of interest.

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