The potential of food waste as bioplastic material to promote environmental sustainability: A review

M O Ramadhan* and M N Handayani
Study Program of Agro-industry Technology Education, Faculty of Technology and Vocational Education, Universitas Pendidikan Indonesia, Jalan Dr. Setiabudhi No 207 Bandung 40154, West Java, Indonesia

Email: ramadhanoka@upi.edu

Abstract. Food waste is a challenge for sustainable development since it can increase greenhouse gas emissions and other environmental issues. Food processing and manufacturing are known to raise food waste. Meanwhile, plastic waste is a big problem in environmental pollution. This study aims to explore the potential of food waste as bioplastic material as an environmentally friendly alternative packaging. The method used was an effective literature review. The results showed that many food wastes have the potential to be developed as bioplastics if they contain biopolymers such as starch, cellulose, or other biopolymers. Some of the food wastes are obtained from the food processing industry such as sludge waste, cassava peel, banana peel, pineapple peel, durian seed, jackfruit seed, avocado seed, and chicken feather. The Development of bioplastics from food waste has a double benefit that can solve two problems indirectly, namely reducing plastic waste and food waste at the same time, thereby promoting environmental sustainability.

1. Introduction
Environmental sustainability has been a real challenge for a living being due to the rising of population, urbanization, and standard of living [1]. It also becomes a major concern in the Sustainable Development Goals (SDGs) since it declared as the three of the world’s biggest challenge: responsible consumption and production (SDGs Number 12), attention to climate action (SDGs Number 13), and life below water (SDGs Number 14) [2].

For years, plastic waste has become one of the biggest problems due to their excessive use, its difficulty in decomposition, also its huge of mass cause a lot of negative impact to landfill and water pollution [3]. Especially for single-use plastic commonly used for plastic packaging including objects that can only be used once before they are thrown away, generated nearly 50% of the plastic waste in 2015 [4]. The most possible solution is to substitute synthetic polymeric materials by biodegradable materials [3]. After usage, it will be degraded by microorganisms and minimalize the adverse ecological impact [5].

On the other side, food waste is known as one of the materials that lead to a huge environmental impact. In 2008, food waste contributes to global anthropogenic greenhouse gas (GHG) emissions about 19%-29%, releasing more than 16,000 megatons of carbon dioxide equivalent (MtCO₂e) to the atmosphere, and other environmental issues [6]. Food waste has been proved by several researchers that it can be developed into environmentally friendly biopolymers [7].
The purpose of this study is to summarize any kind of food waste that proved can be developed into bioplastic material with potential applications in food packaging to promote environmental sustainability.

2. Food waste
The Food and Agriculture Organization (FAO) defined food waste as follows: ‘Food loss is defined as the decrease in quantity or quality of food.’ Food waste is part of food loss and refers to discarding or alternative (nonfood) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer-level” [8].

Food waste has a different definition in the food supply chain (FSC), even though it is most easily determined at the retail and consumer stages, lead to 'food' for human consumption [9]. Food loss is qualitative, such as a decrease in nutritional value, and unwanted changes in taste, color, texture, or quantitatively measured by volume or weight reduction [10]. The source of food waste comes from various stages in the food supply chain. Start from the beginning of FSC including production (damage during harvesting, late time of harvesting, etc.), distribution (out-grade, contamination, damages during transport, etc.), also the consumption of food (left-over food, poor cooked, served too much, etc.) [10].

Food waste is generally classified into two categories-avoidable and unavoidable. Avoidable food waste is the waste that could be prevented (such as through better planning), whereas unavoidable food waste is food waste that cannot be sold or eaten [11]. Examples of avoidable food waste are food that is thrown away, left-over food, and over-purchasing, while the unavoidable one such as bones, shell, feather, and more.

The current report shows that there are 1.3 billion tons of food wasted globally every year [12]. Food waste also contributes to greenhouse gas (GHG) emissions during the final disposal process at the final disposal site (uncontrolled release of methane) and during activities related to food production, processing, manufacturing, transportation, storage, and distribution. Other environmental impacts are value reduction and pollution of natural resources such as soil, water, and biological life behind it. These tons of food waste not only affect the environment but also affect the economic side. The economic impact is the waste of the costs to solve the chain reaction problems [13].

3. Plastic waste
For decades, the world dependence on petroleum-based synthetic polymers or commonly known by the public as plastics has become the one most appealing material used for a wide variety of applications. More than 400 million tons of plastic are produced every year in the world [14]. This record is proportional to their characteristics of the material due to low price, ease of production, strong endurance, low density, and its aesthetic look.

In 2015, 36% of the world’s plastic production is designed as plastic packaging with single-use/disposable purposes. These include, among other items, food packaging, grocery bags, cutlery, bottles, straws, cups, and more. It also contributes to 47% of plastic waste generated globally. Therefore, plastics currently the most common and persistent pollutants in the world. In the end, plastics are recycled into other things, burned by incineration, landfilled, dumped, or littered in the environment. If current consumption patterns do not change and the development of environmentally friendly alternative materials is not carried out, there will be around 12 billion tons of plastics wasted in landfills and the environment by 2050. Being part of the natural ecosystem bringing billions and long-lasting negative effects on the environment both life on land and below the water [14].

There are a lot of plastic forms, such as plastic bags, that have been found to poison the respiratory passages and stomachs of various species in the ocean. Animals such as dolphins, turtle mistakenly see a plastic bag as their food. There is an emerging fact that toxic chemicals were absorbed during the transfer of the manufacturing process from inserting plastic into animal tissue, finally entering the human’s food chain as well [15]. Although the prevention of plastic waste is a priority, reducing the
use of plastic is certainly not easy. Therefore researchers, policies, and industries are currently trying to develop new alternative materials that are biodegradable and environmentally friendly.

4. Bioplastic

Biodegradable polymers are known as bioplastic made from polymers derived from biological sources [16]. These polymers can be degraded environmentally by microorganisms and water in compost piles [17]. Bioplastic can be categorized as petroleum-based biodegradable polymers (fossil-based), bioplastics from mixed source (bio-petroleum), and renewable resource-based polymers (naturally from plants and animals) [18].

There are so many advantages for the environment due to the use of bioplastic such as potentially lower the carbon footprint and GHG emissions, lower energy cost in manufacturing, reduction of permanent litter, and much safer to the environment [19]. Bioplastics also have advantages in the characteristics of the material such as much greater water vapor permeability than standard plastic, less oily feel, good printability, softer, and more tactile.

The method of bioplastic making may be different for each material used, the bioplastic characteristics produced, and various product configurations [20]. According to previous research, figure 1 summarized the complex process for each material, each process has a variety of methods, ingredients, and compositions used.

![Figure 1. The general process of bioplastic making.](image)

Pre-Treatment including processes such as grinding, drying, hydrolyzing the material. Not all parts of the waste are used in the bioplastic manufacturing process, such as extracting only its starch and cellulose. And the most important part is characterizing materials such as adding plasticizer agent, odor controlling agent, and biological material [20].

5. Potential of food waste as bioplastic material

5.1. Sludge waste from food industry

The sludge that is freshly activated from wastewater treatment in a food processing industry can be used to make biodegradable plastic. Active sludge contains various types of microorganisms that can be used to produce PHB (Poly-b-hydroxybutyrate), produced by various bacteria as microbial polyester and stored in cells in the form of granules. Some bacterial species which naturally produce PHB are *Ralstonia eutrophes*, *Alcaligenes*, *Pseudomonas*, *Bacillus*, *Rhodococcus*, *Staphylococcus* and *Micrococcus* [43]. This material can be suitable for the synthesis of environmentally friendly plastics material [21]. PHB production costs are very high, so the use of activated sludge is expected to be more efficient.

PHB production from activated sludge is carried out as follows: fresh activated sludge is collected from food processing wastewater and enriched in synthetic media as a carbon source using acetic acid. After the enrichment process, the bacterial strain was isolated on a nutrient agar plate by spreading mud. Based on the characteristics of the colony five different strains of bacteria were observed. Filtering the isolated strains for PHB production. At the end of the process, the culture is smeared on a glass slide, stained with black Sudan B, and examined under a process of contrast microscope for PHB beads. All five strains were determined to accumulate PHB granules [22]. The production and recovery process of PHB from activated sludge can reduce sludge waste that requires further treatment and at the same time increase the efficiency of PHB production.
5.2. Cassava peel

Because of its starch content, cassava peel is an agricultural waste that can be used as a bioplastic material. Starch is universal, renewable, and easily obtained so that it becomes potential material for bioplastic manufacturing [23]. The study of making bioplastics from cassava peel starch has been carried out by combining the materials of starch and chitosan as a plasticizer by using sorbitol. The results showed that the best mechanical properties for bioplastics with a tensile strength value of 1.37 MPa was obtained at the addition of sorbitol 30% with a ratio of starch: chitosan (7:3). Young modulus value of 3.7 MPa was obtained at the addition of sorbitol 30% and a starch: chitosan ratio of 8:2, and an elongation value of 26.55% was obtained with 50% sorbitol addition, and starch: chitosan ratio of 9:1 [24].

Making bioplastics from cassava peel begins with the extraction of starch from cassava peel. Furthermore, making cassava peel starch solution 10% (w/v), while chitosan was dissolved in glacial acetic acid with a concentration of 20% (w/v). Cassava peel starch was mixed with chitosan at a certain ratio and stirred at gelatinization temperature (80°C) for 25 minutes. Then mixed homogeneously with sorbitol at a certain concentration. Then, print the homogeneous solution on a plate with a thickness of 2.5 mm and dried at 60°C for 5 hours to form a bioplastic sheet [24].

Comparison with other research has shown that the addition of microcrystalline cellulose (MCC) can increase the tensile strength value up to 9.12 MPa by using only 20% sorbitol. In the contrary to tensile strength, a decrease in elongation at break was reported. The improvement in bioplastics with reinforcing MCC could be attributed to the strong hydrogen bond between hydroxyl groups of the interface of both MCC fillers and starch matrix. This formation is also influenced by the percolation mechanism [44].

5.3. Banana peel

Banana peels as agricultural processing waste can be used in making bioplastics because they contain cellulose, starch, pectin, and other polymers. Cellulose is modified to obtain thermoplastic materials through acetylation (cellulose acetate) [25]. The use of pectin in making bioplastics functions as an emulsifier that increases intermolecular bonds in the film [26].

The utilization of banana peels has been done by adding citric acid to prevent browning so that pectin produced by banana peels is brighter. Pectin of Kepok banana peel extracted with citric acid at 90°C for 3 hours, has a water content of 11.55%, ash content of 3.060%, methoxyl content of 3.966%. Bioplastics produced from pectin Kepok banana peel has a film thickness ranging from 0.00311 – 0.00387 cm, permeability 35.30 – 63.63%, with traction strength of 2.6286 – 10.5620 MPa, extension value 16.66 – 58.33%. The best bioplastics in the study resulted from the addition of 5 grams of pectin [26].

Types of banana peels that have good characteristics to be used as bioplastics are yellow banana peels compared to green bananas and red bananas. although the difference between the three was very slight. However, the transparency of visual appearance and ease of production is found in green bananas due to their higher starch content [45].

5.4. Pineapple peel

Pineapple peel is a waste that comes from household consumption as well as the pineapple processing industry. The main constituent of the peel is extracted as cellulose through refluxing with acid or alkaline solutions [27]. Cellulose is a natural polymer, consisting of glucose units with a homogeneous chain structure. Cellulose can be converted to carboxy methylcellulose (CMC) through the etherification process.

Pure cellulose potentially can be made from pineapple by refluxing pineapple skin powder with 0.5 M HCl and 1 M NaOH solution at 90°C for 1 hour and 2 hours. Then, the solid material bleached with calcium hypochlorite. Pure cellulose was immersed in a mixture of isopropyl alcohol and NaOH for 12 hours. After that, it was reacted with chloroacetic acid at 55°C for about 6 hours. The optimum
conditions for carboxymethylation are 5 g cellulose, 13.0 g chloroacetic acid and 40% w / v 50 mL NaOH. The optimized product has a DS of 0.50 and can be used as an element in bioplastics [28].

5.5. Durian seed

Durian seeds are waste from food processing as well as part of durian fruit that is not consumed because it feels slimy and itchy on the tongue. Even so, the seeds have nutrients including protein, carbohydrates, fats, calcium, and phosphorus [29]. Carbohydrates in the form of starch in durian seeds have the potential to be used as material for making bioplastics. However, starch-based bioplastics have some disadvantages such as low mechanical strength and less resistance to water [30].

A starch-based bioplastic study has been carried out that utilize starch from durian seeds with the addition of chitosan as a filler, and plasticizer by using sorbitol. Durian seed starch used in the study had a water content of 12.73%, an/ash content of 0.51%, the starch content of 76.65%, amyllose content of 22.34%, amylopectin content of 54.32%, the protein content of 11.61%, and fat content of 0.61%. The result showed bioplastics had optimal mechanical properties at a heating temperature of 70°C with a composition between durian seed starch and chitosan of 7:3 grams and the addition of 20 grams of sorbitol [31].

5.6. Jackfruit seed

Jackfruit seed, which constitutes 8-15% of the jackfruit, is potential food wastes due to its high starch content [32]. It can be used for bioplastics production as raw material. A study on making bioplastics from jackfruit seed starch has been carried out. The starch had a moisture content of 6.04%, amyllose content of 16.39%, ash content of 1.08%, starch content of 70.22%, amylopectin content of 53.83%, protein content of 4.68%, fat content of 0.54%. The bioplastic making was a combination of starch, chitosan, and sorbitol as a plasticizer. The best bioplastic was obtained by the ratio of starch: chitosan (w / w) = 8:2 and sorbitol concentration of 25% with a tensile strength of 13,524 MPa [33].

Meanwhile, other studies developed bioplastic from jackfruit seeds using glycerol as a plasticizer. The starch concentrations used ranged from 2-6% w/w and glycerol from 20 to 60 g / 100 g starch. The study states that jackfruit seed starch can be used as raw material for bioplastic, with the character of low opacity, moderate permeability of water vapor, and relatively high mechanical stability, by gelatinized starch dispersions process using glycerol [33].

5.7. Avocado seed

Avocado seed, which represents 10-22% from the total weight of avocado [34], is potential food wastes due its high starch content [35]. This starch content is a raw material for making bioplastic, as same as jackfruit seed starch. A bioplastic development study from avocado seed starch has been carried out by adding chitosan and glycerol. Avocado seed starch used had a moisture content of 1.087%, an/ash content of 1.007%, the starch content of 67.6950%, amyllose content of 32.4739%, amylopectin content of 35.3212%, the protein content of 10.440%, the fat content of 1.860%, peak viscosity is 3847 cP by setting the gelatinization temperature at 85.17°C. The best bioplastic conditions of avocado seeds were obtained at 90 °C with a ratio of starch: chitosan (w / w) = 7:3 and glycerol 0.2 ml / g with a tensile strength of 5.096 MPa, breaking extension 14.016%, Modulus Young 36.359 MPa. Bioplastics with chitosan as fillers and glycerol as plasticizers have a smooth and soft fracture surface and few cavities [36].

5.8. Chicken feather

The fur is the by-products of animal sources besides feet, head, bones, and viscera [37]. Usually, the hair is discarded or burned which can be an environmental problem [38]. Though fur is one of the potential resources to make biodegradable materials. Feathers contain 90% of a protein known as keratin which is a worldwide by-product of the poultry industry.

A few researchers conducted studies to develop potential ingredients from fur and keratin in making bioplastic [39,40,41]. There is a study of bioplastic synthesis using keratin from chicken
feathers. Keratin solution can be extracted from chicken feathers, then produce plastic films by mixing it with glycerol (2%). The mixture is stirred at 60°C for 5 hours with constant magnetic stirring. The mixture was then poured into an aluminum weighing vessel and dried in an oven at 60°C for a day. The resulting bioplastics had good mechanical and thermal properties and was proven to be biodegradable [42].

6. Conclusion
Bioplastic can be made from polymers derived from biological sources, one of them is food waste. It comes from the food processing industry or household consumption such as sludge waste, cassava peel, banana peel, pineapple peel, durian seed, jackfruit seed, avocado seed, and chicken feather. The development of bioplastic from food waste has a double benefit that can solve two problems, indirectly reducing plastic waste and food waste at the same time, thereby promoting environmental sustainability.

References
[1] AlQattan N, Acheampong M, Jaward F M, Ertem F C, Vijayakumar N and Bello T 2018 Reviewing the potential of Waste-to-Energy (WTE) technologies for sustainable development goal (SDG) numbers seven and eleven Renew. Energy Focus 27 97–110
[2] GA U 2015 Transforming our world: the 2030 agenda for sustainable development. (New York: Division for Sustainable Development Goals)
[3] Gonçalves de Moura I, Vasconcelos de Sá A, Lemos Machado Abreu A S and Alves Machado, A V 2017 Bioplastics from agro-wastes for food packaging applications Food Packag. 223-63
[4] Giacovelli C 2018 Single-use plastics: a roadmap for sustainability (UN Environment Program Report)
[5] Mohanty A K, Misra M and Hinrichsen G 2000 Biofibres, biodegradable polymers and biocomposites: An overview Macro. Mater. and Engineer. 276(1) 1–24
[6] Vermeulen S J, Campbell B M, and Ingram J S I 2012 Climate change and food systems Ann. Review of Env. and Resour. 37(1) 195–222
[7] Shah A A, Hasan F, Hameed A and Ahmed S 2008 Biological degradation of plastics: a comprehensive review. Biotech. Advan. 26(3) 246–65
[8] Footprint F F W 2014 Full-Cost Accounting Final Report
[9] Parfitt J, Barthel M and MacNaughton S 2010 Food waste within food supply chains: quantification and potential for change to 2050 Philo. Trans. of the Royal Soc. B: Bio. Scien. 365(1554) 3065–81.
[10] Buzby J C and Hyman J 2012 Total and per capita value of food loss in the united states Food Policy 37(5) 561-70
[11] Bagherzadeh M, Inamura M and Jeong H 2014 Food Waste Along the Food Chain (OECD Publishing) 71
[12] Kojima R and Ishikawa M 2013 Prevention and Recycling of Food Wastes in Japan: Policies and Achievements (Japan: Kobe University)
[13] Lipinski B, Hanson C, Lomax J, Kitinoja L, Waite R and Searchinger T 2013 Reducing food loss and waste World Resour. Instit. Work. Paper 1 1-40.
[14] Geyer R, Jambeck J R and Law K L 2017 Production, use, and fate of all plastics ever made Scienc. Advan. 3(7) e1700782
[15] Jambeck J R, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A and Law K L 2015 Plastic waste inputs from land into the ocean Science 347(6223) 768-71
[16] Chen Y J 2014 Bioplastics and their role in achieving global sustainability J. of Chem. and Pharm. Research 6(1) 226–31
[17] Zheng Y, Yanful E K and Bassi A S 2005 A review of plastic waste biodegradation Critic. Rev.
[18] Reddy M M, Misra M and Mohanty A K 2012 Bio-based materials in the new bioeconomy Chem. Engin. Prog. 108(5) 37-42
[19] Pilla S 2011 Handbook of Bioplastics and Biocomposites Engineering Applications (John Wiley & Sons) 81
[20] Hagemann R and D'Amico D 2009 Bio-plastic Composite Material, Method of Making Same, and Method of Using Same (US 2009/0110654 A1)
[21] Fang L, Wenqing L, Darin R and Tingyue G 1998 Production of poly-b-hydroxybutyrate on molasses by recombinant Escherichia coli Biotech. Letters 20(4) 345–8
[22] Kumar M S, Mudliar S N, Reddy K M K and Chakrabarti T 2004 Production of biodegradable plastics from activated sludge generated from a food processing industrial wastewater treatment plant Biore. Tech. 95(3) 327-30
[23] Ma X, Chang P R, Yang J and Yu J 2009 Preparation and properties of glycerol plasticized -pea starch/zinc oxide bio nano composite Carbo. Poly. 75 472-8
[24] Fathahah U, Lubis M R, Rosnelly C M and Moulana R 2013 Making and characterizing bioplastic from cassava (manihot utilissima) peel starch with sorbitol as plasticizer Proc. the 7th International Conf. of Chemical Engineering on Science and Apppl
[25] Rana G K, Singh Y, Mishra S P and Rahangdale H K 2018 Potential use of banana and its by-products: a review. Int. J. Curr. Microbiol. Appl. Sci. 7(6) 1827-32
[26] Chodijah S, Husaini A and Zaman M 2019 Extraction of pectin from banana peels (musa paradisica fomatypica) for biodegradable plastic films JPhCS 1167(1) 012061
[27] Xu W, Reddy N and Yang Y 2009 Extraction characterization and potential applications of cellulose in corn kernels and distillers’ dried grains with solubles (DDGS) Carbohydr. Polym. 76 521-27
[28] Chumee J and Khemmakama P 2014 Carboxymethyl cellulose from pineapple peel: useful green bioplastic advan. Mater. Resear. 979 366-9
[29] Jufri M, Dewi R, Ridwan A and Firli 2006 Studi kemampuan pati biji durian sebagai bahan pengikat dalam tablet ketoprofen secara granulasi basah M. Ilmu Kefarm. Depart. Farm. FMIPA 3(2)
[30] Ban W 2006 Influence of natural biomaterials on the elastic properties of starch-derived films: an optimization study J. of Appl. Poly. Science 15 30-8
[31] Ginting M H S, Kristiani M, Amelia Y and Hasibuan R 2016 The effect of chitosan, sorbitol, and heating temperature bioplastic solution on mechanical properties of bioplastic from durian seed starch (Durio zibethinus) Int. J. of Engin. Res. and Appli. 6 33-8
[32] Mukprasirt A and Sajjaanantakul K 2004 Physico-chemical properties of flour and starch from jackfruit seeds (artocarpus heterophyllus lam.) compared with modified starches. Int. J. of Food Scien. & Tech. 39(3) 271-6
[33] Lubis M, Harahap M B, Manullang A, Ginting M H S and Sartika M 2017 Utilization starch of jackfruit seed (Artocarpus heterophyllus) as raw material for bioplastics manufacturing using sorbitol as plasticizer and chitosan as filler JPhCS 801(1) 012014
[34] Gómez-López V M 1999 Characterization of avocado (persea americana mill.) varieties of low oil content J. of Agri. and Food Chem. 47(7) 2707-10
[35] Kahn V 1987 Characterization of starch isolated from avocado seeds J. of Food Scien. 52(6) 1646-8
[36] Ginting M H S, Tarigan F R and Singgih A M 2015 Effect of gelatinization temperature and chitosan on mechanical properties of bioplastics from avocado seed starch (Persea Americana Mill) with plasticizer glycerol The Int. J. Of Engin. And Scien. 4 36-43
[37] Zhu G Y et al 2010 Hydrolysis technology and kinetics of poultry waste to produce amino acids in subcritical water J. of Analy. and App. Pyrol. 88(2) 187-91
[38] Jin E, Reddy N, Zhu Z and Yang Y 2011 Graft polymerization of native chicken feathers for thermoplastic applications J. of Agri. and Food Chem. 59(5) 1729-38

in Biotech. 25(4) 243–50
[39] Tanabe T, Okitsu N, Tachibana A and Yamauchi K 2002 Preparation and characterization of keratin–chitosan composite film Biomaterials 23(3) 817-25
[40] Ullah A, Vasanthan T, Bressler D, Elias A L and Wu J 2011 Bioplastics from feather quill Biomacromolecules 12(10) 3826-32
[41] Moore G R P, Martelli S M, Gandolfo C, do Amaral Sobral P J and Laurindo J B 2006 Influence of the glycerol concentration on some physical properties of feather keratin films Food Hydro. 20(7) 975-82
[42] Ramakrishnan N, Sharma S, Gupta A and Alashwal B Y 2018 Keratin based bioplastic film from chicken feathers and its characterization Int. J. of Bio. Macromol. 111 352-8
[43] Ansari S and Fatma T 2014 Polyhydroxybutyrate-a biodegradable plastic and its various formulations Int. J. of Innov. Res. in Scien. Engin. and Tech. 3(2) 9598-602
[44] Maulida S M and Tarigan P 2016 Production of starch based bioplastic from cassava peel reinforced with microcrystalline cellulose avicel PH101 using sorbitol as plasticizer Int. J. Phys. Conf. Ser 710 12012
[45] Singh R and Dakshinamoorthy A N D Comparative Study of Bioplastic Sheets from Different Varieties of Banana Peel [Online] Available at: <http://reports.ias.ac.in/report/20428/comparative-study-of-bioplastic-sheets-from-different-varieties-of-banana-peel> [Accessed 23 October 2020]