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Conversion of agro waste into biodegradadable bio plastic from peel of fruits and weed

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ABSTRACT

The ecology has suffered greatly as a result of synthetic plastics. As a solution for this issue, alternative processes for making bio-based plastics are being promoted. Fruit peel and plant leaves are used as renewable resources to make bio-based polymers. The goal of the current study is to prepare biopolymers from fruit waste. Basic laboratory procedures were used to transform orange peels, sweet limes, jackfruit, pineapple waste, and water hyacinth leaves into bioplastic. These plastics made by addition of starch and glycerol. Biodegradability testing and Fourier transform infrared (FTIR) spectroscopy were used to establish the bio-based plastic's characteristics. Orange peel bioplastic was very clear, water hyacinth was highly fire resistant and non-swelling, and pineapple waste bioplastic was the least water soluble in nature. Mosambi Peel composite and pineapple bioplastic demonstrated 100% disease prevention with an 88.8% degradation rate, but Jackfruit Rags-based bioplastic failed disease prevention due to fungus and was discovered to be a slow deteriorating material. The technique of producing bio-based plastic is described as easy, unique, and cost-effective. As a result, mosambi peel has been discovered to be appropriate for bioplastic due to its high availability, antifungal content, rapid breakdown, and fire resistance. The study concludes fruit waste can be one of the alternative raw materials used to prepare biodegradable plastic. Further optimization studies are required to develop standard bioplastic from agro waste.

Key words: Bio plastic, fruit waste, PHB, biodegradation, Citrus, peel

INTRODUCTION

Plastics have detrimental effects on the ecology because of their mechanical and chemical properties, especially their resilience. Thus, the creation of biodegradable bioplastics as a remedy has resulted from the plastics' perpetual existence and vulnerability to breakdown. (Urbanek *et al.,* 2017). The best ways to get rid of biodegradable plastics are through home and municipal composting; landfills are the least ideal option (Davis and Song, 2006). Four distinct types of biodegradable polymers are considered environmentally benign because of their biocompatibility and capacity to biodegrade (Heedia-guerrero *et al.,* 2019) These categories include biopolymer blends, chemical manufacturing techniques, and microbial production techniques. Strips and peels, which are separated by the original's side effects, are the main source of monomers used in second-generation bioplastics (Prosperi *et al.* 2018). Many bacterial strains are capable of producing PHA and PHB; PHA copolymer PHBV and terpolymer (Jung *et al.,* 2019). Bioplastics are biodegradable plastics produced using the inexhaustible sources like vegetable, fruit waste, plant leaf, cereals etc (Souza *et al.,*2019). India and China are among the major nations that can take the lead in the development of biopolymers based on leafy vegetables (Sharma *et al.,* 2020). Five banana peel films (BP films) with various levels of maize starch (1 to 5%) were created as a co-biopolymer, while a control film was created without any corn starch (Sultan and Johari,2017). The development of biofilms using citrus trash was investigated, making use of the integrated power of pectin and the strength of cellulose fibres (Batori *et al.,*2017).Food bundling, development, and farming are the three primary purposes of interest, according to (Brassoulis *et al.,* 2010). The increased use of conventional plastic may have a negative impact on the environment. One solution is to use biodegradable bioplastics, which can help reduce the amount of natural hazards associated with plastics by decomposing with the aid of microorganisms. Bioplastics are environmentally friendly, reusable, and harmless. The purpose of the research is to distinguish and characterize

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bio plastic from agricultural waste

MATERIALS AND METHOD

Raw material

Water hyacinth, orange peel, Jack fruit waste, Mosmabi peel, Pineapple waste Peels of above fruits were collected from the local juice corner located around Tiruchirappalli.

Pre-treatment

After properly cleaning with distilled water, the agricultural waste was allowed to air dry for 3h. Peel specimens have been pre-treated at 40°C with a liquor ratio of 5:50 (wt/v) using a 1% sodium hydroxide (NaOH) solution. minor and other greasy elements were eliminated from the peels by immersing them in an alkaline solution for thirty minutes. After that, the fibers were neutralized with 0.5% acetic acid, to remove any remaining NaOH residue, and then rinsed three times with water.

Preparation of Bioplastic

25 grams of fruit peel paste were used in the plastic production process. 50 milliliters of water were added to the sample, and it was left to soak for ten minutes. Samples were mixed with 5 ml of glycerol and grinded in a blender jar in order to obtain a homogenous solution. Next, the mixture was ultrasonicated at 450Hz for 5cycle. After that, a portion of the homogeneous mixture filtrate was taken and boiled with 5% starch. a portion of the specimen without starch was kept separately. Both the mixture was poured on petriplates and kept at 60°C overnight and kept for curing for 48h. The weight of the film was measured after it was exposed to sunlight for several days.

Preparation of leaf extract polymer

Following the collection of the fresh, clean water hyacinth leaf dust particles, they were rinsed under clear, flowing tap water. About 25g of leaves were soaked in 1N NaOH for 5 min and rinsed well. 100 mL of distilled water was added and grinded under. One part of the extract was mixed with 5 mL of glycerol, and 5 g of starch was kept at 60°C using a magnetic stirrer. The sample was then spread out onto clean, dry aluminum foil and allowed to cure for 48 hours.

Solubility test

The 2 x 2-centimeter film samples were dried at room temperature for a full day prior to being weighed in order to ascertain the initial film weight. The samples were incubated for 24 hours at 25°C in glass beakers filled with 100 mL of distilled water. After the specimens were dried for 24 hours at 50°C in an oven, the amount of water-soluble material was measured by weighing the solid that was left over. To find the proportion of water absorbed in the cured film, calculations were performed.W_0-W_f/W_0 x100

Swelling index at pH 7

The swelling index was utilized to ascertain the edible bio-films' ability to swell when they were immersed in water. Every movie was first given a weight. To evaluate swelling behavior, dry film samples are immersed in distilled water with different pH levels of 7 for a full day. The filter paper applied over surface subsequently absorbs the excess liquid that has collected on the films' surfaces. After taking each film out of the water, it was weighed again until the weight of the films was constant. To calculate the water absorption or swelling index of films, the following formula was utilized.

SI= Final weight- Initial weight/ Initial weight X 100

Transparency of the Biofilms

The film's opacity at 600 nm was measured using a visual spectrophotometer. The level of transparency was computed using the following formula.

% of Transparency= A_{600}/Thickness of sample

Biodegradation test

The soil burial approach was used to facilitate the biodegradation of the generated plastic. To conduct the test, the resultant film was chopped to 2 × 2 cm dimensions, and 150 g of dirt were added to each glass plate. Films that had been previously weighed and weighed 0.5 g were sliced and placed in plates 5 cm below the surface of the muck. To examine the impact of moisture content on sample degradation, one of the film samples was misted with water while the other was kept dry. For a month, these two samples were investigated. We calculated the rate of deterioration using weight loss.

Fourier transform infrared spectroscopy (FTIR)

On a block of NaCl, a smear of the completely degraded bio-plastic sample soaked in chloroform was applied. The materials were submitted to FTIR analysis (450–4000 cm^{-1}) with a Perkin Elmer to look into chemical interactions. The spectral resolution in the Attenuated Total Reflection (ATR) mode was 1 cm^{-1}, and the scan rate was 100 scans per second.

Control of disease incidence

Colletotrichum brevisporum was found in infected papaya fruit and used as a pathogen. The antifungal activity of bioplastic was assessed using the mycelial development and spoiling of fruit infected with *Colletotrichum brevisporum* on papaya. Bioplastic was put over the papaya fruit, and then pathogen spores were sprayed on the film. The untreated section is utilized as a control. After a 5-day incubation period, fungal growth and illness incidence based on anthracnose symptoms were evaluated.

Disease incidence = number of infected spots/tot inoculated spot x 100

RESULTS AND DISCUSSION

Bioplastic prepared

Biodegradable plastic films (BDFs) are sustainable alternative to synthetic non-biodegradable polymers. Bioplastic from orange, mosabmi peel, jackfruit, pineapple waste, and water hyacinth with glycerol (G) and starch (S) was developed. Orange peel (OPG), pineapple waste (PG), and water hyacinth (WH) alone failed to convert into bioplastic without starch. All other preparations were turned into bioplastics and were found to be somewhat dark (image 1) before disappearing and turning light. Pineapple waste (13.25g) produced the highest output of bioplastic at 1200 µm thickness and 69% transparency. Water hyacinth had the second highest yield (14.8g) at 2400 µm, with a poor transparency of 48%. Biofilm manufacturing OPGS was 7.9g, whereas MPG was 10g, MPGS yield was 8.8g, JFG 7.6g, and JFGS 8.6g. The biofilm thicknesses for OPGS, MPG, MPGS, JFG, and JFGS were 600, 650, 1230, 780, and 900 µm, with a transparent rate of 73≥72≥69≥71≥71% (Table 1).

Table 1: Yield of Bio plastic produced per 25g peel

S.No	SAMPLE	Code	Yield (g)	Thickness µm	% Transparency
1.	Orange Peel (G+Starch)	OPGS	7.9	600	73
2.	Mosambi Peel(glycerol)	MPG	10	650	72
3.	Mosambi Peel (G+Starch)	MPGS	8.8	1230	69
4.	Jackfruit Rags (glycerol)	JFG	7.6	780	71
5.	Jackfruit Rags (G+S)	JFGS	8.6	900	71
6.	Pineapple waste (G + Starch)	PGS	13.25	1200	69
7.	Water Hyacinth (Glycerol)	WG	--	-	-
8.	Water Hyacinth (Glycerol + Starch)	WGS	14.8	2400	48

Increased starch concentration is connected with increased solids content in the film-forming process, giving birth to thicker films. Berger et al (2020) previously reported bioplastic conversion of orange peel. Trieu Khoa et al (2022) have reported bioplastic fromackfruit. Zavareze *et al.* (2012) observed a similar pattern with bioplastics. López and García (2012) found that glycerol interferes with polymeric chain connection, resulting in a less stiff and compact film structure. The microscopic surface view of specimen demonstrates that all produced bioplastics have a homogeneous and clear surface, with the exception of jackfruit and water hyacinth waste plastics, which have small fissures on the surface due to their brittle character. Other films exhibited smooth surfaces, although some microvoids were discovered, which may be attributed to the degree of plasticizer dispersion in the polymer matrix. The surface morphology of the bioplastic films was comparable to that of the recycled polythene plastic material tested (Lico *et al.,* 2011). Yaradoddi *et al.*(2022) have produced plastic film from orange peel by applying simple methodology. Production of bioplastic from water hyacinth was earlier reported by Anantachaisilp *et al.* (2021).

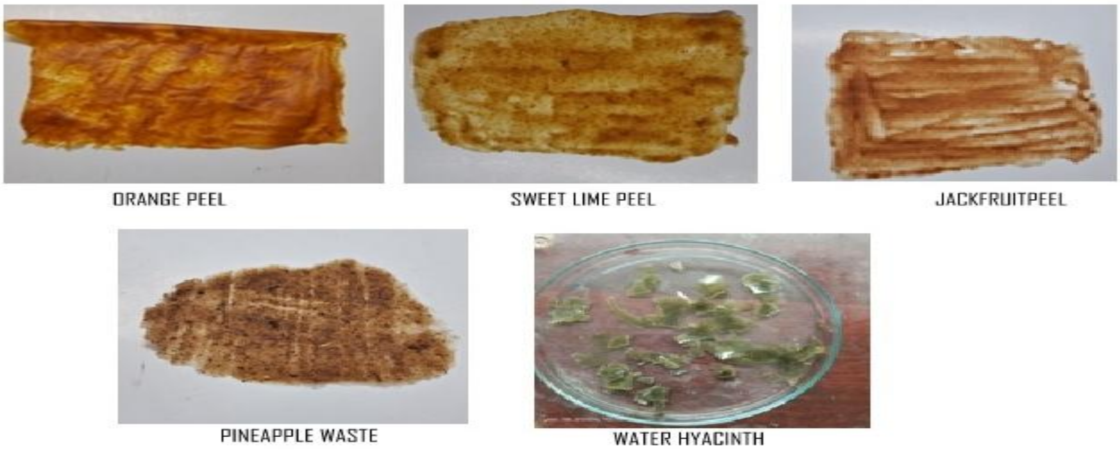

Image 1: Prepared Bioplastics from agro waste

Physiochemical properties

The specimen swelling, water solubility and fire resistance tests a finding of each bioplastic was image 2. Table 2 shows the weight loss rates for each specimen. For specimens, this study presents the burning rate test and weight loss test for bio plastics with different weight fraction changes, which were recorded as a minimum 0.01mm combustion rate for WG, 0.02 mm for PGS, and a maximum of 0.06 mm MPG.

Table 2: Water swelling and fire-resistant properties

Sample	Water swelling	Combustion rate mm/s
OPGS	++	0.03
MPG	+	0.06
MPGS	++	0.04
JFG	+	0.03
JFGS	+	0.03
PGS	++	0.02
WG	-	0.01

The combustion rate of jack fruit waste plastics such as JFG and JFGS was 0.03 mm, whereas MPGS was 0.04mm. The solubility test findings revealed that the glycerol resource had lower swelling and solubility than the starch resource bio plastic. Out of seven, water hyacinth has no swelling and moderate solubility (50%).Pineapple and jackfruit waste had the lowest solubility (33% each). Orange Peel have had high solubility and found to be unstable. These finding reveals that the ratio of starch and glycerol may alter the swelling property and solubility of material is further needed. The solubility index was provided in Table 3. The presence of lipids may reduce the swelling of the bioplastic and restrict amylose retrogradation, resulting in brittle bioplastics (Singh and Nath, 2013).

Table 3: of water solubility

Sample	Solubility		
	Initial wt in g	Final Wt in g	%
OPGS	0.12	0.03	75
MPG	0.14	0.06	58
MPGS	0.36	0.18	50
JFG	0.18	0.12	44
JFGS	0.28	0.16	43
PGS	0.36	0.28	33
WG	0.42	0.21	50

Bio potential of bioplastic

The antibacterial impact of bioplastic sheets employing fruit peel medium and water hyacinth was investigated, as well as their antagonistic effect on common soil beneficial microorganisms such as *Rhozobium* sp and phosphate solublizing *Bacillus* sp. All bioplastics showed no antibacterial activity, indicating that they are nontoxic to soil microorganisms (Table 4). The bioplastic depicted the antifungal activity against *Colletotrichum* sp, which revealed that the composite of Jackfruit rags and water hyacinth had much higher antifungal activity than other trash composites. Orange peel waste has a 50% control on fungal infection incidence. No inhibition was seen in the mosambi and pineapple waste bioplastic composite. Table 5 shows the percentage of illness decrease

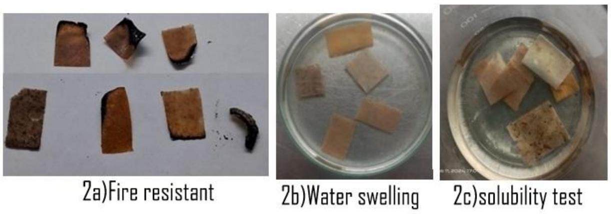

Image 2: Physiochemical test on Bioplastic

achieved with each treatment option. Out of four infected sites, two were infected with orange peel, and none were infected with Jackfruit Rags. Water hyacinth indicates drastically reduced anthracnose on papaya fruit. When the fungi were introduced to the control location, illness incidence increased significantly. Mohamed *et al.* (2013) revealed that chitosan film has antifungal characteristics that reduce fungal infections. In another study microbial consortia were able to degrade the bio plastics, and influenced soil microbiome and root growth (Bandopadhyay *et al.,* 2020). Shaik Munnysha and Bunke (2024) has reported that to overcome the burden of chemicals, need eco-friendly alternates to protect agro system.

Table 4: Antibacterial activity

Sample	Zone of inhibition mm
Orange Peel	-
Mosambi Peel(G)	-
Mosambi Peel (G+S)	-
Jackfruit Rags(G)	-
Jackfruit Rags (G+S)	-
Pineapple WASTE (G+S)	-
Water Hyacinth(G+S)	-

Biodegradation of Bio plastic

1.5 cm bioplastic samples were first weighed (W1) and then placed in cups with moist garden soil for 30 days at room temperature and weight loss was taken twice during 15th and 30th day. Except for Jackfruit (G+S/52% degradation), all other bioplastics lost more than 70% of their weight by day 15 (Table 6). Orange peel and mosambi peel waste bioplastic had the highest degradation rates of 81% and 82%, respectively. Jackfruit (GS) had the least deterioration, measuring 52%. According to data from the 30th day of degradation among the bioplastic (Table 7), mosambi Peel (G+S) resulted in an 88.8% weight reduction from the original weight, followed by 85% in Pineapple waste (G). The loss of weight among Orange Peel was 84% and 83.6% in Jackfruit (G). The leaf-based bioplastic from water Hyacinth (G+S) showed 82% loss of weight and 59.6% in Jackfruit Rags (G+S). The strength and durability of biopalstic also influenced b glycerol (Bátori *et al.* 2019).

Table 5: Prevention of fungal infection and spread

Sample	Infected site out of 4	Disease incidence %
Orange Peel	2	50
Mosambi Peel(G)	0	0
Mosambi Peel(G+S)	0	0
Jackfruit Rags(G)	4	100
Jackfruit Rags(G+S)	4	100
Pineapple waste(G)	0	0
Water Hyacinth(G+S)	0	100

The biodegradability test revealed that the created bioplastic sweet lime sheet decomposed more than 80% and others are degraded 60-70% range on 30th day in the soil. OPGS showed maximum soil adherence and WG biolfilm doesn't showed any soil adherence. Bioplastics MPG and JFG found low soil adherence property. MPGS, JFGS and PGS exhibited moderate soil adherence. The growth of fungi on plastic was directly propotional to the soil adherence (table 8). OPGS, JFG, and JFGS showed good fungal colonization than other bioplastics. The spraying of water increased the enzymatic activity of the soil microbes.

Table 6: percentage of Biodegradation after 15th day

S. No.	Sample	Initial Weight (g)	Final wt (g)	% of Reduction	Fungal growth
1	Orange Peel	1.15	0.22	81	+
2	Mosambi Peel (G)	1.82	0.50	72	-
3	Mosambi Peel (G+S)	1.97	0.35	82	-
4	Jackfruit Rags(G)	1.22	0.25	79	+
5	Jackfruit Rags (G+S)	0.52	0.25	52	-
6	Pineapple waste(G)	1.34	0.35	74	+
7	Water Hyacinth (G+S)	0.5	0.13	74	+

Table 7: Percentage of Biodegradation after 30th day

S. No.	Sample	Initial weight (g)	After 30 days(g)	% of reduction.
1	Orange Peel	1.15	0.18	84
2	Mosambi Peel(G)	1.82	0.40	78
3	Mosambi Peel(G+S)	1.97	0.22	88.8
4	Jackfruit Rags(G)	1.22	0.20	83.6
5	Jackfruit Rags(G+S)	0.52	0.21	59.6
6	Pineapple waste(G)	1.34	0.20	85
7	Water Hyacinth (G+S)	0.5	0.09	82

The carbohydrate contents contained in the peel supply carbon sources, which further contributed in the growth and proliferation of soil microorganisms specifically fungi was noted. Similar report was given by (Berger *et al.,* 2019). Alisha *et al.* (2022) reported that natural based bioplastics from banana peel are quickly degradable in nature. Biodegradable pineapple based plastic was reorted by Ali *et al.* (2017)

Table 8: Soil adherence and fungal growth

Sample	Soil adherence	Fungi growth
OPGS	+++	+++
MPG	+	+
MPGS	++	+
JFG	+	++
JFGS	++	++
PGS	++	+
WG	-	-

+++(High); ++(moderate);+(low);-(nil)

FTIR analysis

FAST-degrading antifungal active bioplastic was chosen for FTIR investigation. Figure 1 shows the FTIR of Mosambi Peel films made of non-degraded bioplastics. The addition of glycerol and water can cause the first wide absorbance peak in the 3415cm^{-1} region, indicating vioration of the O-H and N-H stretches. The absorbance peak at 2920 cm^{-1} indicates C-H alkane stretching. The peak around 1632 cm^{-1} indicates the existence of aldehyde groups in amides, whereas the peak at 1650 cm^{-1} corresponds to C=C stretching. The peaks at 1419 and 1321 cm^{-1} indicate C-H bending and the presence of a methyl group. C-O stretching peaks at 1151 cm^{-1} and C-N stretching at 1030 cm^{-1} are indicative of cellulose and hemicellulose from lignocellulosic materials, respectively. Functional groupings and vibrations.

Table 9: Functional group of mosambi peel bioplastic

Vibration control	Functional group	Vibration 30th day	Functional group
	O–H and N–H	3693 medium	O–H
2920 weak	C–H alkane	3619 medium	N–H
1650 weak	C=C alkenes	3467 medium	N–H
1632 weak	C=O amides	1637 strong	C=C alkenes
1419 medium	C–H	1031 strong	CO
1321weak	C–H	911 strong	=C-H bend
1151 weak	C–O	793 weak	
1030 weak	C-N	754	

FTIR examination of Mosambi Peel films on the 30th day revealed a medium peak at 3693 cm^{-1} for O-H, 3619 cm^{-1} for N-H stretching, and 1637 cm^{-1} for significant interaction of alkenes. The FTIR testing findings, which reveal that bioplastics have wavelength values similar to the component raw materials, notably in the 1000-2000 cm^{-1} range, which contains the C-H functional groups of cellulose and glycerol. Peaks emerge at wavelengths of 500-1000 cm^{-1}, showing the CO functional groups of cellulose and glycerol were more or less identical in both samples (Figure 1). SEM micrograph also give more detail features morphology of bioplastic in control and 15th day was recorded. MGS is predicted to affect the smooth of bioplastic surface. But a coarse and high dense surface with pore was observed in control bioplastic whereas less dense large pore were observed on degraded. The thickness of control was 8513µm reduced as 7796 µm in test. After the samples were examined under a SEM, they revealed noticeable surface degradation. The samples' 15th day revealed no outward indications of deterioration. On the fifteenth day, there are only minor alterations seen at Sample. The samples from the 30th day revealed a notable alteration in the composition. The biodegradation process that occurred over the bioplastic film was confirmed by SEM images, which also showed fractures and a loss of film nature. Following the end of the real-world testing phase, the bioplastic sample displayed visible alterations and fractured upon contact.

CONCLUSION

Starch based biodegradable bioplastics were prepared from the citrus fruit peels and water hyacinth. The agrowastes found to be ideal for preparation of bioplastics capable to control plant disease may use for foliar application. Further optimization and stability test are requiring improving the productivity for commercial use.

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REFERENCES

Ali, R.R., Rahman, W.A., Kasmani, R.M., Ibrahim, N., Hasbullah, H., Sadikin, A.N., Abouzari, E. (2017) Pineapple peel fibre biocomposite: characterisation and biodegradation studies. *Chemical engineering transactions,* **56**: 1333-1338.

Alisha, A., Priyanka, D., Kaiser, Y., Owais, Y. (2022) Mosambi (*Citrus limetta*) peel and Sago based biodegradable film: Development and characterization of physical, water barrier and biodegradation properties. *Bioresource Technology Reports***18**:351.

Anantachaisilp, S., Siripromsombut, S., Ruansoong, T., Kwamman, T. (2021) An eco-friendly bioplastic film obtained from water hyacinth. In *Journal of Physics: Conference Series, IOP Publishing.* **1**: 012110.

Bandopadhyay, S., Liquet, Y., González, JE., Henderson, KB., Anunciado, MB., Hayes, DG., DeBruyn, JM. (2020) Soil Microbial Communities Associated With Biodegradable Plastic Mulch Films. *Front Microbiol*.**11**:587074.

Bátori, Veronika., Magnus Lundin., Dan Åkesson., Patrik R. Lennartsson, Mohammad J. Taherzadeh, Akram Zamani. (2019) "The effect of glycerol, sugar, and maleic anhydride on pectin-cellulose thin films prepared from orange waste." *Polymers* ;**11**(3):392.

Berger, C., Cachutt-Alvarado, D., Fraustro-Ortega, M.F., Macías-Ochoa, J., Domínguez-Soberanes and Hernández-Lozano, L.C. (2019) "Biodegradable Polymer Obtained from Orange Peels," 2019 IEEE 39th Central America and Panama Convention, Guatemala City, Guatemala, **39**: 1-5.

Berger, P., Cachutt-Alvarado, C., Domínguez-Soberanes, J., Hernández-Lozano, L.C., Ortega-Fraustro, D., Macías-Ochoa, M.F., Licea-Domínguez, S. (2020) Biopolymers obtained from orange waste based on a decision tree. In *IEEE Andescon* .**1**:1-6.

Bidari, R., Abdillah, A.A., Ponce, R.A.B., Charles, A.L. (2023) Characterization of Biodegradable Films Made from Taro Peel (*Colocasia esculenta*) Starch. *Polymers*. ***15***(2); 338.

Davis, G. and Song, J.H. (2006) Biodegradable Packaging Based on Raw Materials from Crops and Their Impact on Waste Management. Industrial Crops and Products. **23**: 147.

José, A. Heredia-Guerrero, Gianvito, Caputo., Susana, Guzman-Puyol., Giacomo, Tedeschi., Antonio, Heredia., Luca, Ceseracciu., José, J. Benitez, Athanassia Athanassiou. (2019) Sustainable polycondensation of multifunctional fatty acids from tomato pomace agro-waste catalyzed by tin (II) 2-ethylhexanoate. *Materials Today Sustainability*, **3**(4):100004

Jung, H.R., Jeon, J.M., Yi, D.H., Song, H.S., Yang, S.Y., Choi, T.R., Bhatia, S.K., Yoon, J.J., Kim, Y.G, Brigham, C.J. (2019) Poly (3-hydroxybutyrate-co-3-hydroxyvalerate-co-3-hydroxyhexanoate) terpolymer production from volatile fatty acids using engineered *Ralstonia eutropha*. *Int. J. Biol. Macromol.*138:365.

Lico, E., Vilma, R., Spiro, D., Elias E. (2011) Morphological and chemical study of recycled plastic materials by using scanning electron microscopy and energy dispersive analysis. *Mater Prot* 52:231–236.

López, OV., García, MA. (2012) Starch films from a novel (*Pachyrhizus ahipa*) and conventional sources: development and characterization. *In Mater Sci Eng C.* **32**:1931–1940.

Prosperi, M., Sisto, R., Lombardi, M., and Zhu, X. (2018) Production of bioplastics for agricultural purposes: A supply chain study. *Rivista di Studi sulla Sostenibilita*, 1: 119-136.

Rudnik, E., Briassoulis, D. Degradation behaviour of poly (lactic acid) films and fibres in soil under Mediterranean field conditions and laboratory simulations testing. Ind Crop Prod. 2011;33: 648-658.

Shaik, M., Bunke, R.N. (2024) Advances in microbial biopesticides for integrated disease and pest management: A review. *Annals of Plant and Soil Research* **26**(4): 557- 563

Sharma, P., Gaur V.K., Kim S., Pandey A. (2020) Microbial strategies for bio-transforming food waste into resources. *Bioresour.Technol*. 299: 122580.

Singh, AV., Nath, LK (2013) Evaluation of chemically modified hydrophobic sago starch as a carrier for controlled drug delivery. *Saudi Pharm J*. **21**:193–200.

Souza, AC., Benze, R., Ferrão, ES., Ditchfield, C., Coelho, ACV., Tadini, CC (2012) Cassava starch biodegradable film: Influence of glycerol and clay nanoparticles content on tensile and barrier properties and glass transition temperature. *LWT Food Science and Technology*. **46**(1): 110-117.

Sultan, N.F.K and Johari, W.L.W.(2017) The development of banana peel/corn starch bioplastic film: a preliminary study. *Bioremediation Science and Technology Research*; **5**(1): 12–17.

Trieu Khoa Nguyen, Nguyen Thy Ton That, Nien Thi Nguyen, Ha Thi Nguyen. (2022) "Development of Starch-Based Bioplastic from Jackfruit Seed". *Advances in Polymer Technology,*10: 6547461.

Urbanek, A.K., Rymowicz, W., Strzelecki, M.C., Kociuba, W., Franczak, Ł., Miro ´nczuk, A.M. (2017) Isolation and characterization of Arctic microorganisms decomposing bioplastics. *AMB Express*, **7**:148.

Veronika, B., Dan, Å., Akram, Z., Mohammad, J. Taherzadeh., Ilona Sárvári, Horváth. (2018) Anaerobic degradation of bioplastics: A review,Waste Management **80:** 406-413,

Yaradoddi, SJ., Banapurmath, NR., Ganachari, SV., Manzoore Elahi, M. S., Ashok M.S., Shrinidhi, K., Mujtaba M. A. (2022) "Bio-based material from fruit waste of orange peel for industrial applications." Journal of Materials Research and Technology**17**: 3186-3197.

Zavareze, EDR., Pinto, VZ., Klein, B., El Halal, SLM., Elias, MC., Prentice-Hemández, C., Dias, ARG. (2012) Development of oxidised and heat–moisture treated potato starch film. Food Chem. 1**32**:344–350.