

**SYNTHESIS AND CHARACTERIZATION OF
ORANGE PEEL BASED BIOCOMPOSITES FOR
SUSTAINABLE PACKAGING AND ENCAPSULATION
APPLICATIONS**

DISSERTATION

In partial fulfilment for the award of the degree of

Master of Science in Biotechnology

Submitted by

KUNAL KHANNA

302101013

Under the Guidance of

Prof. Moushumi Ghosh



THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

Department of Biotechnology

Thapar Institute of Engineering & Technology, Patiala

July 28, 2023

Certificate

This is certified that the thesis entitled “**Synthesis and characterization of orange peel-based bio composites for sustainable packaging and encapsulation applications.**” submitted by **Mr. Kunal Khanna** (302101013), in partial fulfilment of requirement for the award of degree of **Master of Science** in Biotechnology at Thapar Institute of Engineering & Technology (TIET), Deemed to be University, Patiala is a record of student’s bona fide work carried out under my supervision and guidance. The matter embodied in the thesis has not been submitted in part or full to any other university or institute for award of any other degree.



(Supervisor)

Dr Moushumi Ghosh

Professor

Department of Biotechnology

TIET, Patiala

Declaration

I hereby declare that the work presented in the dissertation entitled “**Synthesis and characterization of orange peel based bio composites for sustainable packaging and encapsulation applications**” in partial fulfilment of requirement for the award of degree of **Masters of Science** in Biotechnology at Thapar Institute of Engineering & Technology (TIET), Deemed to be University, Patiala is an authentic record of my own work during the period from January 2023 to July 2023, under the supervision of Dr. Moushumi Ghosh, Professor, Department of Biotechnology, TIET. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree in India or Abroad.

Dated: 28-07-2023

Place: Patiala

Kunal Khanna
(Kunal Khanna)

Acknowledgement

Throughout the writing of this dissertation, I have received great deal of support and assistance. Foremost I would like to express my sincere gratitude to my supervisor **Dr. Moushumi Ghosh** whose expertise, co - operation, supervision and timely guidance helped me to complete the project successfully and reach my goal.

I would particularly thank **Mrs. Sukhmani Gandhi**, for her wonderful collaboration, patience and motivation. You were always willing to help me by sharing your knowledge, skills and gave me the right direction. Madame has provided me with all the patience and knowledge needed to complete this project. I would like to thank **Ms. Harshpinder Kaur** for providing me with the tips and guidance for research. Though it was an independent project but without my lab seniors' advice and guidance it was impossible to make out. My sincere gratitude to **Mr. Diptarka Roy** for always motivating me and supporting me in tough times by sharing knowledge and tips.

I am thankful to **Department of Biotechnology**, Thapar university for providing necessary instrumental support to carry out my work. Most of work would have been incomplete without sincere support from lab assistants. So, I owe my word of thanks to **Mr. Ram Newal Yadav, Mr. Lallan Yadav, Mr. Surinder** and **Mr. Bhagwant**.

I owe my deepest gratitude to my friends and family for their constant support and patience in tough times. They will remain my inspiration throughout my life. I wish to acknowledge all those, whose names have not been mentioned here but who helped me in any form during my dissertation.

Date:

Place: Patiala

Kunal Khanna

Contents

Title	Page no.
Chapter 1 Introduction	1-5
Chapter 2 Review of literature	6-10
Objectives	11
Chapter 3 Materials and methodology	12-21
Chapter 4 Results and discussions	22-32
Salient Findings	33
References	34-39
Annexure	40

List of Tables

S. No.	Tables	Page no.
1.	Outcome of different studies	8
2.	Antioxidant activity	24
3.	Physical properties of orange peel powder	27
4.	Chemical composition of orange peel powder	31

List of Abbreviations

Abbreviation	Full form
FTIR	Fourier transform infrared spectroscopy
XRD	X-ray diffraction
TGA	Thermogravimetric analysis
SEM	Scanning electron microscopy
PLA	Polylactic acid
OH	Alcohol
TPS	Thermoplastic starch
PHA	Polyhydroxyalkanoates
DWP	dairy waste whey
WPC	whey protein concentrate
DPPH	2,2 -diphenyl-1-picrylhydazyl
FC reagent	Folin ciocalteu reagent
DW	Distilled water
OD	Optical density
OPP	Citrus peel powder
TFC	Total flavonoids concentration
TPC	Total phenolic concentration
Pfp	Passion fruit peel
MIC	Minimum inhibitory concentration
OPC	Orange powder composite

List of Figures

S. No.	Figures	Pages
1.	Composition of Citrus peel powder	3
2.	Consumption of plastic	5
3.	Bioplastic production methods	9
4.	Orange powder preparation process	12
5.	Proximate analysis	23
6.	Cellulose content	25
7.	Pectin content	25
8.	Compositional analysis	26
9.	Antimicrobial activity	28
10.	FTIR spectra	29
11.	SEM images for the membrane prepared from orange peel powder	30
12.	SEM images for the membrane prepared from orange peel powder (in association with plasticizer)	31
13.	Membranes prepared from orange peel powder	32

Summary

A bio composite is a material formed from two or more distinct components one of which is derived from nature that are combined together to produce a new material with greater efficiency. Bio composites are made up of different kinds of organic/inorganic components, such as natural and manufactured polymers, polysaccharides, proteins, sugars etc., Different types of bio composites like films, membranes etc. The present study aimed in developing bio composite material from orange peels powder. The orange peels were collected from local shop that were further treated with sodium hypochlorite solution to prevent microbial growth. After, treatment powder was made, further characterization of orange peel powder was done in which moisture content, ash content, crude fat, pectin estimation as well as cellulose estimation was studied. In the present study, proximate composition and biological activities of the orange fruit peel extract was studied. Antimicrobial activity confirmed, prepared bio composite material has resistance against Gram negative bacteria that defines prepared material have wide range of applications in future. FTIR analysis confirmed presence of functional groups in prepared bio composite material, SEM confirmed morphological surface or appearance of prepared material. Hence, it can be concluded that prepared material has wide scope in coming future.

Chapter-1 Introduction

Plastics have become an indispensable part of our daily lives, serving various purposes such as packaging and shopping. Currently, there is approximately 8.3 billion tons of plastic globally, with 6.3 billion tons ending up as waste. Plastics are extensively used in the medical field. While they offer numerous advantages, their disposal poses a significant concern. When plastics are improperly disposed of in the environment, they contribute to pollution, particularly when dumped into rivers, endangering plants and animals. Furthermore, the release of harmful chemicals from plastic waste poses a threat not only to animals but also to humans. Plastic has several disadvantages, including its slow decomposition rate and the high cost associated with recycling. Moreover, plastic poses a substantial threat to the environment, flora, fauna, and human health. One solution to address these problems is the production of biodegradable plastics that are eco-friendly and less harmful to plants, animals, and humans. Bioplastics can be created to easily wrap food materials, posing no harm if accidentally consumed by animals and causing no environmental pollution when decomposed. To produce bioplastics, waste materials abundant in the environment should be chosen as the source. Many food waste materials, such as banana peels, citrus peels, guava peels, and guava seeds, are wasted in our daily lives. Thoughtful consideration can utilize these waste materials effectively in the production of bioplastics. Bioplastics can be derived from citrus peels, banana peels, guava peels, and similar sources. Various researchers have conducted experiments using different food waste materials to develop bioplastics. In an article titled & quote; Bio-originated substance from the wastage citrus peel for industry level applications, & quote; Areti Markopolou et al. collected native food-waste from existing environments and redirected fruit waste that would otherwise end up in landfills. For example, citrus peels and seafood from Spain and

Barcelona were fruitfully used to produce recyclable bioplastics. As this innovation represents a green alternative to the problems caused by conventional plastics, both the government and private sectors are providing sufficient funding for the development of eco-friendly and less harmful bioplastics from fruit waste materials. This rapidly growing industry attracts the attention of scientists, researchers, and master students due to its potential and the significance of these green composites as a substitute for synthetic plastics, with wide-ranging applications in the food industry. The main principle underlying the management of disposable solid waste is the generation of beneficial and less toxic materials using modern and eco-friendly techniques and practices. The production of bioplastics depends on various factors, such as ensuring easy transportation and distribution to the target populations. Numerous studies have been conducted, and according to an article titled "Bio-originated substance from the wastage citrus peel for industry level applications," citrus peel contains limonene, a natural substance with anti-inflammatory and antioxidant properties that contribute to disease prevention. Bioplastics are synthesized from normal and renewable sources such as potatoes, corn starch, etc. They possess several properties, including being biodegradable, cost-efficient, eco-friendly, less harmful, less toxic, easily transportable, and having antimicrobial, anti-inflammatory, and antioxidant properties. They also exhibit properties that aid in stress reduction. After the production of bioplastics, various substances are added to enhance their mechanical properties and flexibility. One notable example of bioplastic with properties similar to conventional plastics is Polylactic acid (PLA). Now the primary concern is determining which fruit waste can be used in bioplastic synthesis and why it should be chosen. Researchers have observed that out of the approximately 6.3 billion tons of fruit waste, a significant portion is comprised of citrus waste, leading scientists to consider using citrus peels as a source material for bioplastic synthesis. Citrus peels are selected for bioplastic production due to their many characteristics, including antimicrobial, anti-inflammatory, and antioxidant properties. They

also possess stress-reducing properties, a sufficient amount of pectin that helps maintain the tensile strength of bioplastics, and cellulose content that enhances their mechanical properties. Furthermore, citrus peels offer additional advantages for bioplastic production. Their antimicrobial properties make them suitable for applications where, hygiene is crucial. The anti-inflammatory and antioxidant properties of citrus peels add value to the bioplastics by potentially providing health benefits. These properties can contribute to reducing inflammation and oxidative stress, promoting overall well-being. Moreover, citrus peels contain a significant amount of pectin, a substance that helps maintain the tensile strength of bioplastics, ensuring their durability and resilience. Additionally, the cellulose content present in citrus peels enhances the mechanical properties of the bioplastics, making them more robust and suitable for various applications.

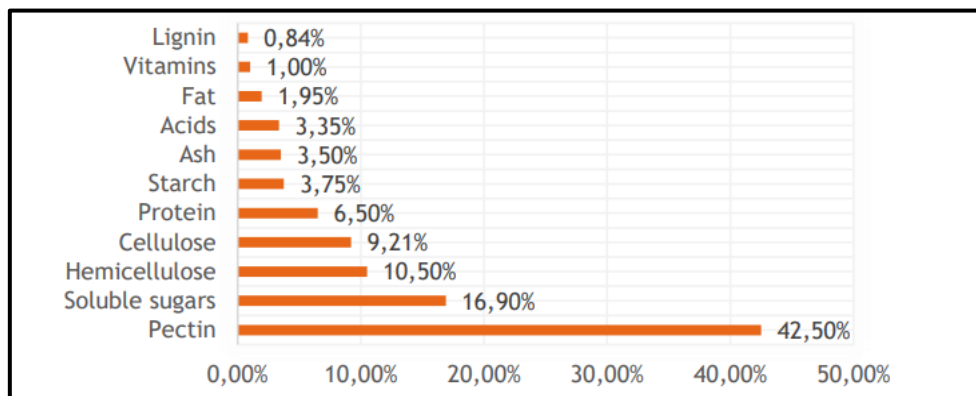


Figure 1. Composition of citrus peel powder [Duwee *et al* (2022)]

Figure 1 depicts that citrus peel powder contains lignin, vitamins, fat, acids, ash, starch, protein, cellulose, hemicellulose, soluble sugars and pectin. By utilizing citrus waste as a raw material for bioplastic production, researchers and scientists can not only tackle the issue of plastic waste but also harness the unique properties of citrus peels to create eco-friendly alternatives. This approach not only addresses environmental concerns but also opens up opportunities for the development of sustainable materials with diverse applications across industries. The application of citrus peels as a substitute for plastic in the encapsulation of medicines and as a

coating material for food items is an exceptionally groundbreaking idea in the field of plastic applications. This innovative approach highlights the immense potential of utilizing a readily available waste material like citrus peels to replace traditional plastic materials in these crucial areas. When it comes to the encapsulation of medicines, citrus peels offer unique properties that make them an excellent alternative. The natural antimicrobial properties found in citrus peels can potentially contribute to preserving the integrity and safety of the encapsulated medicines, reducing the need for synthetic antimicrobial agents. Additionally, the anti-inflammatory and antioxidant properties of citrus peels may have beneficial effects when it comes to protecting the stability and efficacy of the encapsulated pharmaceuticals. In the context of coating materials for food items, citrus peels present a range of advantages. Firstly, their antimicrobial properties can help inhibit the growth of harmful bacteria, improving the shelf-life and safety of food. Secondly, presence of the natural antioxidants in citrus peels may aid in preserving the freshness and quality of the coated food items by preventing oxidative damage. Moreover, the pleasant citrus aroma that citrus peels possess can impart a desirable fragrance to the coated food, enhancing its sensory appeal. The utilization of citrus peels as an alternative to plastics in these applications is not only environmentally friendly but also offers potential health benefits. By reducing reliance on synthetic plastic materials, we can mitigate the negative impact of plastics on the environment and human health. Furthermore, incorporating citrus peels as a natural and renewable resource can contribute to the development of sustainable packaging and coating solutions. Overall, the innovative use of citrus peels as a replacement for plastic encapsulation of medicines and coating materials for food items represents a remarkable step forward in the application of plastics. This ingenious idea showcases the immense potential of harnessing natural waste materials to address the challenges posed by conventional plastics, leading us towards a more sustainable and eco-friendly future. In conclusion, the utilization of fruit waste, particularly citrus peels, for the

production of bioplastics offers numerous advantages. These bioplastics are biodegradable, cost-efficient, eco-friendly, and less harmful compared to conventional plastics. Citrus peels possess antimicrobial, anti-inflammatory, and antioxidant properties, along with stress-reducing capabilities. Their high pectin and cellulose content further enhance the mechanical properties of the bioplastics. With ongoing research and funding in this field, bioplastics derived from fruit waste materials have the potential to revolutionize the industry and contribute to a greener, more sustainable future

Scope of study

The present study can minimize consumption of wastes that were generated from conventional plastics. Sustainable thinking provides better resolution to utilize waste generated by fruits as well as vegetables into production of biodegradable & ecofriendly bioplastics that not only decrease consumption of bioplastics but can also be used in various industries as a packaging material. Citrus peel serve as a perfect example from which bioplastic can be made as it has many properties like antimicrobial properties, antioxidant properties etc. and bioplastic made from citrus peel can be used for packaging material in various industry.

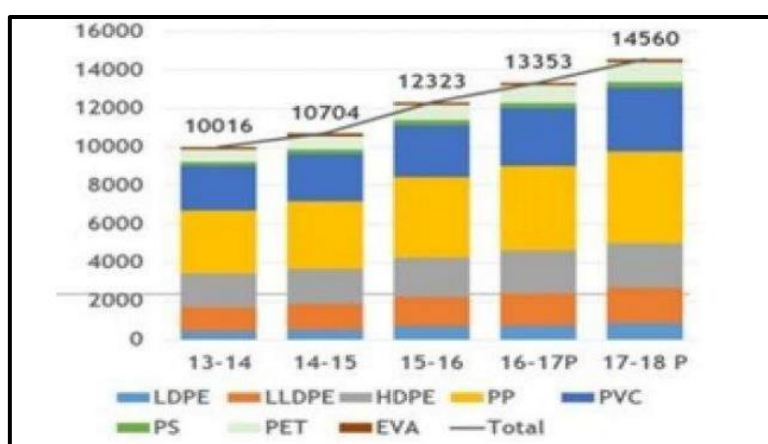


Figure 2. Consumption of plastic

Chapter-2 Review of literature

2.1. Plastics

Plastic goods have become an important part of modern life because they are used so often in packaging, shopping and trash bags, food containers, wrapping toys, wrapping industrial products and wrapping building materials [Mikkili *et al.*, (2014)]. Due to the fact that plastic and its products don't break down in nature, dumping huge amounts of them has become a world environmental problem. The growing worry about the overuse of non-biodegradable goods and traditional plastic has pushed people to look for green materials to make biodegradable plastic. Biodegradable plastic is a good option to petrochemical plastics because it is biodegradable, doesn't harm the environment, and is cheaper [Rawte *et al.*, (2001)]. Carbon dioxide, gas, water, biomass, hemicellulose, and other biopolymers are easy to get rid of when bioplastics break down [Shamsuddin *et al.*, (2017)]. Plastic is the most common polymer used in everyday life. This is because plastic has many uses and comes in a variety of forms, such as film, boards, and sheets. Plastic can also be moulded to fit any packing need [Manimaran *et al.*, (2016)]. Bio-based and recyclable plastics made from green materials can be used instead of regular plastic [Cacique *et al.*, (2017)]. Huge amounts of agricultural waste are generated every year, which is a problem for the environment because it is hard to handle, get rid of, treat, and recycle. Common approach is practiced on large scale for disposal of agricultural waste. The production of sewage and the release of greenhouse gases are two other environmental problems that come with landfilling.

2.2 Use of agro-waste for synthesis of bio-composite material

Using agro waste as feedstock or raw material for other industrial processes seems like the best way to get rid of agro waste and provide an inexpensive, easy-to-find, and plentiful fodder for industries to use to make money [Hsu *et al.*, (2020)]. Because people use a lot of things that don't break down, there are more worries about the environment. This has made it important to make eco-friendly bioplastic from things like agricultural waste and food waste [Debtera *et al.*, (2019)].

2.3. Use of citrus leaves

According to Zhang *et al.*, (2023), new top-down method was discussed for production of high performance pectocellulosic bioplastics from citrus leaves that were high in pectin and cellulose. It was observed that pectocellulosic bioplastic formed exhibited excellent water, stability, water vapor barrier properties and antioxidant activity.

2.4. Utilization of banana peel

According to Jayachandra *et al.*, (2016), bioplastic material was developed using fruit waste material mainly banana peel. The polymer formed by blending banana peel with glycerol helped in making bioplastic that was flexible, strong and easy to use. FTIR and XRD analysis confirmed that polymer was bioplastic. One of the most significant findings discovered from study was degradation tractability of the developed product.

2.5. Use of passion fruit peel

According to Moro *et al.*, (2017), extruded starchy bioplastic was developed that was reinforced with passion fruit peel. Extrusion turned out to be an interesting tool that made the Pfp in the starch bioplastic more evenly distributed.

2.6. Synthesis of bio-composite material from starch and chitosan blends

(Bioplastics synthesis from starch and chitosan Blends) is a different paper that was published. Plastics were created from non-renewable oil-based resources, which causes them to collect in the form of trash when they are disposed of. The author of this article has discussed plastics in detail. The scientific community recognized the use of biobased, biodegradable plastics manufactured from plant starch, a carbohydrate, as an alternative solution to this issue. Shrimp carapaces was used to get chitosan, which was employed to make a polymer blend in order to assess how the reactants affected the properties of bioplastics. The author of this essay has covered the drawbacks of conventional plastic as well as the advantages of bioplastic over conventional plastic.

Table 1. Outcomes of different studies

S. No.	Source	Outcome of study	References
1.	Starch, chitosan	Chitosan increased tensile strength of bioplastic	Cacique <i>et al.</i> , 2017
2.	Corn starch, PLA	Light weight and durable bioplastic synthesized	Keziah <i>et al.</i> , 2018
3.	Eggshell, chitosan, starch	Eggshell increase tensile strength, reduce water absorption of bioplastic	Kasmuri <i>et al.</i> , 2018
6.	Banana peels, acetic acid	Glycerol increases flexibility of bioplastic	Ghamande M <i>et al.</i> , (2018)
7.	Starch, TPS, PLA	Good oxygen barrier in dry state for bioplastic synthesis	Fabunmi <i>et al.</i> , (2013)
9.	PHA, enzyme	PHA increase tensile strength of bioplastic	Saharan <i>et al.</i> , (2011)

10.	Food waste, PHA, chitin	Bioplastic synthesised that was used in spray material, electronic devices as well as chemical media	Tsang <i>et al.</i> , (2017)
11.	Corn and rice starch, PHA	Biodegradable bioplastic synthesised	Marichelvam <i>et al.</i> , (2019)

2.7. Synthesis of bioplastic from fossil fuels derived material

According to Jogi *et al.*, (2020) bioplastic was derived from fossil based biodegradable polymers like polyvinyl alcohol and polyethylene adipate, bioplastic formed from fossil based non-biodegradable polymers (example- polyolefins and polystyrene), from biodegradable polymers (cellulose and PLA). Author have discussed various methods from which bioplastic was synthesised.

Extracted directly from biomass	Produced by natural or genetically modified organisms	Synthesized from bio-based monomers	Synthesized from petrochemicals	Produced by combining technologies and polymers
<ul style="list-style-type: none"> • Starch • Cellulose • Gluten 	<ul style="list-style-type: none"> • PHA 	<ul style="list-style-type: none"> • PLA • PGA 	<ul style="list-style-type: none"> • PVOH 	<ul style="list-style-type: none"> • Starch-gelatin blends

Figure 3. Bioplastic production methods

According to Chalermthia *et al.*,(2020) bio- based plastics was produced from natural and renewable sources, that have been found to be better replacers for petroleum- based bioplastics. Bio- plastics have been made from whey protein under different scenarios: like low – cost dairy waste whey (DWP), whey protein concentrate (WPC), super pro designer software.

2.8. Effect of antimicrobial and antioxidant properties on pomegranate peel powder

According to Hanani et al (2019), pomegranate peel powder was incorporated into fish gelatin film-forming solution to develop an active packaging film. The physical, antioxidant, mechanical and antimicrobial properties of the films were studied. The study revealed fish

gelatin containing pomegranate peel powder has great potential as an active film with antioxidant and antimicrobial properties, hence helps in maintaining the quality and prolonging the shelf life of the food products.

2.9. Effect of drying technique on bioactive properties

Ozcan *et al.*, (2021), reported effect of drying techniques on bioactive properties, phenolic compounds and fatty acid composition on lemon as well as orange peel powders. Study showed variable effects on radical scavenging activity, total phenolics, flavonoids, carotenoids, phenolic compounds and fatty acid composition of both lemon peel powder as well as orange peel powder.

Objectives

The present work aims to contribute to formation of bioplastic from fruit waste material

This study therefore emphasized on

- Synthesis of bio-composite from orange peel powder
- Characterization of the synthesised bio-composite materials

Chapter-3 Material and methods

3.1. Collection and processing of wastage orange peels

On campus, used orange peels were gathered, the white fibers were removed, and the peels were washed in a sodium hypochlorite and water solution (to stop the growth of bacteria). If there is any fruity pulp, it was removed out and eliminated prior to the washings with water and sodium hypochlorite solution. Concentration of sodium hypochlorite solution was 0.8%. These peels were washed for two days with sodium hypochlorite solution and then dried in a tray drier at temperature of 55°C. Peels were appropriately broken down into small pieces and meticulously dried to create a fine powder. The powder was then analyzed for preliminary tests. The orange peel powder preparation process is depicted in Figure 4.

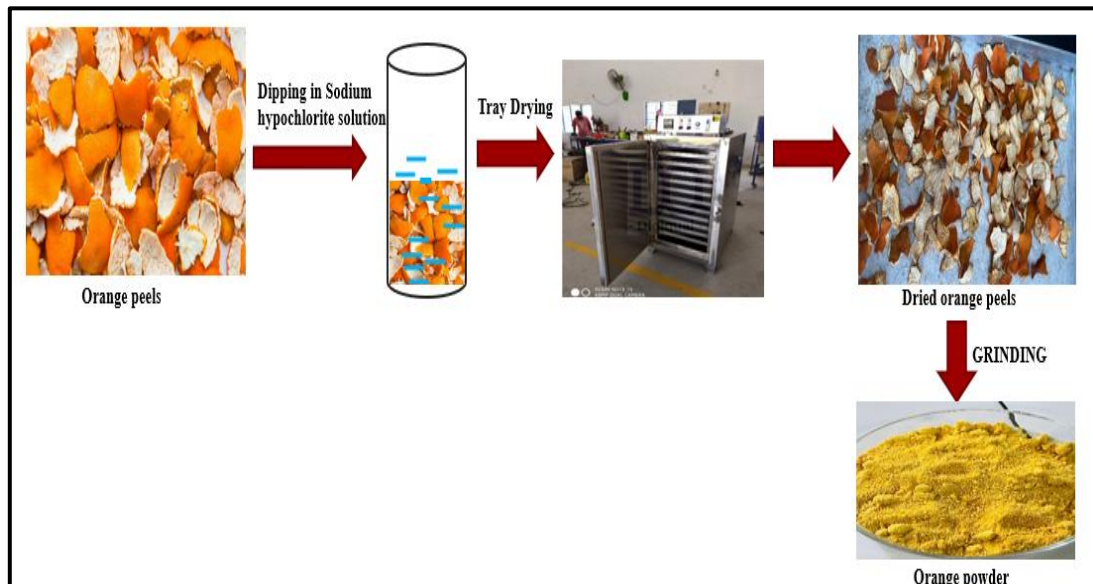


Figure 4. Orange powder preparation process

3.2. Characterization of orange peel powder

3.2.1 Moisture content [Ullah *et al* (2012)]

Moisture content were calculated using AOAC standard method and oven dehydration method. Prior to beginning the moisture measurement technique, the sample's starting weight (W_1) is established. The sample is put in an oven that has been preheated to a certain temperature, often between 100°C and 110°C, and left there to dry. Depending on the particular object being examined, the temperature range may change. Periodically removing the sample from the oven and weighing it (W_2) allows for weight determination while the sample was drying. Drying continues until the difference in weight between two measurements was within a reasonable range, such as 0.1% or less.

$$\text{Moisture content} = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

where, W_1 = initial weight of sample, and, W_2 = final weight of sample, respectively.

Moisture content was observed by comparing the weights of the Petri plate at the beginning and end of the drying process. The sample's moisture content was represented by the weight differential. Three runs of the test increase the likelihood of accurate and reliable results by lowering errors and variability.

3.2.2 Ash content [Ullah *et al* (2012)]

Muffled furnace method was employed to ascertain the ash content. The orange peel sample was weighed using a crucible. The sample was heated till red hot (charring) and kept in muffle furnace at 550°C. Before placing a crucible into the muffle furnace, it should be properly cleaned and weighed to get rid of any impurities or leftovers. Process was carried carefully to avoid sample loss. Sample was kept in muffle furnace for 5-6 hours, until constant weight was

obtained. This guarantees full oxidation of all combustibles and complete combustion of all organic materials. As soon as ashing process was over, crucible was removed from muffle furnace and allowed it to cool for some time and final weight was calculated by weighing crucible along with sample that has been ashed.

$$\text{Ash content (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

W_1 = initial weight of sample, and, W_2 = final weight of sample, respectively.

3.2.3 Crude fat [Kumar *et al* (2012)]

The method used to calculate crude fat was by extraction of petroleum ether. 5g of orange sample was weighed and transferred in Duren bottle containing 20ml of petroleum ether. Duren bottle was placed on magnetic stirrer and temperature was lowered to avoid evaporation of excessive petroleum ether. For proper mixing sample and solvent was mixed for 4 hours. After the extraction phase, mixture was filtered to separate fat from leftover sample. Tiny beaker was weighed, solution was filtered. Filtered solution was poured carefully, which now contains the fat that was removed as well as the petroleum ether, into the little beaker that has previously been weighed. Beaker was placed with the extracted solution in the oven for drying of solvent. Temperature was maintained low enough to prevent petroleum ether from evaporating too quickly as petroleum ether is flammable and quickly evaporates and that's why this step is essential. Once all of the solvent was evaporated, beaker was removed from the oven and allowed it cool, then again weighed it with residue. The crude fat content was calculated by dividing the weight of the residue (fat) by the original weight of the sample.

$$\text{Crude fat} = W_2 - W_1 \quad (3)$$

where, W_1 = initial weight of sample, and, W_2 = final weight of sample, respectively.

3.2.4. Pectin estimation [Kamble *et al* (2017)]

This test was done to see whether the orange powder-based film will be robust enough since pectin helps sustain mechanical strength. 10g of orange powder was weighed and dissolved in 125ml of hot water to ensure proper mixing. After adding the solution and HCl to keep the pH at 2, the mixture was heated in a water bath at 100°C for three hours. Further, the solution was allowed to cool for an hour and followed by this filtration was initiated. The filtrate (solvent) obtained was allowed to dry in oven at 105°C for a while. After drying the solution, once the volume was left up to 50ml, it was placed in fridge for 30 min. The cooled solution was mixed with chilled ethanol and precipitates of pectin were observed. The solution was allowed to stand still for 30 min. Repeated filtration of the mixture was done in order to obtain the pectin residues on the filter paper.

The petri plate was weighed empty before it was weighed with the residues. The residues were transferred to the Petri plate after they were dried in the oven for a while.

3.2.5. Cellulose estimation [Vallejo *et al* (2021)]

In order to carry out cellular estimation, various steps were carried out, these steps are elaborated below:

A. Dewaxing stage

- 5g of citrus powder was taken and dissolved in toluene and ethanol in ratio 65:35, respectively.
- This solution was filtered and the obtained remains were rinsed with ethanol
- Further, this residual powder was dried overnight at 105°C.

B. Bleaching stage

- For this, the residues obtained after drying overnight were mixed with 1:30 (w/v) solution of sodium hypochlorite and acetate buffer. The solution was kept for incubation for 4 hours at 100°C.
- After incubation the solution was filtered and the leftovers were collected. These collected residues were rinsed several times with sodium sulphate (Na₂SO₄). These residues were kept for drying overnight at 105°C.

C. Alkali treatment

- The obtained dried residue powder was dissolved in NaOH solution with solid to solvent ratio of 1:50 (w/v).
- To ensure proper mixing, it was kept on magnetic stirrer for 45 mins then it was filtered and the residues were collected.

D. Application of acids

- The residues were rinsed with 10% acetic acid and as a result crude fibres were obtained and it was subsequently treated with acetic acid and nitric acid in a 10:1 ratio. (1:40) (w/v).
- Followed by this, crude fibres were incubated for 15 minutes at 120°C. After incubation, the crude fibres were filtered and washed with ethanol and water alternatively. Crude fibres were kept for drying at 105°C in hot air oven.
- Citrus powder extract was prepared for further conducting antioxidant activity. Extract was prepared by dissolving 1 gm of citrus powder, in 80% (v/v) of methanol solution. Magnetic stirrer was employed for proper mixing of the solution. The solution was further centrifuged at 5000 rpm for 10 minutes and supernatant was collected.

3.2.6. Antioxidant activity [Ozcan *et al* (2020)]

- Antioxidant activity of the sample was measured and calculated using DPPH assay. For preparing DPPH solution, DPPH radical was dissolved in 0.13mM of methanol.
- 0.2ml of orange powder extract (already prepared in 4.2), 2ml methanol and 4.2 ml 0.13mM DPPH were mixed in test tube and was kept in dark for 30 mins.
- After incubation, the absorbance of the mixture was recorded at 517 nm wavelength and the percentage antioxidant activity was calculated.

3.2.7. Phenolic content [Ozcan *et al* (2020)]

- Folin ciocalteu was employed for determination of protein content in orange extract. 1mL of orange powder extract was added to 15 ml of FC reagent. To that add 1ml of 7.5% of sodium carbonate (Na_2CO_3) and keep it in dark for 30 mins.
- Record the absorbance of the solution at 765 nm wavelength.

3.2.8. Flavonoid content [Ozcan *et al* (2020)]

1mL of orange extract was added to 3mL distilled water and 0.3mL sodium nitrite. Keep it still for 5mins. 10% of 0.3mL of aluminium chloride was added and incubated at room temperature for 5 minutes.

After incubation was over 1mL of 1M NaOH solution and volume was made. Then the solution was incubated for 30 minutes in dark, after incubation was over, OD was measured against suitable blank.

3.2.9. Crude fibre [Kumari *et al* (2017)]

1gm of dried sample was extracted 3 times with 10mL of petroleum ether. After extraction pellet was air dried and in this 3mL of 0.1275M H_2SO_4 was added followed by addition of

17mL of 0.1275M H₂SO₄. The solution was filtered with the help of funnel. To remove the acid content hot water was used to wash the insoluble residue. Further, a flask was taken with residue and 3ml of 0.313M sodium hydroxide (NaOH) was added. Then, hot NaOH 17ml (0.313M) was also added. The prepared mixture was blended and then filtered after 30 minutes. Afterwards, 1% HCl was used to wash the residue and then washing was done using boiling water so that there was no chance of residual acid to be present in the final mixture. Before drying the residue at 100° C, it was washed using ethanol and ether. The residue was weighed after drying to determine the final crude fibre content. Fibre content was calculated by dividing loss in weight of sample to its original weight expressed in grams per 100 ml of distilled water.

3.2.10. Tapped Density [Tze *et al.*, (2012)]

5 gm of orange powder was weighed and was measured in cylinder. Measuring cylinder was tapped until particles of orange powder were settled properly. Before tapping initial volume of powder was determined. Orange powder was tapped for another 4-5 hours for proper settling of particles of citrus powder. Tapping action should be constant and regular. After orange powder was properly tapped final volume of orange powder was observed.

$$\text{Tapped density} = \frac{W_1}{V_2} \quad (4)$$

where, W_1 = initial weight of sample, and, W_2 = final volume of sample, respectively

3.2.11. Bulk density [Tze *et al.*, (2012)]

5 gm of orange powder was weighed and was measured in cylinder. Carefully weighed the sample in measuring cylinder and amount of space powder occupies was measured. Bulk density is the final space that the orange powder occupies without any external force or tapping.

Bulk density was calculated by dividing powder mass by its volume. Volume was measured in form of grams. Bulk density was defined as how closely particles of orange powder was condensed in the absence of any external force.

$$\text{Tapped density} = \frac{W_1}{V_1} \quad (5)$$

where, W_1 = initial weight of sample, and, V_1 = volume occupied by sample, respectively

3.2.12. Porosity [Tze *et al.*, (2012)]

The difference between the bulk density and tapped density divided by the tapped density, and then multiplied by 100 to get the percentage of porosity. The proportion of voids or empty space in the powder sample is represented by this value

$$\text{Porosity} = \frac{1 - \rho_1}{\rho_2} \quad (6)$$

where, ρ_1 = bulk density, ρ_2 = tapped density

3.3. Preparation of bio-composite material

During preparation of bio-composite material, formulation was prepared by mixing of powder with distilled water, sodium alginate and glycerol. Homogenization process was carried out and materials were poured into petri dishes and further dried in an oven. Firstly, 4.6gm of citrus peel powder was measured in beaker and 160ml of distilled water was added. Stirred well until all the powder was dissolved properly. 0.46gm of sodium alginate and 0.38ml of glycerol was

added to the solution. The solution was homogenized using magnetic stirrer for 1 hour. Casting of homogenized mixture was done by pouring into petri plates of suitable thickness.

Then, the homogenized mixture was oven dried at 100°C for 48 hours. After 48 hours, the desired stable structure was formed.

3.4. Characterization of the bio- composite material

The prepared bio-composite material was characterized by using different analytical techniques such as FTIR (Fourier transform infrared spectroscopy), SEM (Scanning electron microscopy) and antimicrobial activity.

3.4.1. FTIR

The samples were subjected to FTIR analysis in the range 450-4000 cm^{-1} using Perkin Elmer spectrum to study the chemical interactions between the chemicals. FTIR analysis was done to study functional groups present in prepared sample.

3.4.2. SEM

Scanning Electron Microscope, JEOL-JSM-6510LV was used to investigate the surface morphologies of the orange peel-originated membranes. The sample was dried completely and coated with gold layer to make the sample conductive before the measurement. At different magnifications morphologies of the orange peel membranes were observed.

3.4.3. Antimicrobial activity

Antimicrobial activity- Antimicrobial activity was performed using disk diffusion method. In disk diffusion method discs with known amounts of antimicrobial drug have been placed on top of an agar plate with nonselective medium and a suspension of a strain *Escherichia coli* to develop a lawn of growth.

Nutrient agar medium was prepared by dissolving 1.5 gm of nutrient agar in 100 ml of distilled water. Solution was autoclaved at 121°C for 15 minutes. Kept it undisturbed until the solution reached room temperature. Poured the media into petri plates of uniform thickness. Allowed it to solidify. After plates were solidified 100 micro liter of Escherichia coli was spreaded on agar plates and kept it for undisturbed for few minutes. Discs were kept on agar plates and on top of that sample was poured carefully and incubated at 100°C for 24 hours. Readings were observed after 24 hours. As a result of this minimum concentration at which max zone of inhibition was observed was calculated.

Chapter 4-Results and Discussions

4.1. Proximate analysis of orange peel powder

4.1.1. Moisture content

The moisture content of food powder helps to make food powder microbiologically safe. Moisture content % is calculated using equation (1), moisture content is found to be $13.12 \pm 0.52\%$, which is slightly different from previously reported work ($9.2 \pm 0.01\%$) by Gotmare *et al.*, (2018). It is observed that orange peel powder is free from any harmful organisms. Higher moisture content can indicate fruit waste powder is more susceptible to contamination by harmful organisms.

4.1.2. Ash content

Ash is the residual inorganic matter, in which many minerals are present that remains after heating. Ashes describes about mineral content present in orange peel powder. Ash content is found to be $1.17 \pm 0.4\%$, whereas, ash content described by Gotmare *et al.*, (2018) as $7.8 \pm 0.01\%$, mineral content in orange peel powder is found to be 1.17%.

4.1.3. Crude fat

Crude fat was determined using petroleum ether method. Orange peel powder, which contains crude fat, may also have antioxidant properties that can be beneficial in fat-rich food products. Crude fat is found to be 0.012 gm, crude fat reported by Raj *et al.*, (2014) as 2 gm.

4.1.4. Protein

Protein content is determined by using FC reagent. Protein content in orange peel powder is found to be 7.07 ± 0.31 mg/g, while protein content described by Ozcan *et al.*, (2022) as 6.25 ± 1.44 mg/g.

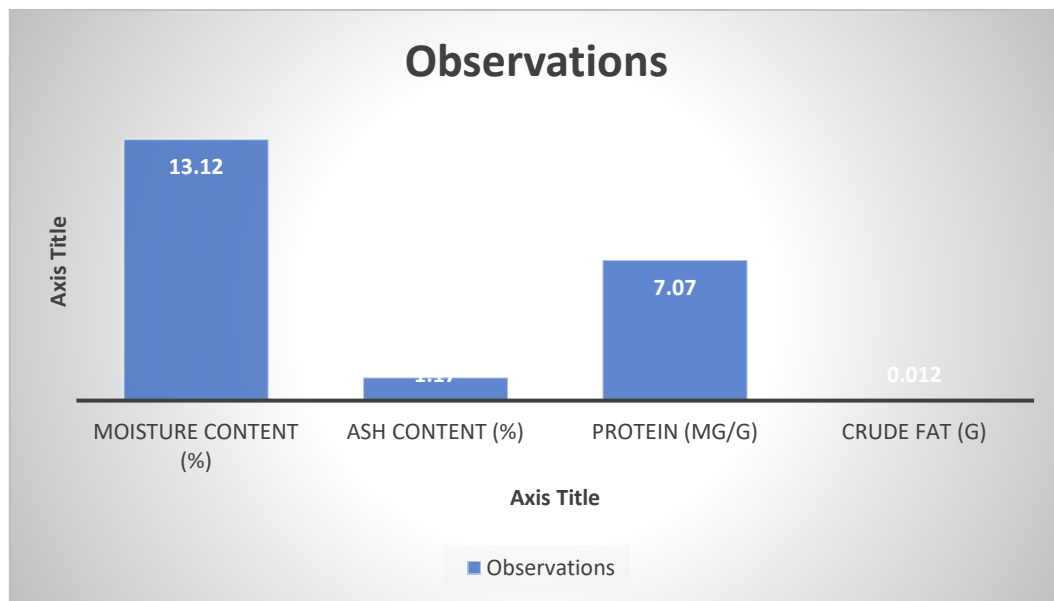


Figure 5. Proximate analysis

4.2. Compositional analysis

4.2.1. Flavonoid concentration

Flavonoid concentration of orange peel powder comes to be 0.74 ± 0.04 mg/g, whereas flavonoid concentration reported by Obafaye *et al.*, (2018) as 1.20 ± 0.02 mg/g, while flavonoid concentration described by Ozcan *et al.*, (2022) as 0.53 ± 0.52 mg/g. As a result of this it can be concluded that prepared material posse's anti-inflammatory as well as antiviral properties.

4.2.2. Antioxidant activity

Antioxidant activity is determined using DPPH (1,1-diphenyl-2-picrylhydrazyl). Antioxidant activity is found to be $90.81 \pm 4.32\%$, antioxidant activity reported by Ozcan *et al.*, (2022) as $63.48 \pm 0.00\%$. It was observed that orange peel powder has high antioxidant activity, hence it is concluded that it has high resistance towards many diseases. Table 2 represents percentage antioxidant activity of orange peel powder

Absorbance				% Inhibition			STD	Average
DPPH	1.465	-	-					
OPP	0.062	0.178	0.164	95.77	87.85	88.81	4.32	90.81 ± 4.32

4.2.3. Cellulose estimation

Multiple steps were performed for extraction of cellulose. Procedure is repeated multiple times for effective results. Cellulose was estimated using equation 3. Cellulose is found to be $11.26 \pm 3.02\%$. Cellulose can be used as a thickening agent, stabilizer, bio-adhesive, gelling agents and structural filler for preparation of bio-composite material.



Figure 6. Extracted cellulose

4.2.4. Pectin estimation

Pectin estimation is a multistage extraction process. Pectin is a high molecular polysaccharide that helps in maintaining integrity of bio-composite material. Pectin can be used as gelling agent for preparation of bio-composite material. Pectin percentage is found to be $11.45 \pm 4.81\%$, which is slightly different from previously reported value 7.5% by kamble *et al.*, (2017).

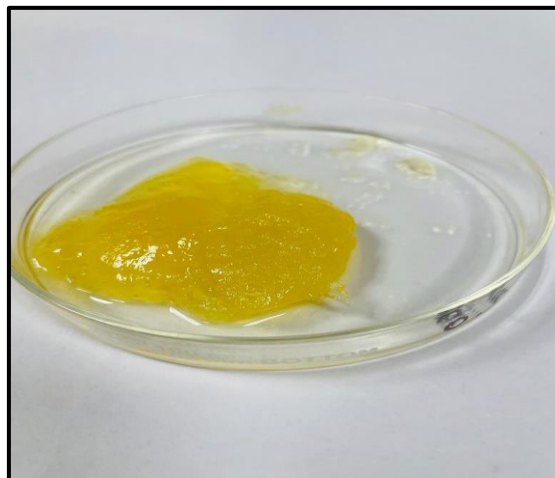


Figure 7. Extracted pectin

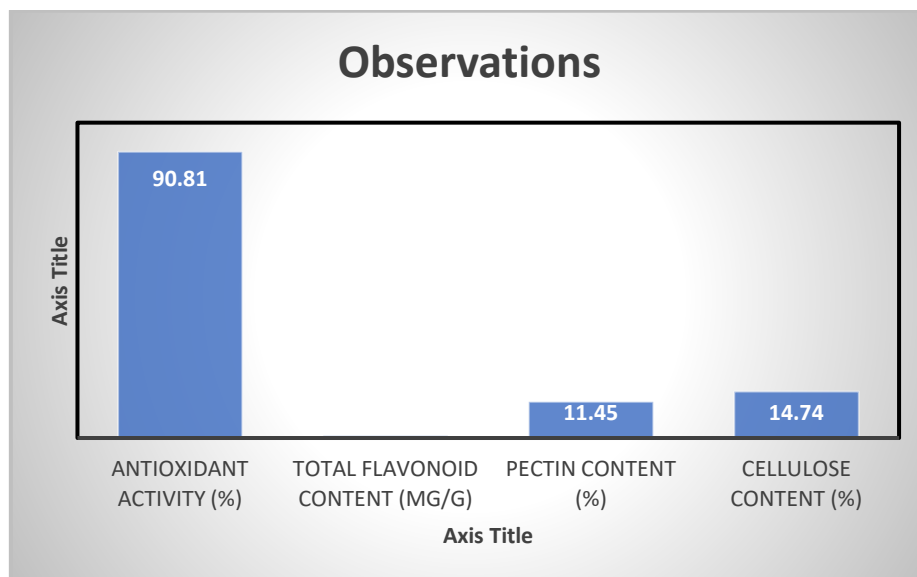


Figure 8. Compositional analysis of orange peel powder

4.3. Physical properties

4.3.1. Bulk density

Bulk density is the important factor that helps in determining flowability, handling, storage and processing of powder. Using equation (5) bulk density is calculated as $1.97 \pm 0.06 \text{ gm/cm}^3$.

4.3.2. Tapped density

Tapped density is very important for powder characterization because of the simplicity and rapidity of measurement. This helps in determining cohesiveness as well as flowability of powder. Using equation (4) the tapped density is calculated as 1.50 gm/cm^3 , which is different from previously reported work (0.271 gm/cm^3) by Sankalpa *et al* (2016).

4.3.3 Porosity

Porosity directly effects thermal diffusivity of powder. Porosity is the important factor determining moisture content of powder. Using equation (6), porosity is calculated. Porosity is found to $31.11 \pm 3.85\%$.

The bulk density, tapped density and porosity play important role in flowability, powder handling, processing etc.

Table 3. Physical properties of orange peel powder

Bulk density (g/cm ³)	1.97 \pm 0.06
Tapped density (g/cm ³)	1.50
Porosity (%)	31

4.4. Biological property

4.4.1. Antimicrobial activity

Figure 9 shows antibacterial effects of citrus powder sample towards different concentration of orange powder sample on *S. Aureus* and *E. coli*. The result showed that the control sample caused no zone of inhibition. The sample with higher concentration of OPP, from 6% to 8% showed significantly increased antimicrobial activities. Among all the tested, the highest antimicrobial activity was recorded against *E. coli*, and int this case sample with 8% caused highest antimicrobial activity at 8mm at MIC 3000 μ g/ml. This result was supported by a study by Yashaswini *et al.* (2018) who reported that orange peel powder showed the highest antimicrobial effect on *E. coli* at 7.75 ± 0.12 mm. Results showed that antimicrobial activity of orange peel powder was stronger against gram – negative bacteria (*E. coli*).

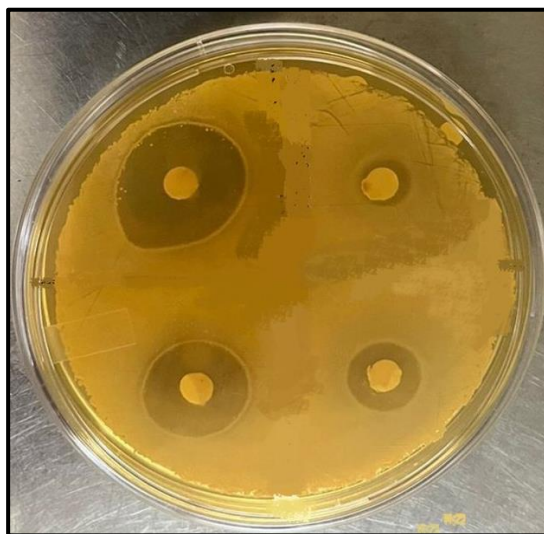


Figure 9. Antimicrobial activity in *E. coli*

4.5. Physicochemical characterization

4.5.1. Fourier transform infrared spectroscopy (FTIR)

Figure 10 represents the FTIR spectra of the membranes prepared from orange peel powder (as indicated by blue colour) and orange peel powder in association with glycerol as plasticizer (as indicated by red colour), respectively. The bands for the membrane prepared from orange peel powder are found at 3278, 2930, 1602, 1518, 1408, 1367, 1267, 1030, 922, and 815 cm^{-1} , respectively. Band at 3278 cm^{-1} represents hydroxyl group with O-H stretching vibrations [Yaradoddi *et al* (2022)]. Band at 2930 cm^{-1} can be assigned as vibrations of C-H group [Duwee *et al* (2022)]. Band at 1602 cm^{-1} represents alkene, aromatic compounds with C=C stretching vibrations [Yaradoddi *et al* (2022)]. Band at 1518 cm^{-1} can be assigned as stretching vibrations of C=O group [Duwee *et al* (2022)]. Band at 1408 cm^{-1} corresponds to carbohydrate group [Yaradoddi *et al* (2022)]. Band at 1030 cm^{-1} indicates vibrations of C-O-C and C-O-H group [Devaritouchae *et al* (2023)]. Bands for the membrane prepared from orange peel powder in association with glycerol as plasticizer are found at 2933, 2894, 1645, 1604, 1514, 1410, 1370, 1277, 923 and 815 cm^{-1} . Band at 2933 cm^{-1} corresponds to stretching vibrations of C-H group

which is little shifted from previous band and shoulder peak is observed at 2894 cm^{-1} that also represents stretching vibrations of C-H group, which confirms presence of glycerol in material [Danish *et al* (2016)]. Doublet is found at position 1645 and 1604 cm^{-1} which differs from pure orange peel powder. Band at 1645 corresponds to stretching vibrations of C=C group which signifies presence of glycerol in prepared material [Danish *et al* (2016)]. Slight difference is observed in bands at 1519, 1410, 1370 and 1277 cm^{-1} , respectively as compared to pure orange peel powder. Band at 1277 cm^{-1} represent presence of carbonyl group [Deshmukh *et al* (2022)].

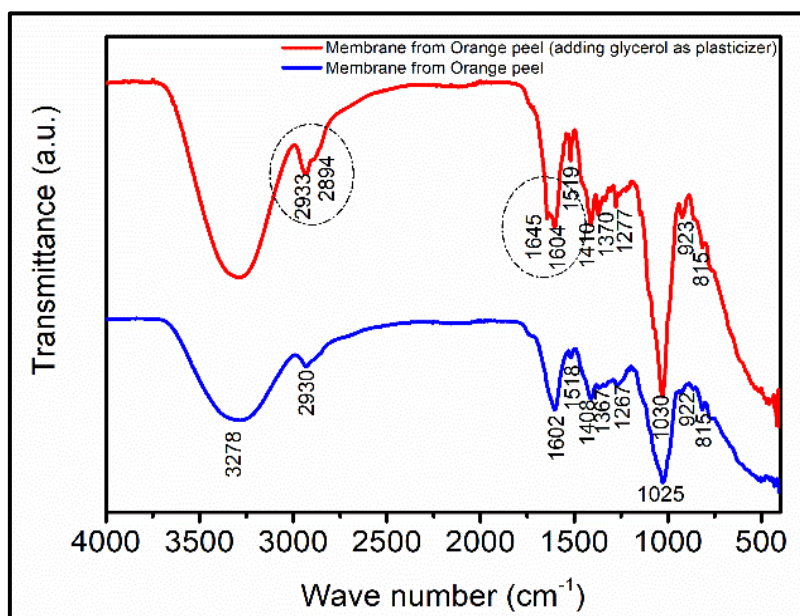


Figure 10. FTIR Spectra of prepared material

4.5.2. Scanning electron microscopy (SEM)

The SEM analysis represented the surface morphological variation of the synthesized bio-originated samples. The surface morphology as shown in **Figure 11 (d)** exhibits an irregular uneven nature along with some fibres in the sample; also, difference in the particle size and shape of the polysaccharides were observed such that the particles appear to vary in shapes as uneven pores, smooth and highly irregular. Therefore, it is concluded that the different polymers present in the film affect the shape of the particles. However, it is concluded that

surface of orange peel-originated substance in association with glycerol as plasticizer, surface is found to be smooth as shown in figure 12a (500 μm), no pores is observed at 500 μm . From this it is concluded that plasticizer that was added in material have decreased the intermolecular forces that have resulted in increasing flexibility and stability of prepared material.

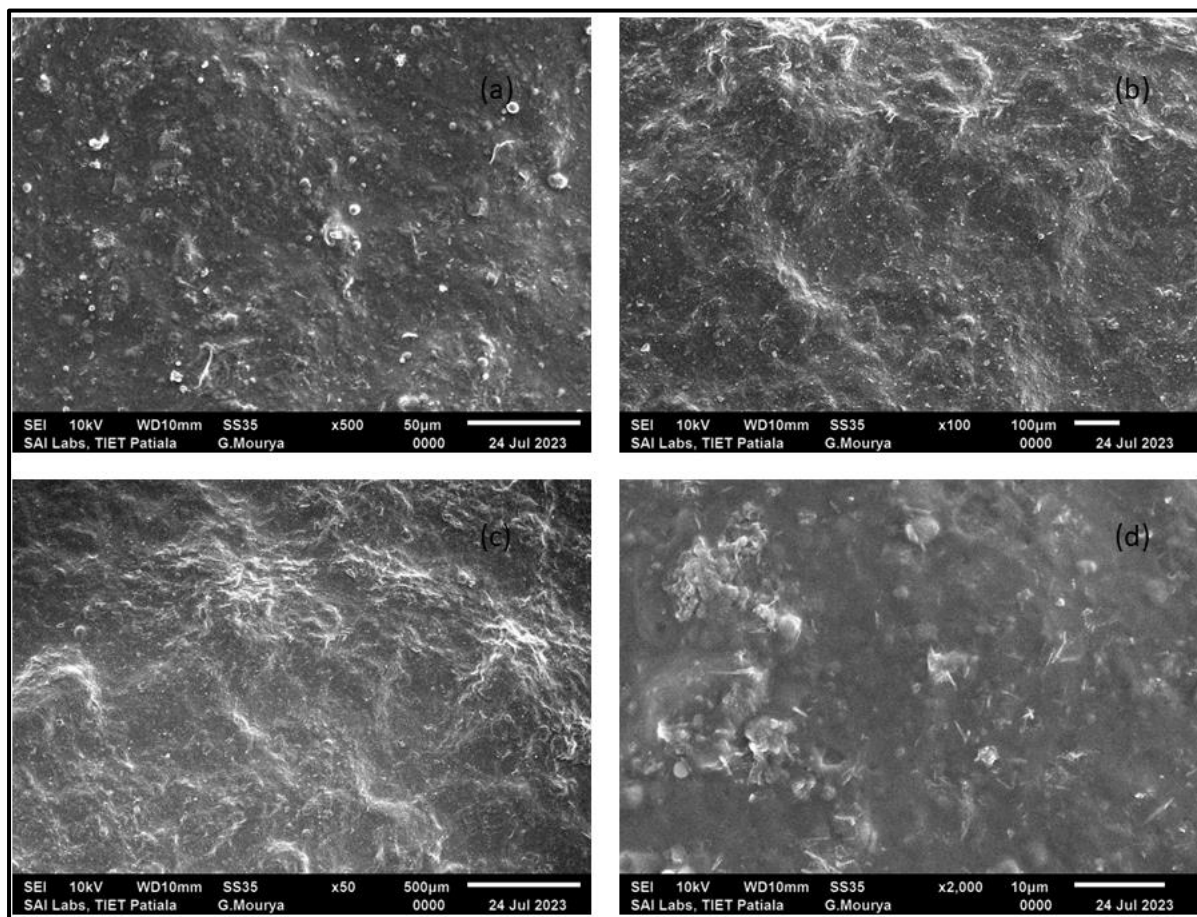


Figure11. SEM images of different magnifications for the membrane prepared from orange peel powder

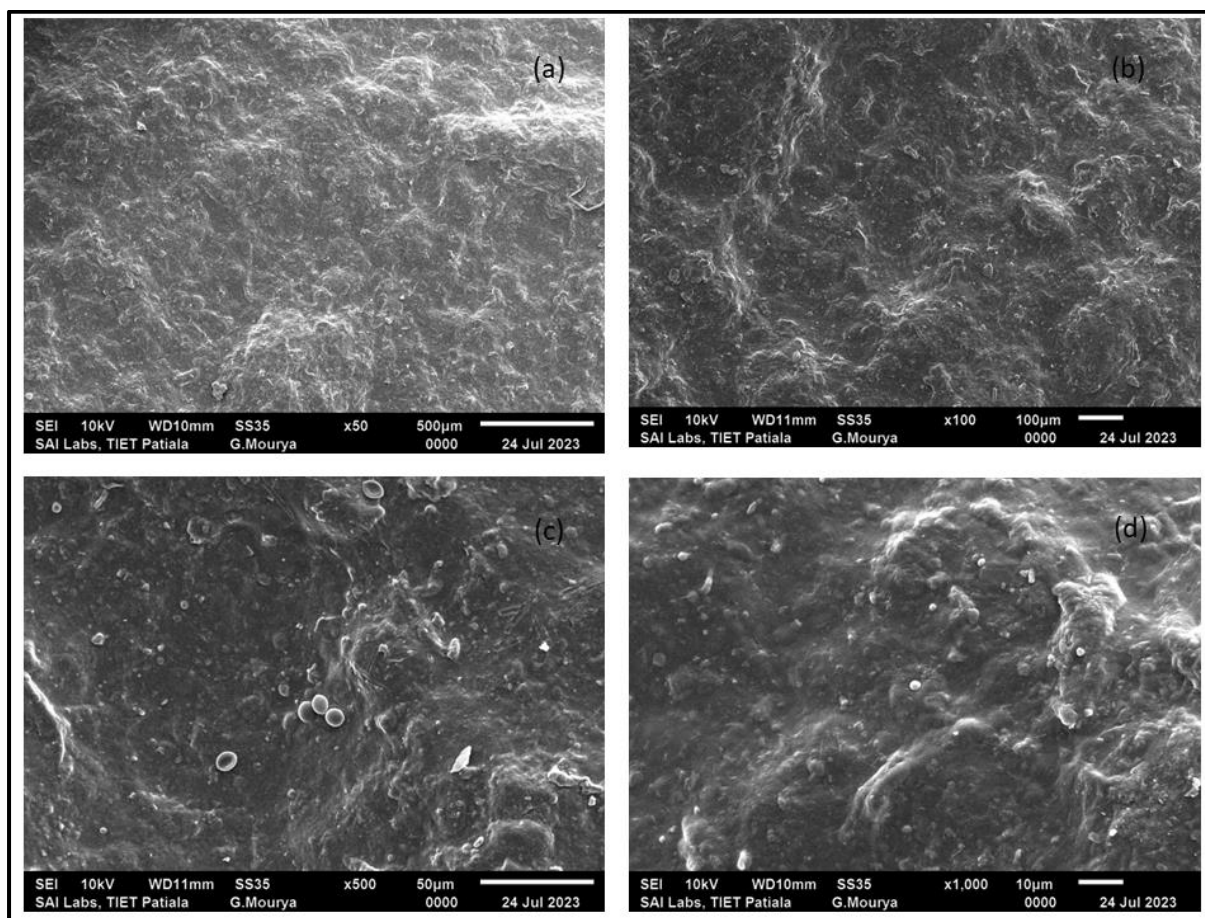


Figure12. SEM images of different magnifications for the membrane prepared from orange peel powder in association with glycerol as plasticizer

Table 4. Chemical composition of orange peel powder

Compositions	OPC-1	OPC-2	OPC-3
Orange powder	4.6g	4.6g	4.6g
Sodium alginate	0.46g	0.46g	0.46g
Glycerol	1.38g	-	-
Sorbitol	-	1.38g	-



Membrane prepared from orange peel powder, without utilization of any plasticizer



Membrane prepared from orange peel powder, without utilization of glycerol as plasticizer



Membrane prepared from orange peel powder, without utilization of sorbitol as plasticizer

Figure 13. Membranes prepared from orange peel powder with three different formulations

Salient findings

It was concluded that fruit waste material has been successfully utilized for preparation of bio-composite material. The present work is new for some industries and prepared bio-composite material have great scope, as a packaging material in various industries. Bio-composite material was prepared as a green alternative to reduce or minimize consumption of conventional plastics. This study plays vital role as method relies on naturally available resources like citrus peels, that not only decreases pollution caused by conventional plastics but also turned to be responsible for growth of industry in coming future. It was also concluded that no harmful contents were present in the material. Hence, developed material is eco-friendly in nature. The most important constituents of bio-composite material i.e., cellulose and pectin that helps in increasing tensile strength of prepared material making it suitable to be used as packaging material in food industries. Antimicrobial test proves that prepared bio material was suitable enough to inhibit growth of microbes and hence, can prevent food material from contamination and results in increasing shelf life of product.

References

- Chalermthai, B., Ashraf, M. T., Bastidas-Oyanedel, J. R., Olsen, B. D., Schmidt, J. E., & Taher, H. (2020). Techno-economic assessment of whey protein-based plastic production from a co-polymerization process. *Polymers*, *12*(4), 847.
- Cacique, P. P., Rios, M. N., Barbosa, I. O., & Wentz, A. P. (2017). Bioplastics production from starch and chitosan blends. *Revista Eletrônica Perspectivas da Ciência e Tecnologia-ISSN: 1984-5693*, *9*, 46-53.
- Keziah, V. S., Gayathri, R., & Priya, V. V. (2018). Biodegradable plastic production from corn starch. *Drug Invention Today*, *10*(7), 1315-1317.
- Sidek, I. S., Draman, S. F. S., Abdullah, S. R. S., & Anuar, N. (2019). Current development on bioplastics and its future prospects: an introductory review. *INWASCON Technol. Mag*, *1*, 3-8.
- Kasmuri, N., & Zait, M. S. A. (2018). Enhancement of bio-plastic using eggshells and chitosan on potato starch based. *Int. J. Eng. Technol*, *7*, 110-115.
- Ghamande, M., Kulkarni, A., Shah, N., Kothari, S., & Bhosale, S. (2018). Bio-plastic (Generating plastic from banana peels). In *International conference on new frontiers of engineering, management, social science and humanities* (pp. 39-42).
- Jogi, K., & Bhat, R. (2020). Valorization of food processing wastes and by-products for bioplastic production. *Sustainable Chemistry and Pharmacy*, *18*, 100326.
- Fabunmi, O. O., Tabil, L. G., Chang, P. R., & Panigrahi, S. (2006). Developing biodegradable plastics from starch. In *ASABE/CSBE North Central Intersectional Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

- Tsang, Y. F., Kumar, V., Samadar, P., Yang, Y., Lee, J., Ok, Y. S., ... & Jeon, Y. J. (2019). Production of bioplastic through food waste valorization. *Environment international*, *127*, 625-644.
- Yaradoddi, J. S., Banapurmath, N. R., Ganachari, S. V., Soudagar, M. E. M., Sajjan, A. M., Kamat, S., ... & Ali, M. A. (2022). Bio-based material from fruit waste of citrus peel for industrial applications. *Journal of Materials Research and Technology*, *17*, 3186-3197.
- Choudhary, P., Pathak, A., Kumar, P., & Sharma, N. (2022). Commercial production of bioplastic from organic waste-derived biopolymers viz-a-viz waste treatment: A minireview. *Biomass Conversion and Biorefinery*, 1-11.
- Tyagi, V. K., & Aboudi, K. (Eds.). (2021). *Clean Energy and Resources Recovery: Biomass Waste Based Biorefineries, Volume 1*. Elsevier.
- Marichelvam, M. K., Jawaid, M., & Asim, M. (2019). Corn and rice starch-based bioplastics as alternative packaging materials. *Fibers*, *7*(4), 32.
- Özcan, M. M., Ghafoor, K., Al Juhaimi, F., Uslu, N., Babiker, E. E., Mohamed Ahmed, I. A., & Almusallam, I. A. (2021). Influence of drying techniques on bioactive properties, phenolic compounds and fatty acid compositions of dried lemon and citrus peel powders. *Journal of food science and technology*, *58*, 147-158.
- Raj, A., & Masih, D. (2014). Physico chemical and rheological properties of wheat flour bun supplemented with citrus peel powder. *International Journal of Science and Research*, *3*(8), 391-394.
- Obafaye, R. O., & Omoba, O. S. (2018). Citrus peel flour: A potential source of antioxidant and dietary fiber in pearl-millet biscuit. *Journal of food biochemistry*, *42*(4), e12523.

- Babu, J., Nath, S. B., & Kodali, V. P. (2014). Isolation, screening and extraction of polyhydroxybutyrate (PHB) producing bacteria from sewage sample. *Int. J. Pharm. Tech. Res*, 6(2), 850-857
- Rawte, T., & Mavinkurve, S. (2001). Biodegradable plastics-bacterial polyhydroxyalkanoates. *Indian Journal of Microbiology*, 41(4), 233-245.
- Shamsuddin, I. M., Jafar, J. A., Shawai, A. S. A., Yusuf, S., Lateefah, M., & Aminu, I. (2017). Bioplastics as better alternative to petroplastics and their role in national sustainability: a review. *Adv. Biosci. Bioeng*, 5(4), 63.
- Manimaran, D. S., Nadaraja, K. R., Vellu, J. P., Francisco, V., Kanesen, K., & BinYusoff, Z. (2016). Production of biodegradable plastic from banana peel. *Petrochem. Eng*, 1, 1-7.
- Pandit, S., Savla, N., Sonawane, J. M., Sani, A. M. D., Gupta, P. K., Mathuriya, A. S., ... & Prasad, R. (2021). Agricultural waste and wastewater as feedstock for bioelectricity generation using microbial fuel cells: Recent advances. *Fermentation*, 7(3), 169.
- Hsu, E. (2021). Cost-benefit analysis for recycling of agricultural wastes in Taiwan. *Waste Management*, 120, 424-432.
- Debtera, B. (2019). Synthesis and experimental study of production bioplastic from banana peels. *Addis Ababa Science and Technology University, College of Biological and Chemical Engineering*, 1-44.
- Zhang, S., Fu, Q., Li, H., Wu, P., Waterhouse, G. I., Li, Y., & Ai, S. (2023). A pectocellulosic bioplastic from fruit processing waste: robust, biodegradable, and recyclable. *Chemical Engineering Journal*, 463, 142452.

Yaradoddi, J., Patil, V., Ganachari, S., Banapurmath, N., Hunashyal, A., Shettar, A., & Yaradoddi, J. S. (2016). Biodegradable plastic production from fruit waste material and its sustainable use for green applications. *Int. J. Pharm. Res. Allied Sci*, 5(4), 72-81.

Moro, T. M., Ascheri, J. L., Ortiz, J. A., Carvalho, C. W., & Meléndez-Arévalo, A. (2017). Bioplastics of native starches reinforced with passion fruit peel. *Food and Bioprocess Technology*, 10, 1798-1808.

Sankalpa, K. B., Ramachandra, C. T., Dinesha, B. L., Nidoni, U., & Hiregoudar, S. (2016). Effect of drying and grinding methods on physical and hydration properties of sweet citrus peel powder. *International Journal of Food and Fermentation Technology*, 6(2), 295-300.

Arvind, P. (2018). Antimicrobial Properties of Orange (*Citrus reticulata* var. Kinnow). Peel Extracts against Pathogenic Bacteria. *International journal of current microbiology and applied sciences*, 7(3), 737-46.

Ramakuela, M., Adeniyi, A., Onyango, M., Mbaya, R., & Oyewo, O. A. Performance Evaluation of Orange Peels as Anti-Scaling Agent for Pretreatment of Water.

Faix, O., & Böttcher, J. H. (1993). Determination of phenolic hydroxyl group contents in milled wood lignins by FTIR spectroscopy applying partial least-squares (PLS) and principal components regression (PCR).

Manthey, J. A. (2006). Fourier transform infrared spectroscopic analysis of the polymethoxylated flavone content of orange oil residues. *Journal of agricultural and food chemistry*, 54(9), 3215-3218.

Yu, X., & Sun, D. (2013). Microwave and enzymatic extraction of orange peel pectin. *Asian journal of Chemistry*, 25(10), 5333-5336.

Dey, S., Basha, S. R., Babu, G. V., & Nagendra, T. (2021). Characteristic and biosorption capacities of orange peels biosorbents for removal of ammonia and nitrate from contaminated water. *Cleaner Materials*, 1, 100001.

Ullah, N., Ali, J., Khan, F. A., Khurram, M., Hussain, A., Rahman, I. U., ... & Ullah, S. (2012). Proximate composition, minerals content, antibacterial and antifungal activity evaluation of pomegranate (*Punica granatum L.*) peels powder. *Middle-East Journal of Scientific Research*, 11(3), 396-401.

Tze, N. L., Han, C. P., Yusof, Y. A., Ling, C. N., Talib, R. A., Taip, F. S., & Aziz, M. G. (2012). Physicochemical and nutritional properties of spray-dried pitaya fruit powder as natural colorant. *Food Science and Biotechnology*, 21, 675-682.

Gupta, U. R. V. I., & Solanki, H. I. T. E. S. H. (2015). Quantification of ash and selected primary metabolites from non-edible parts of several fruits. *Int J Pharm Pharm Sci*, 7, 288-90.

Suri, S., Singh, A., & Nema, P. K. (2022). Current applications of citrus fruit processing waste: A scientific outlook. *Applied Food Research*, 2(1), 100050.

Joshi, P., Sharma, O. P., Ganguly, S. K., Srivastava, M., & Khatri, O. P. (2022). Fruit waste-derived cellulose and graphene-based aerogels: Plausible adsorption pathways for fast and efficient removal of organic dyes. *Journal of Colloid and Interface Science*, 608, 2870-2883.

Rahman, M. S. (2001). Toward prediction of porosity in foods during drying: a brief review. *Drying Technology*, 19(1), 1-13.

Gupta, U. R. V. I., & Solanki, H. I. T. E. S. H. (2015). Quantification of ash and selected primary metabolites from non-edible parts of several fruits. *Int J Pharm Pharm Sci*, 7, 288-90.

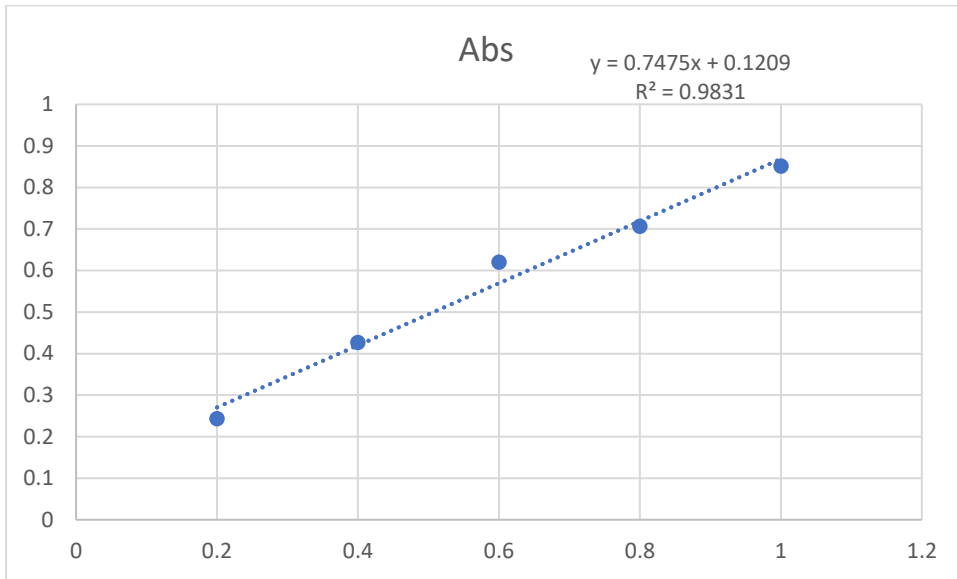
Danish, M., Mumtaz, M. W., Fakhar, M., & Rashid, U. (2017). Response surface methodology based optimized purification of the residual glycerol from biodiesel production process. *Chiang Mai J. Sci*, 44(4), 1570-1582.

Puccini, M., Licursi, D., Stefanelli, E., Vitolo, S., RASPOLLI GALLETTI, A. N. N. A., & Heeres, H. J. (2016). Levulinic acid from orange peel waste by hydrothermal carbonization (HTC). *Chemical Engineering Transactions*, 50, 223-228.

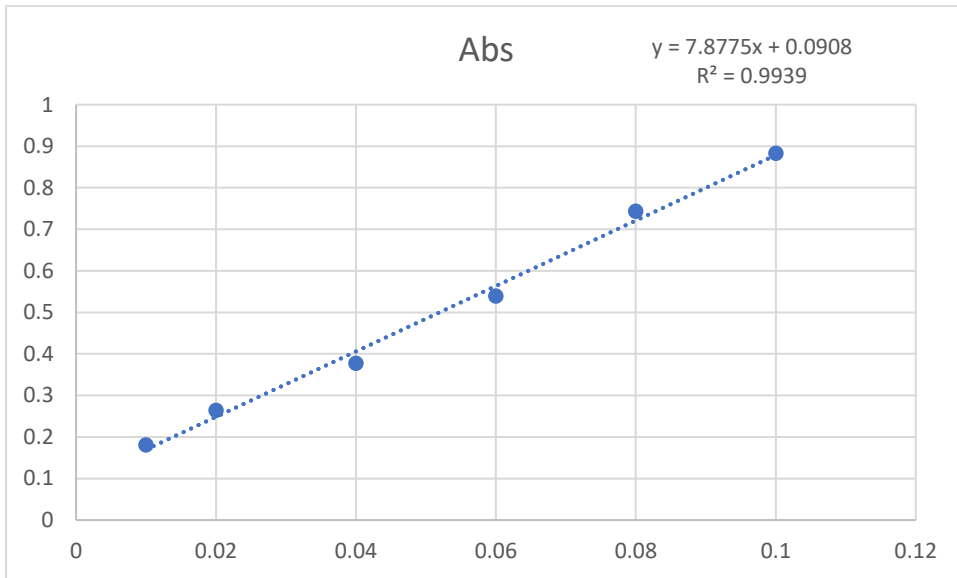
Duwee, Y. S., Kiew, P. L., & Yeoh, W. M. (2022). Multi-objective optimization of pectin extraction from orange peel via response surface methodology: Yield and degree of esterification. *Journal of Food Measurement and Characterization*, 16(2), 1710-1724

Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscopy of organic material. *Indonesian Journal of Science and Technology*, 4(1), 97-118.

ANNEXURE - I



STANDARD CURVE FOR TOTAL PHENOLIC CONTENT



STANDARD CURVE FOR TOTAL FLAVANOID CONTENT

MSC. THESIS "Synthesis and characterization of orange peel-based bio composites for sustainable packaging and encapsulation applications."

by Kunal Khanna

Submission date: 28-Jul-2023 06:22PM (UTC+0530)

Submission ID: 2138032344

File name: Project_thesis_-_Copy_3_for_plag.docx (66.51K)

Word count: 4893

Character count: 27174

Moushmi Choudhary

MSC. THESIS "Synthesis and characterization of orange peel-based bio composites for sustainable packaging and encapsulation applications."

ORIGINALITY REPORT

3%

SIMILARITY INDEX

%

INTERNET SOURCES

3%

PUBLICATIONS

%

STUDENT PAPERS

PRIMARY SOURCES

- 1 Jayachandra S. Yaradoddi, Nagaraj R. Banapurmath, Sharanabasava V. Ganachari, Manzoore Elahi M. Soudagar et al. "Bio-based material from fruit waste of orange peel for industrial applications", *Journal of Materials Research and Technology*, 2021
Publication 1%
- 2 F. Staib, S. K. Mishra, A. Blisse. "Interaction between aspergilli and streptomycetes in the soil of potted indoor plants: A preliminary report (contribution to the epidemiology of human aspergillosis)", *Mycopathologia*, 1980
Publication <1%
- 3 Lamminen, M.O.. "Mechanisms and factors influencing the ultrasonic cleaning of particle-fouled ceramic membranes", *Journal of Membrane Science*, 20040701
Publication <1%