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Paper based packaging material coated with microbial polyhydroxyalkanoates: An approach towards 100% biodegradability

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Polyhydroxyalkanoates (PHAs) are the polyesters produced by microorganisms under limiting conditions of nitrogen, phosphorus, oxygen or magnesium in the presence of excess of carbon. Polyhydroxybutyrate (PHB) was the first discovered form of PHA in 1926 and is from Bacillus Megaterium. Today, more than 300 microorganisms are known to synthesis and accumulate PHA intracellularly. Also genetically modified microbes and plants are being reported for the production of PHA. PHA can be of short chain length (3±5 carbon atoms) or medium chain length (6±14 carbon atoms).

Polyhydroxyalkanoates are found to be fully biodegradable. The biodegradability can be ensured based on marine biodegradability, industrially compostability, home compostability, soil biodegradability and anaerobic digestibility. Among the plastics, only thermoplastic starch based and PHA based compounds are fully degradable. Also compared to thermoplastic starch the production of PHA can be done using substrates which cannot initiate a competition for human or animal food. The biodegradability and biocompatibility are the major characteristics of PHA which makes it stands in prime position among other plastics. PHA acts as a potential candidate to replace the petroleum based plastics but the cost of production and lower yield matters. Now a days researchers are focussed to increase the yield of PHA production using waste substrates for microbial culture and also on the utilisation of different wastes like municipal waste, sewage, agricultural waste etc. so as to reduce the cost of production. Fish oil was also freported to be useful for the production of PHA (Table. 1).

Paper, as a packaging material is safe for the environment because of its fully biodegradable property. The global production of paper is mainly constituted by use of wood (92%) and only 8% is produced using agricultural wastes (Fahmy et al. 2017). Paper is composed of long chain molecules of cellulose, having a disrupted crystalline structure with amorphous regions. The water vapour barrier properties of paper is low because of this porous nature and also the OH groups contributes to hydrophilic nature. Hence when used as packaging for food, it easily absorbs water and loses the mechanical strength.

Inorder to improve the barrier properties, other materials such as plastic, aluminium etc. are used. This inturn adds to the mechanical properties also. Coatings with ethyl vinyl alcohol, poly olefins, rubber latex, fluorocarbon etc. are given to increase the gas barrier properties. But the biodegradability of paper will be lost because of these synthetic treatments. The use of natural polymers can be an alternative.

Paper coatings with PHA

The properties of PHA depends on the constituted monomers. This in turn is affected by the substrate used, conditions of culture and the microorganism. The hydrophobic character of PHA

Table. 1. Reports on utilisation of fish oil for production of PHA

Substrate	Microorganism	Yield (% of dry cell waste)	Reference
Waste fish oil, glycerol and fish sauce	*Salinivibrio species* M318	51.5	Van Thuoc et al, 2019
Alaska pollack oil	*P. oleovorans* NRRL B-778 *P. oleovorans* NRRL B-14682*P. oleovorans* NRRL B-14683 *P. resinovorans* NRRL B-2649 *P. corrugata* 388 *P. putida* KT2442	27 6 52 53 43 39	Ashby and Solaiman, 2008
Waste fish oil (15g/L), Gum Arabic (2.5g/L),Cell growth medium	Cupravidus necator	75	Kaesavan, 2014

makes it resistant to hydrolytic degradation. They have good barrier property against oxygen and water vapour, good UV resistance and poor resistance towards acids and bases.

Different techniques can be applied for coating PHA over paper. PHB dissolved in chloroform can be used to make a coating using solvent casting method. The barrier properties against moisture, surface roughness and tensile strength increase with increase in concentration of PHB used. Next method is compression moulding which gave similar properties as in solvent casting The additional step of acetylation of paper board increased the adhesion of PHB over paper and the characteristics were improved. The PHB coating was found to be a good substitute for tetra pak packaging. The third method is extrusion coating. The adhesion of PHB/V extrusion coating on paper is to be improved by pretreatment of the paper with acrylic based primer (Rastogi and Samyn, 2015).

The PHB was found to be suitable for paper sizing than PHBV and a temperature of 160R"C gave improved film formation by PHB melting. The PHB can give better water barrier properties but lower oil resistance than PLA coatings. Because of increased microbial activity, the paper coated with PHA was found to be more biodegradable than the biopolymer alone (Masood, 2017).

Disadvantage of PHA as a coating for paper

The major drawback of PHA is its thermal instability which causes difficulties in processing.

The melting temperature of PHA varies depending on the monomers and copolymers. Usually the melting point starts from 120^0C and can go beyond 300^0C.