Pediocin and Grape Seed Extract as Antimicrobial Agents in Nanocellulose Biobased Food Packaging: A Review

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Abstract. The food industry is a life-long and highly demanded industry as it is an essential human need. Food safety has become an urgent discussion related to this industry since the foodborne disease has gradually increased. One of the causes of the disease is L. monocytogenes, usually discovered in fresh meat, ready-to-eat meat, vegetables, and milk. L. monocytogenes causes an infection known as listeriosis. Food packaging plays an essential role as it protects the food from external contaminants to increase the shelf life. The high usage of conventional food packaging derived from fossil fuel contributes to the environmental issue as it creates long-term wastes. Therefore, biobased food packaging has been in favor as it is biodegradable. However, it lacks antimicrobial properties, so the development of biobased material as the antimicrobial food packaging is a potent solution in the food safety scope. This review paper intends to summarize current advancements in incorporating antimicrobial agents with nanocellulose biobased food packaging to increase the packaging’s functional value. Pediocin is the antimicrobial agent produced by Pediococcus sp. integrated with Grape Seed Extract (GSE), which gives an antioxidant property that boosts the food packaging’s antimicrobial effect. Observations show that incorporating these antimicrobials agents obstructs the growth of L. monocytogenes in biobased food packaging. Incorporating antimicrobial agents into nanocellulose matrix shifts the tendency to make biobased packaging that gives better mechanical strength and longer shelf life. Overall, this greener antimicrobial food packaging could be a solution to environmental waste as well as foodborne pathogens.

1. Introduction
Food is an essential part of our lives. A complex workflow such as supply chain, food production, consumption, and services are integrated to provide this primary human need. A significant concern is food safety issues regarding product quality, sanitation, and health [1]. By 2017, the global food and beverage industry has seen substantial growth over the last five years, and this trend is expected to continue as the industry is projected to be $5776 billion worth [2]. However, this positive industrial growth is not balanced with the global foodborne disease trend that still gradually increases. The World Health Organization (WHO) stated that nearly one in 10 people worldwide fall ill every year after eating contaminated food, leading to over 420,000 deaths [3]. Foodborne diseases are caused by microbial contamination of food and occur at many stages of the food lines. In the United States, L. monocytogenes is one of the top 5 pathogens causing foodborne illnesses resulting in death by 2011 [4]. Infection of L. monocytogenes causes listeriosis, which has a mortality rate of 30%[5].
Food packaging plays a significant role in protecting food from pathogens and preserving its condition [6]. On the other hand, food packaging waste has been a significant problem. The packaging industry still heavily relies on products derived from fossil fuels. Packaging contributes to 42% of plastic waste [7]. A new sustainable approach is needed to solve these problems. One solution is by incorporating natural antimicrobial and antioxidant into bio-based food packaging, which promotes a longer food shelf life. Two common antimicrobial agents that have been used in food packaging are grape seed extract (GSE) and pediocin. Grape seed is a by-product derived from wine processing and grape juice industries [8]. Phenolic compounds in grape seeds have been known to have antimicrobial and antioxidant effects [9]. GSE has been proven to act as antimicrobial both in vivo and in vitro [10], [11]. Pediocin is a unique bacteriocin with anti-listeria activity. According to Acuña et al. [12], Pediocin is the most studied bacteriocins and commercially used as bio preservatives. However, commercial pediocin has only existed and is widely used. The antimicrobial property comes from its complex peptide structure, and its efficacy to reduce L. monocytogenes pathogen in food has been proven by many researchers.

Bio-based packaging uses materials derived from primarily annual renewable resources, thus excluding the paper-based material [13]. One of the renewable resources that are being developed is cellulose. Cellulose is the most abundant organic polymer on Earth [14]. Many biomass contains a high concentration of cellulose. The role of cellulose in biomass is a structural component in the cell wall of green plants, algae, and oomycetes. To enhance the mechanical properties of cellulose, cellulose is modified into a nanocellulose structure. This review paper aims to summarize the potentials of incorporating antimicrobial and antioxidant agents from GSE and pediocin into the nanocellulose matrix. This incorporation gives advantages to the better mechanical strength of packaging and longer shelf life of food.

2. Antimicrobial Agents

2.1 GSE

2.1.1 GSE Characteristic. GSE contains 74 to 78 % polyphenols, which are oligomeric proanthocyanidins (B₁, B₂, B₃, B₄, B₂-G, B₂-G, B₂-G', C₁) [15], [16]. These compounds’ activity is believed to be the reason for GSE antimicrobial, antioxidant, and health benefit effects [17]. Studies have reported some health benefits of consuming GSE, particularly in treating cardiovascular diseases, obesity, type 2 diabetes, inflammatory bowel disease, neurogenerative disorders, asthma, eye disease, and osteoarthritis [18]. Another research also reported that GSE could be used as nutraceuticals or new drugs for treating Malignant Mesothelioma (MM) cancer [19]. Giving its health benefit, GSE is not reported to exhibit toxicity or adverse health effects on daily consumption [20], [21].

2.1.2 Extraction of GSE and its Recent Advancement
Research showed that grape seed contains the highest amount of polyphenols, making it the primary extraction [22], [23]. Many methods have been developed to increase the yield of polyphenolic compounds in GSE. The conventional method, such as soxhlet extraction, involves organic solvents such as n-hexane and ethanol in extraction, separation, and GSE purification [24]. Dimić et al. [25] conducted the extraction by using n-hexane to extract grape seeds sample for 6 hours with 15 exchanges of extracts and filtration of the solvent. The solvent was then evaporated under vacuum conditions at 40℃. A novel extraction of GSE was conducted by using supercritical fluid to reduce the usage of toxic solvents, such as n-hexane [26]. Coelho et al. [27] conducted the process using supercritical CO₂ at various temperatures, pressures, and flow rates. Grape seed was dried for 48 h at 343 K before being extracted with a continuous flow rate of supercritical CO₂. They concluded that extraction using supercritical fluid yield the same amount of extract as the conventional n-hexane extractions while using a less harmful solvent.

2.2 Pediocin
2.2.1 Pediocin Characteristic
Bacteriocin refers to the bacteria that can inhibit or kill other bacteria because of the ribosomal synthesized antimicrobial peptides. Produced bacteriocins vary depending on the action against the targeted bacteria [28]. Lactic Acid Bacteria (LAB) is the most widely used bacteriocin producer in a food fermentation context. It includes the genera Pediococcus, Lactococcus, Lactobacillus, and Streptococcus. LAB converts sugar into lactic acid and other substances that act as bio-preservatives, such as diacetyl, hydrogen peroxide, acetone, and other organic acids. Pediocin is the bacteriocin that is classified as Class IIA in the product of LAB classification. The class is unique for its anti-listeria activity that has drawn interest in research and application [29].

Aromatic and aliphatic amino acids arrange pediocin to be a structure of the 44-residue peptide. N-terminal is a highly conserved, hydrophilic, and cationic region. It poses a three-desolate β-sheet reinforced by a disulfide bond, which consists of two cysteine residues. A consensus motif -YGNGV- was found in the N-region. This motif is responsible for the antilisterial activity of pediocin. The C-terminal region is a less conserved region located at the structure tip like a tail. According to Drider et al., it is essential to determine the target cell specificity of pediocin [30]. The C-terminal consists of two cysteine residues. It marks a hairpin domain as the disulfide bond bends the cysteine residues. In their study, Johnsen et al. proposed that the overall pediocin structure is amphiphilic, centered, and α-helix corresponding to the N-terminal [31].

Pediocin is heat stable both in high temperatures like the sterilization process and cold temperature. Pediocin SA-1, the pediocin isolated from P. acidilactici, remains stable at 121 °C for more than 60 minutes. Moreover, the antimicrobial activity was not affected even by storage at -80, -20, 4, and 30°C for four weeks. It was also not interrupted even under a week of incubation at pH values from 3.0 to 12.0, which indicates pediocin activity is retained at a wide pH range. [32]. Furthermore, pediocin antimicrobial activity is still working subsequent to lipase, lysozyme, and D/R-Nase treatments, but it could be damaged by proteolytic enzymes [33].

2.2.2 Antimicrobial mechanism of Pediocin. Pediocins are sensitive to gram-positive bacteria like L. monocytogenes [34]. Before the pore formation in the cytoplasmic membrane, pediocin interacts with the targeted bacteria in prior, which occurs by the electrostatic effect of the cationic N-terminal with the lipoteichoic acid from the bacteria. [35]. After that, the native divalent cations are removed from the cell surface, causing outer membrane destabilization for the peptide to enter and contact the cytoplasmic membrane. This phenomenon is referred to as auto-promoted uptake [36]. After the contact occurred, the C-terminal of pediocin establishes the pore to penetrate the targeted cell’s hydrophobic site [36]. The pores effluence the intracellular substances, reduce the adenosine triphosphate in the cytoplasm, vanish the proton force, and, eventually, cell death [37].

2.2.3. Synthesis of Pediocin. Pediocins are synthesized successfully in rich media [38]. Process variables such as oxygen, pH, temperature, and NaCl are different in every production strains. They are homofermentative as glucose is fermented to DL-lactate in every case via the Embden-Meyerhof-Parnas pathway, but patterns of assimilation fermentation carbohydrate may differ between strains. [39]. P. acidilactici is the most widely used producer strain. The strains mostly ferment glucose, fructose, galactose, ribose, and xylose to DL-lactate. However, it is also reported that a few strains can ferment lactose, sucrose, and maltose [34]. Amado et al. produced pediocin in the culture of P. acidilactici NRRL B-5627 with Man, Rogosa, Sharpe (MRS) medium [40]. The synthesis was held in a fermenter under 200 rpm agitation and 30 °C. It took 92 hours of cultivation, and the pH medium was adjusted to 3.5 at the end of the culture to promote the pediocin release from the cell surface. In order to increase the bacteriocinogenic activity, an ultrafiltration process was added. Papagianni and Anastasiadou [41] concluded that the optimum temperature for growth is 40°C, but it can grow until 50°C. A pH of 6.0 is regarded as the optimum condition for starting cultivation, and the pH could fall to levels as low as 3.6 during bacterial growth.
3. Potential Usage of GSE and Pediocin in Food Industries

3.1 GSE Usage as Antioxidant
Recent studies have shown that GSE effectively increases the shelf-life of cold storage meat and fruit while used in food film packaging [20]–[22]. This likely happens due to GSE’s capability to decrease aerobic mesophilic bacteria’s growth rate, Pseudomonas spp., mold, and yeast in food, thus reducing the rate of oxidation and maintaining the color stability of the product [42], [45]. However, a high GSE concentration could lead to a higher oxidation rate as it can reduce metals to a lower valence state [46]. Table 2 shows the GSE concentration used in different methods and their effects on different food products.

| Food Products          | GSE Concentration (w/w) | Methods                        | Effect                                      | References |
|------------------------|-------------------------|--------------------------------|---------------------------------------------|------------|
| Fresh strawberries     | 1%                      | Incorporation of GSE into chitosan film | Higher shelf-life of strawberries up to 30 day | [42]       |
| Roasted chicken        | 0.2- 1%                 | Solution spraying on the meat surface | Lower bacterial count on treated meat than control on 0.5% of the concentration | [45]       |
| Snakehead fillets      | 0.052%                  | Direct immersion in GSE solution | Chilled fillet shelf-life increase three days than control | [47]       |
| Refrigerated salmon    | 0.8%                    | Incorporation of GSE into chitosan film via microcapsules | Lower *Pseudomonas* spp. on the seventh day of storage than chitosan-alone film | [48]       |

Based on Table 1, it was observed that 0.5% - 1% w/w concentration of GSE shows a reduction of the bacterial count, ranging from 4 – 8 log CFU/g, which promotes longer shelf life. The direct method of using GSE to the food product and indirect method by using film still shows the usage of GSE as an antioxidant. However, previous literature suggested that direct usage of GSE could affect the taste of food [47]. The downside of incorporating GSE into food packaging is that it lowers the tensile strength of packaging and thickens the film, increasing its opacity [44], [49].

3.2 Pediocin Application as the active biopackaging to control L. monocytogenes
Biopreservation implies using hostile microorganisms or their metabolic products to inhibit or wipe out undesired microbes [50]. High consumer demand for good quality and natural foods and strict government provisions make the food manufacturers struggle to warrant safety aspects [51]. The adverse side effects of artificial chemical additives also promote natural antimicrobial substances, like pediocin, to be widely researched and tested for their performance [52].

Active packaging is defined as packaging which able to extend food shelf life and safety by changing the package’s property [53]. Antimicrobial packaging is an active packaging that is reducing, inhibiting, or retarding microbial growth, particularly on the food surface, in order to extend food shelf life. Espitia et al. stated three main methods to incorporate antimicrobial peptides into the active packaging [54]. First, direct peptide incorporation into the polymer. This method was successfully done by Espita et al. [55], who developed the pediocin antimicrobial films to control *L. monocytogenes* in sliced bologna. The polymer matrix was solubilized by mixing it with acetone to make a film-forming solution. The powdered commercial Pediocin ALTA™ 2341 was incorporated in the polymeric solution and mixed homogeneously.
The film solution was distributed on glass slides and dried at 24°C. This method is the simplest and suitable for a polymer that requires mild processing conditions. Second, peptide coating on the polymeric surface. This method is pointed out to be an alternative when it must process the polymer in high pressure and temperature to make the film. The polymer is immersed in a peptide solution. To produce the antimicrobial coating. The polymeric material and peptide are processed separately because extreme conditions are possibly inactivate the antimicrobial activity [56]. Those two methods are resulting in the bioactive components’ migration from packaging toward the food. In the opposite, the third method, peptide immobilization within the polymer, the bioactive components are tied up with the packaging material so that no bioactive components migrate [57]. However, this method has not been widely used because of several drawbacks, such as limitations on diffusion, bioactivity, and molecular mobility losses. Table 2 summarizes some pediocin applications in the active packaging.

**Table 2. Application of Pediocin in The Active Packaging**

| Producer strain                          | Packaging material          | Subject          | Result                                                                 | References |
|------------------------------------------|-----------------------------|------------------|------------------------------------------------------------------------|------------|
| *Pediococcus acidilactici* (in the commercial ALTA™ 2341) | Cellulose                   | Sliced bologna   | *L. monocytogenes* growth reduced by 1.2 log cycles after nine days       | [58]       |
| *Pediococcus acidilactici* (in the commercial ALTA™ 2351) | Cellulose                   | Sliced ham       | *L. innocua* growth reduced for 2 log cycles after 15 days of storage   | [59]       |
| *Pediococcus acidilactici* JBL1095       | Nylon                       | Beef wieners     | An average reduction of 2.7 log CFU/ g during storage at 25°C for eight days | [60]       |
| *Pediococcus pentosaceus* BCC3772        | PLA polymer 4042D and wood sawdust | Raw sliced pork  | *L. monocytogenes* was reduced by 2 log cycles or a 99% reduction of listeria activity | [61]       |

Researches have shown that pediocin incorporated with polymer or biopolymer significantly reduced *L. monocytogenes* activity in the food. Most of the application is on processed meat that requires longer shelf life. However, the application with *Pediococcus acidilactici* is more widely used compared with other strains. The commercial pediocin strains like ALTATM probably influence this as it does not have to isolate the strain from natural sources anymore.
4. Nanocellulose potential as antimicrobial bio packaging

4.1 Nanocellulose properties as biopackaging from lignocellulosic biomass

Cellulose is a polymer of carbohydrates with D-glucose as the monomer. It has a linear structure due to $\beta(1\rightarrow4)$ linked to each monomer [62]. The linear structure of cellulose makes this polymer has a good mechanical property. Recent studies have developed a process to increase cellulose’s mechanical properties to broaden the benefit of cellulose. One of the strategies that have been developed is transforming cellulose into nanocellulose. Table 3 shows the recent studies which reconstruct cellulose to nanocellulose and the result of its properties.

### Table 3. Natural resources of nanocellulose and the result properties.

| Nanocellulose sources | Isolation Technique | Yield (%) | Properties | References |
|-----------------------|---------------------|-----------|------------|------------|
| Oil palm empty fruit bunch, wheat starch, chitosan | Acid hydrolysis | 90 | The addition of nanocellulose could enhance the mechanical strength of the film. | [63] |
| Industrial waste cotton | Acid hydrolysis | 90 | The CMC’s from industrial waste cotton has high thermal stability of 97.13% | [64] |
| Wood | Ethanol and peroxide with ultrasonication | 77 | The value of tensile strength and Young’s modulus after the addition of CNC were more than 50 MPa and 5 GPa. | [65] |
| *L. usitissimum* | Acid hydrolysis | 82 | Cellulose nanocrystals (CNC) showed a good mechanical strength by the value of modulus young achieved 52.35 MPa after the loading 20% of CNC. | [66] |
| Wheat straw | Acid hydrolysis | 75 | Blending the films with cellulose nanocrystals (CNC) increased the mechanical properties. | [67] |

Research has shown that the addition of cellulose nanocrystals from a diverse source of carbohydrates produces stronger mechanical properties to the film. The process of synthesizing nanocellulose as the pretreatment in biodegradable packaging is unique to the carbohydrate source. This pretreatment process disrupted and depolymerized cellulose structure to isolate nanocellulose [68]. Most of the carbohydrate source is utilized by using the acid hydrolysis process to synthesis nanocellulose. The yield of nanocellulose from natural resources varies between 75-90%.

4.2 Impact of nanocellulose in sustainable food packaging

The primary fundamental role of food packaging is to preserve food quality and safety. If all food packaging did its role correctly, food packaging could reduce foodborne disease and food chemical contamination. Meanwhile, commercial packaging focus on practical and easy-to-use aspect rather than the role of reducing food loss and improving food shelf-life. This condition is supported because uneaten...
food’s carbon footprint is estimated to be equivalent to 495 million tons of CO₂ and occupies almost 210 million hectares of land [69]. If there is no real action to resolve this problem, food waste is estimated to rise to over 200 million tons by 2050 [70]. The food packaging issue is not just misunderstood about the primary role of food packaging but also the amount of waste. If there is no real action to resolve this problem, food waste is estimated to rise to over 200 million tons by 2050 [71]. The plastic packaging problem is the chemical leaching in plastics is hormonally active and can be dangerous to the food. The problem of plastic packaging continues when this packaging becomes a waste. The plastic material was hard to achieve sustainability. Only up to 2% of the waste can be utilized in another sector [72]. The rest of them will contaminate their surrounding environment.

Nanocellulose has a high abundance, low weight, high strength, stiffness, non-toxicity, low cost, and biodegradable [73]. This characteristic makes nanocellulose become a promising material that has been utilized in diverse fields. It has been used in medical, packaging, prepared coating, electronics, and membrane [74–77]. In the packaging sector, nanocellulose will support the goal to make sustainable and green packaging. Studies have demonstrated that the use of nanocellulosic based material can enhance the mechanical and functional properties [78]. These properties include biodegradability, transparency, gas barrier properties specific surface area, and heat stability [79], [80].

5. Conclusions
Pediocin and GSE show an effective antimicrobial and antioxidant effect while being used as bioactive food packaging agents. However, most experiments are conducted using low mechanical strength film. Nanocellulose has an immense potential to be used as a substitute for conventional packaging as it is the most abundant polymer on Earth. The modification of cellulose structure into diverse kinds of nanocellulose showed increasing mechanical properties to the packaging. Biobased food packaging has advantages in creating less waste and easier processing than conventional. Many researches have been done to utilize natural resources for replacing conventional fossil packaging. However, sustainability is about using biosource and needs to fulfill the role of packaging to preserve food quality and safety. The procedure for making food packaging does not only utilize a single process. It needs integration of several operations to achieve sustainability in packaging that will be used commercially. Therefore, this review suggests that research needs to be done to scale up, integrate active agents with bio-polymer, and optimize antimicrobial biobased packaging production. Therefore, antimicrobial biobased food packaging can be economically feasible in the future.

References
[1] Sadiku M N O, Musa S M, and Ashaolu T J 2019 Int. J. Trend Sci. Res. Dev 3(4) 128–130.
[2] Lucintel 2012 https://www.lucintel.com/press/global-food-beverage-retail-industry-2012-2017.aspx
[3] WHO 2020 https://www.who.int/news-room/fact-sheets/detail/food-safety#:~:text=An estimated 600 million – almost,healthy life years (DALYs)
[4] CDC 2014 US Department of Health and Human Services, CDC, Atlanta, GA
[5] Ryser E T 2007 Listeria, listeriosis, and food safety Florida: CRC Press
[6] Marsh K, Bugusu B 2007 J. Food Sci 72 (3) R39–R55
[7] Geyer R, Jambeck J R, Law K L 2017 Sci. Adv. 3 (7) e1700782
[8] Lau D W, King A J 2003 pp. 1602–1607
[9] Shahidi F, Janitha P K, Wanasundara P D 1992 Crit. Rev. Food Sci. Nutr. 32 (1) 67–103
[10] Yilmaz Y, Toledo R T, Agric J 2004 Food Chem 52 (2) 255–260
[11] Kong F, Su Z, Zhang L, Qin Y, Zhang K 2019 LWT 101 819–826
[12] Aculañana L, Morero R D, Bellomio A 2011 Food Bioprocess Technol. 4 (6) 1029–1049
[13] Robertson G L 2012 Food Packaging : Principles and Practice, Third Edition USA: Taylor & Francis Group
[14] Klemm D, Heublein B, Fink H P, Bohn A 2005 Angew. Chemie - Int. Ed. 44 (22) 3358–3393
[15] Yali S, Xiaochun L, Xinyu W, Junli W, Xin L, Dayong S 2018 J. Chifeng Univ. (Natural Sci. Ed.
[16] Burdock G A 2004 *Fenaroli’s Handbook of Flavor Ingredients* CRC Press
[17] Moniharapon E, Hashinaga F 2004 *Pakistan J. Biol. Sci.* 7 (6) 1057–1061
[18] Unusan N 2020 *J. Funct. Foods* 67 (no. November 2019) 103861
[19] Di Meo F et al. 2019 *J. Funct. Foods* 61 (no. March) 103515
[20] Wren A F, Cleary M, Frantz C, Melton S, Norris L 2002 *J. Agric. Food Chem.* 50 (7) 2180–2192
[21] Chen Y, Wen J, Deng Z, Pan X, Xie X, Peng C 2020 *J. Funct. Foods* 73 (no. July) 104113
[22] Perumalla A V S and Hettiarachchy N S 2011 *Food Res. Int.* 44 (4) 827–839
[23] Rhodes P L, Mitchell J W, Wilson M W, Melton L D 2006 *Int. J. Food Microbiol.* 107 (3) 281–286
[24] Torres-Acosta M A, Mayolo-Deloisa K, González-Valdez J, Rito-Palomes M 2019 *Biotechnol. J.* 14 (1) 1–31
[25] Dimić I et al. 2020 *Antioxidants* 9 (7) 1–19
[26] Fiori L, Lavelli V, Duba K S, Sri Harsha P S C, Ben Mohamed H, Guella G 2014 *J. Supercrit. Fluids* 94 71–80
[27] Coelho J P, Filipe R M, Robalo M P, Stateva R P 2018 *J. Supercrit. Fluids* 141 68–77
[28] Chen H and Hoover D 2003 *Compr. Rev. Food Sci. Food Saf.* 2 82–100
[29] Ennahar S, Sashiha T, Sonomoto K, Ishizaki A 2000 *FEMS Microbiol. Rev.* 24 (1) 85–106
[30] Drider D, Finland G, Héchard Y, McMullen L M, Prévost H 2006 *Microbiol. Mol. Biol. Rev.* 70 (2) 564–582
[31] Johnsen L, Finland G, Nissen-Meyer J 2005 *J. Biol. Chem.* 280 (10) 9243–9250
[32] Anastasiadou S, Papagianni M, Filioutsos G, Ambrosiadis I, Koidis P 2008 *99 5384–5390
[33] Rodriguez J M, Martínez M I, Kok J 2002 *Crit. Rev. Food Sci. Nutr.* 42 (2) 91–121
[34] Ray B 1995 *Food Biotechnol. Microorg.* 745–795
[35] Papagianni M 2003 *Biotechnol. Adv.* 21 (6) 465–499
[36] Powers J P S, Hancock R E W 2003 *Peptides* 24 (11) 1681–1691
[37] Montville T J, Chen Y 1998 *Appl. Microbiol. Biotechnol.* 50 (5) 511–519
[38] Atlas R 2004 *Handbook of microbiological media USA: CRC Press*
[39] Gasson M 1994 *Genetics and biotechnology of lactic acid bacteria* Glasgow, UK: Blackie Academic & Professional
[40] Amado I R, Fuciños C, Fajardo P, Pastrana L 2016 *J. Dairy Sci.* 99 (10) 8070–8080
[41] Chen Y, Ludescher R D, Montville T J 1997 *Appl. Environ. Microbiol.* 63 (12) 4770–4777
[42] Duran M, Seckin M, Demirel N N, Temizkan R, Burak M, Caner C 2016 *Food Bioprod. Process.* 98 354–363
[43] Xiong Y, Chen M, Warner R D, Fang Z 2019 *Food Control*
[44] Sogut E. and Seydim A C 2018 18 (no. July) 13–20
[45] Guo Y, Huang J, Chen Y, Hou Q, and Huang M 2012 *Poult. Sci.*
[46] Frankel E N 1998 *Lipid Oxidation* Dundee, Scotland: Oily Press
[47] Li Y et al. 2010 *J. Food Microbiol.* 91 (no. November 2019) 103492
[48] Vieira M C 2017 *LWT - Food Sci. Technol.*
[49] Alison M et al. 2020 *Int. J. Biol. Macromol.* 160 769–779
[50] Schillinger U, Geisen R, and Holzapfel W H 1996 *Trends Food Sci. Technol.* 7 (5) 158–164
[51] Franz C M A P, Cho G S, Holzapfel W H, Alvez A 2010 in Biotechnology of Lactic acid Bacteria: Novel Applications, F. Mozzi, R., Raya, and G. . Vignolo, Eds 341–359.
[52] Woraprayote W, Malila Y, Sorapukdee S, Swetwiwathana A, Benjakul S, Visessanguan W 2016 *Meat Sci.* 120 118–132
[53] Vermeeiren H, Develeyere F, Van Beest M, De Kruijf N, Debevere J 1999 *Trends Food Sci. Technol.* 10 (3) 77–86
[54] Perez Espitia P J, de Fátima Ferreira Soares N, dos Reis Coimbra J S, de Andrade N J, Souza Cruz R, Alves Medeiros E A 2012 *Compr. Rev. Food Sci. Food Saf.* 11 (2) 187–204
[55] Espitia P J P, Otoni C G, Soares N F F 2016 Pediocin Applications in Antimicrobial Food
Packaging Systems Elsevier Inc.

[56] Appendini P and Hotchkiss J 2002 Innov. Food Sci 3 113–126
[57] Barish J A and Goddard J M 2011 J. Food Sci. 76 (9)
[58] Espitia P J P, Pacheco J J R, de Melo N R, Soares N de F F, Durango A M 2013 Brazilian J. Food Technol. 16 (3) 226–235
[59] Santiago-Silva P et al. 2009 Food Control 20 (1) 85–89
[60] Degnan A J, Yousef A E, Luchansky J B 1992 J. Food Prot. 55 (2) 98–103
[61] Woraprayote W et al. 2013 Int. J. Food Microbiol. 167 (2) 229–235
[62] Updegraff D M 1969 Anal. Biochem. 32 (3) 420–424
[63] Salehadin M H, Salleh E, Mamat S N H, Muhamad I I 2014 Procedia Chem. 9 23–33
[64] Li Y et al. 2016 Green Chem. 18 (4) 1010–1018
[65] Mujtaba M, Salaberria A M, Andres M A, Kaya M, Gunyakti A, Labidi J 2017 Int. J. Biol. Macromol. 104 944–952
[66] Oun A A and Rhim J W 2016 Carbohydr. Polym. 150 187–200
[67] Lee J A, Yoon M J, Lee E S, Lim D Y, Kim K Y 2014 Macromol. Res. 22 (7) 738–745
[68] Elbehri A, Elliott J, Wheeler T 2015 Assessments of climate change impacts on global-food productivity and implications for food security and trade: Key messages and recommendations
[69] Hall K D, Guo J, Dore M, Chow C C 2009 PLoS One 4 (11) 9–14
[70] Guillard V, Gaucel S, Fornaciari C, Angellier-Coussy H, Buche P, Gontard N 2018 Front. Nutr. 5 (December) 1–13
[71] Henriksson M, Berglund L A, Isaksson P, Fridolfsson A, Lindström T 2008 Biomacromolecules 9 (6) 1579–1585
[72] Abdul Khalil H P S et al. 2014 Renew. Sustain. Energy Rev. 64 823–836
[73] Li J et al. 2014 Carbohydr. Polym. 113 388–393