Hydrophobicity and fluid absorption in paper cups, plates and biopolymeric films

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Hydrophobicity of paper cups and plates for food security?
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Abstract:

The use of paper packaging and utensils (paper cups, paper plates, cutlery) is increasing due to busy lifestyles. Paper packaging and utensils are cheaper, easy to use and dispose of. Since paper is made from cellulose it is degradable, environment friendly, and an alternative to plastic utensils. However, the paper easily absorbs water or has high wettability, so they need a specific coating to make it waterproof to use in food industries. Turning paper into a hydrophobic utensil is challenging. Therefore, this study is investigating the hydrophobicity of commercial paper cups and plates by studying their wettability and contact angle using commercial orange juice.

Contact angle measurement showed that the used cup was not hydrophobic (contact angle paper cup with juice was 83) and absorbed some orange juice. Contact angle measurement showed that the used Walki paper plate was hydrophobic (contact angle with juice was 92) but still absorbed a significant amount of orange juice. The absorbance was increasing with a longer contact time between paper and juice. These paper cups absorbed less juice than plates. A simple hydrophobic coating has improved the wettability and made the paper-based utensils usable but a superhydrophobic coating would have been better for food security i.e., which could have saved 60 ml of orange juice per 100 cups. However, more study with other food and beverage needs to be studied to make a better conclusion.

Keywords: Superhydrophobicity, hydrophobicity, paper cups, paper plates, wettability, contact angle, food security.

Abbreviations

Fig.	Figure
Wt.	weight
Min.	minute
WCA.	Water Contact Angle
FAO	Food and Agricultural Organization
CA	Contact Angle
MFS	Membrane Forming Solution.
ml.	milliliter
gm	gram

Acknowledgments

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Contents

1 Introduction

The increasing population needs more food to feed them. FAO estimated that in the year 2050, we need to increase 60% of food to feed the world population (De Silva 2012). There are several methods to increase the production of food such as improved agricultural practices, good seeds, and maximizing food production in a small area. On the other hand, reducing food waste is another method to increase food availability and address food security. Food packaging is an interesting topic to reduce food waste. Plastic-based food packaging is commonly used and of interest to food industries since plastic is waterproof, strong to hold food, and long-lasting. Nowadays, plastic pollution is a huge concern, so people are looking for alternatives to plastic. Paper-based packaging and utensils are getting more interest from food companies since it is environmentally friendly, degradable, and renewable. It is produced from recyclable biomass such as trees and plants. On the other hand, paper-based packaging and utensils need a good hydrophobic coating to make them waterproof and hydrophobic which is a downside of the production of paper-based products in food industries.

Paper cups/Food packaging materials are getting interested in food industries since package food market is growing especially after Covid 19. Packaging can protect food, keep the food at an appropriate temperature for a long time, and prolong shelf life. Recently, hydrophobic cups and packaging are getting attention in food industries which reduces food waste. Reduction of food waste supports food security and reduces environmental pollution. There are different types of paper cups and food packaging on the market that will somehow reduce the use of plastic-based packaging material. Superhydrophobic coating has become one major way to produce different types of packaging. Superhydrophobic coating claims several benefits such as self-cleaning and odorless capability, heat tolerance, etc. A significant amount of superhydrophobic coating is also made with edible, eco-friendly materials. (Manrich et al., 2017).

Some commercially available paper cups/food packaging have better hydrophobicity than others. Some of the food sticks on the packaging and it is difficult to recover it which increases the food waste. Similarly, there is some food packaging that gets wet before the whole meal is finished, which increases food waste. There is a concept of superhydrophobic coating which claim to reduce food residue in the packaging (Wang et al 2018). Reducing food waste is a rational approach to addressing urgent issues such as food insecurity, water scarcity, global warming, and pollution (Marston, et al., 2021).

Superhydrophobicity is a water-repellent mechanism that can be seen in nature such as water in lotus leaves. Surface coating with superhydrophobic chemicals provides waterproof capabilities that have attracted both industrial and scientific interests (Liu et al 2017). Turning non-hydrophobic material surface can be simply fabricated by a coating method that is facile, low-cost, scalable, and environmental-friendly (Liu et al 2017).

Typical hydrophobic coatings for paper packaging are achieved by micro or nanostructured coatings, which control surface wettability. A superhydrophobic surface is generally defined as exhibiting a water contact angle (WCA) of less than 5° and WCA greater than 90° defines a material to be hydrophobic, whereas a superhydrophobic surface is one in which the WCA is greater than 150°. Superhydrophobic surfaces are prepared due to their potential applications such as self-cleaning (Li et al 2007). Several methods have been successfully developed to produce super hydrophobicity but most of these methods required high temperature or a wet chemical process, and therefore, limiting to use in paper-based products. The modification of paper surfaces has to be performed very carefully (Balu et al. 2008) and they require costly instrumentation. Therefore, superhydrophobic coated paper-based products have a question about their quality.

Paper is one of the oldest inventions and is used in a wide variety of applications, including packaging. The major component of paper is cellulose, a carbohydrate with hydroxyl groups (Sahin et al 2008). Due to hydroxyl groups, it is hygroscopic, and thus commercial paper is easily wetted. To overcome the hygroscopic nature, the sizing of paper is done by many conventional methods (Jielong et al 2012).

Waxes are one of the most hydrophobic materials that can be synthetically produced from petroleum products and are also found in nature. Recently, plant-based waxes such as Soy wax (Marzbani et al 2021), Rice Bran wax (Liu et al 2019) are used (Shen et al, 2020; Wang et al 2016) since they are degradableThese plant-based waxes alone or in combination with animal wax have been used extensively on paper by spray coating techniques using a solvent such as ethanol, acetone, or chloroform to produce the self-assembly of wax into hierarchical structures driven by evaporation of solvents (Wang et al 2016). Recently insect-based wax (wax secreted by insects) is also studied for paper coating (Ahuja and Rastogi, 2023).

1.1 Aims of thesis

The main aim of the study is to validate the reduction of food waste using hydrophobic coated paper cups and plates or food packaging. This study also aims to compare the hydrophobicity of commercial paper cups and plates with our laboratory-produced hydrophobic membrane. The segmented aims are:

(1) to compare the contact angle of hydrophobic materials and their hydrophobicity with different viscous drinks.

(2) to study the hydrophobicity affected by different types of drinks (water, juice, olive oil, milk).

(3) to study the hydrophobicity affected by temperature and contact time. (5 min,10 min, 15 min, 20 min, 30 min,50 min)

(4) to compare the hydrophobicity of commercial paper cups and plates with laboratory-prepared hydrophobic membranes.

The concept of the study is also shown in “Figure 1”.

Figure 1. Food security study in a paper cup with 150 ml liquids.

2 Structure of the Thesis

This thesis is part of a project about hydrophobic membrane preparation, its hydrophobicity and biodegradability. The whole study was conducted as a bachelor thesis by 3 students namely, Dinesh Acharya, Deepa Shrestha (myself) and Sapana Ghimire. Hydrophobic membrane preparation and biodegradability test were studied by Dinesh and Sapana, respectively. So detail of those topics can be found in their thesis.

This thesis is mainly focused on wettability and food security. This thesis includes a literature review, hydrophobic membrane preparation, Contact Angle measurements, a Wettability study and an interpretation of the result for food security. A hydrophobic membrane was prepared by extracting Cutin from tomato peel and mixing it with commercial Pectin. This membrane was studied for its Contact Angle and Wettability and compared with commercial paper cups and plates. Contact Angle was measured for different liquids (orange juice, water, coke, milk, olive oil). The wettability of the membrane was done in water but a wettability study of paper cups and plates was done using orange juice.

3 Literature Review

Ahuja and Rastogi (2023) were looking for alternative wax to produce a superhydrophobic coating. They produce wax from insects. The spray-coated paper with insect wax mixture showed good repellency towards different food simulants, such as water, acetic acid, ethanol, octane, and several food products, as measured using contact angles. Lowered water absorption was noted for coated pulp-based bowls. The coating also showed self-cleaning or anti-fouling properties.

Chen, et al (2017) studied the production of durable superhydrophobic paper. A thin layer of starch-based composite, acting as a bio-binder, was first coated onto the paper surface by using the surface sizing technique. The prepared superhydrophobic paper not only exhibited a self-cleaning behavior but also presented enhanced durability against scratching, bending/deformation, as well as moisture.

Li and Rabnabaj (2018) studied the possibilities of the use of melamine coating on paper to increase hydrophobicity. Commercial printing paper and cup paper were coated with melamine. Subsequently, a water-repellent outer layer is applied using poly(dimethylsiloxane) (PDMS)–isocyanate. The paper cup and printing paper were coated as 1.61 ± 1.10 and 0.93 ± 0.74 wt %, respectively. After the coatings, the WCAs were >125° for both and water absorption decreased by 70% for printing paper and by 35% for cup paper. This result indicates that this method will have great potential for the large-scale production of hydrophobic materials for use in food packaging.

Jiang et al (2022) investigated the hydrophobicity using SiO2 with polylactic acid (PLA). They found that the prepared packages possessed excellent thermal stability attributed to inorganic SiO2 incorporation. The excellent film−forming characteristics of polylactic acid PLA improved the tensile strength of the manufactured papers (104.3 MPa) as compared to the original cellulose papers (70.50 MPa). Benefiting from the rough nanostructure which was surface modified by low surface energy stearic acid (SA), the contact angle of the composite papers attained 156.3°. As the novel composite papers have remarkable thermal stability, tensile strength, and barrier property, they can be exploited as a potential candidate for eco−friendly, renewable, and biodegradable cellulose paper−based composites for the substitute of petroleum−derived packages.

Zhang et al (2019) studied a thermo-resistant edible super-hydrophobic coating fabricated using beeswax and coffee. This coating surface has a similar micro/nanoscale structure to that of the leaf surface. With the introduction of coffee lignin, the thermal stability and adhesive force of the coating increased significantly. The apparent contact angle of this coating can remain to be above 150° after a long-time of heating and flushing. This thermo-resistant edible super-hydrophobic coating can solve the problem that original edible super-hydrophobic coating is not resistant to high temperatures and has a broad application prospect in the field of functional food packaging.

Ahuja and Rastogi (2023) studied the hydrophobicity of insect waxes in paper cups and bowls. The insect wax mixture coated (spray) paper showed good repellency against different food simulants, such as water, acetic acid, ethanol, octane, and several food products. Lowered water absorption was noted for coated pulp-based bowls. The coating also showed self-cleaning or anti-fouling properties "Figure 2".

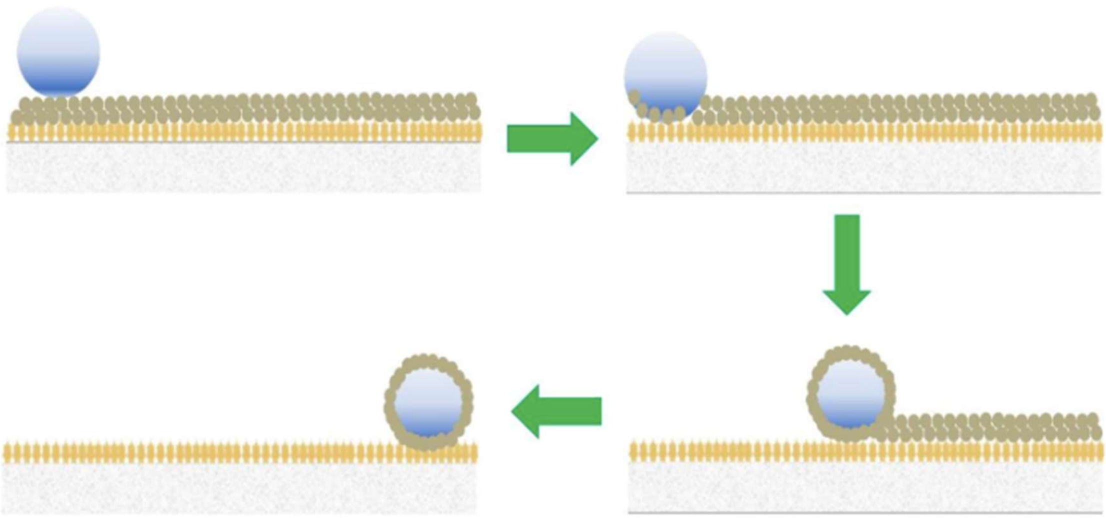


Figure 2. Mechanism of self-cleaning property of the coated paper surface (Ahuja and Rastogi,2023)

4 Theory

4.1 Contact angle

The contact angle is the angle formed between a liquid droplet and a solid surface at the point of contact. It is a measure of the wettability of a surface, with a higher contact angle indicating a more hydrophobic (water-repelling) surface and a lower contact angle indicating a more hydrophilic (water-attracting) surface. The contact angle is influenced by the surface tension of the liquid and the surface energy of the solid. It quantifies the wettability of a solid surface by a liquid via "Young`s equation". $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} \cos(\theta_C)$ where θ is the contact angle measured in the liquid, γL, γS and γSL the surface tensions of liquid, solid and solid-liquid surfaces.

The contact angle that is formed depends on several factors such as the thermodynamics of the surface and surface tension.

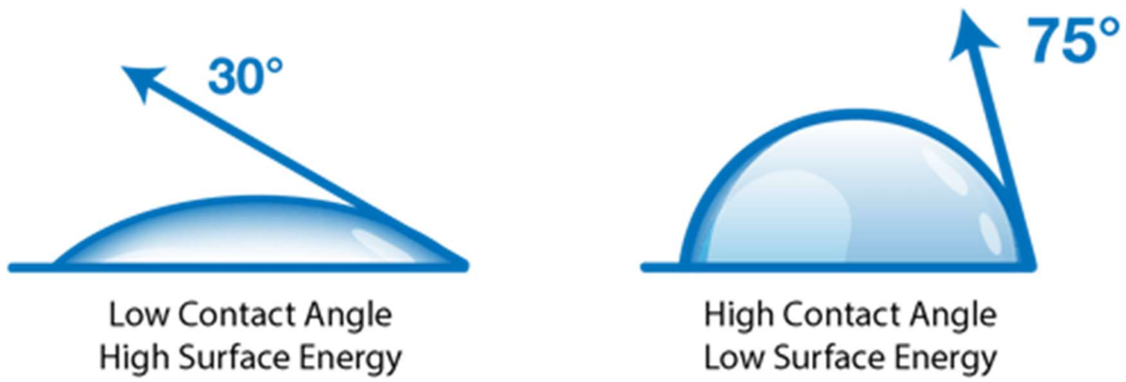


Figure 3: CA depends on surface energy (Source. Brighton Science).

If the water contact angle (WCA) is smaller than 90°, the material is hydrophilic, if WCA is larger than or equal to 90°, the material is hydrophobic and if WCA is larger than 150° it is superhydrophobic ("Fig. 4").

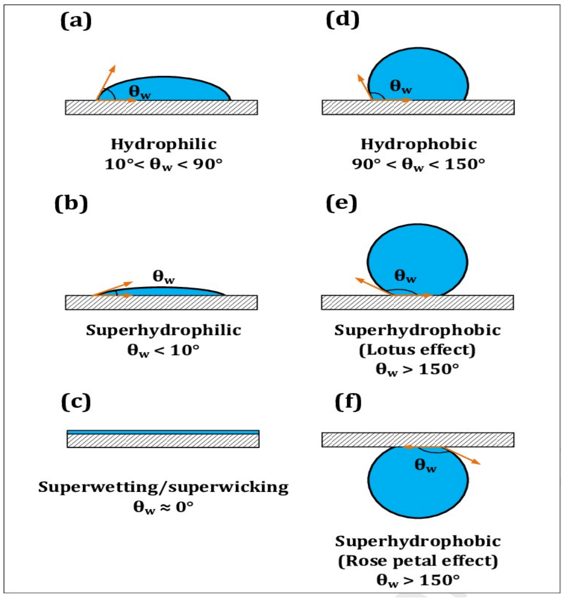


Figure 4. Classification of wetting based on θ w: (a) hydrophilic; (b) superhydrophilic; (c) superwetting/superwicking; (d) hydrophobic; (e) superhydrophobic (lotus leaf effect); (f) superhydrophobic with high adhesion (rose petal effect) (Fig. source. Samata et.al, 2020).

4.2 Superhydrophobic and hydrophobic

In chemistry and materials science, ultrahydrophobic (or superhydrophobic) surfaces are highly hydrophobic, i.e., extremely difficult to make wet (Wikipedia). Several natural maters have superhydrophobic characteristics such as lotus leaves. The first development of artificial superhydrophobic surfaces by Onda et al. (1996) was in the mid-1990s. Since then, scientists and business companies are attracted to superhydrophobic coating. Superhydrophobic is prepared from different chemical compounds which might be not edible. Recently, scientists are interested to prepare an edible superhydrophobic coating from different edible natural products such as potatoes and tomatoes (Wang et al. 2020) ("Figure 5"), beeswax and coffee (Zhang, 2019).

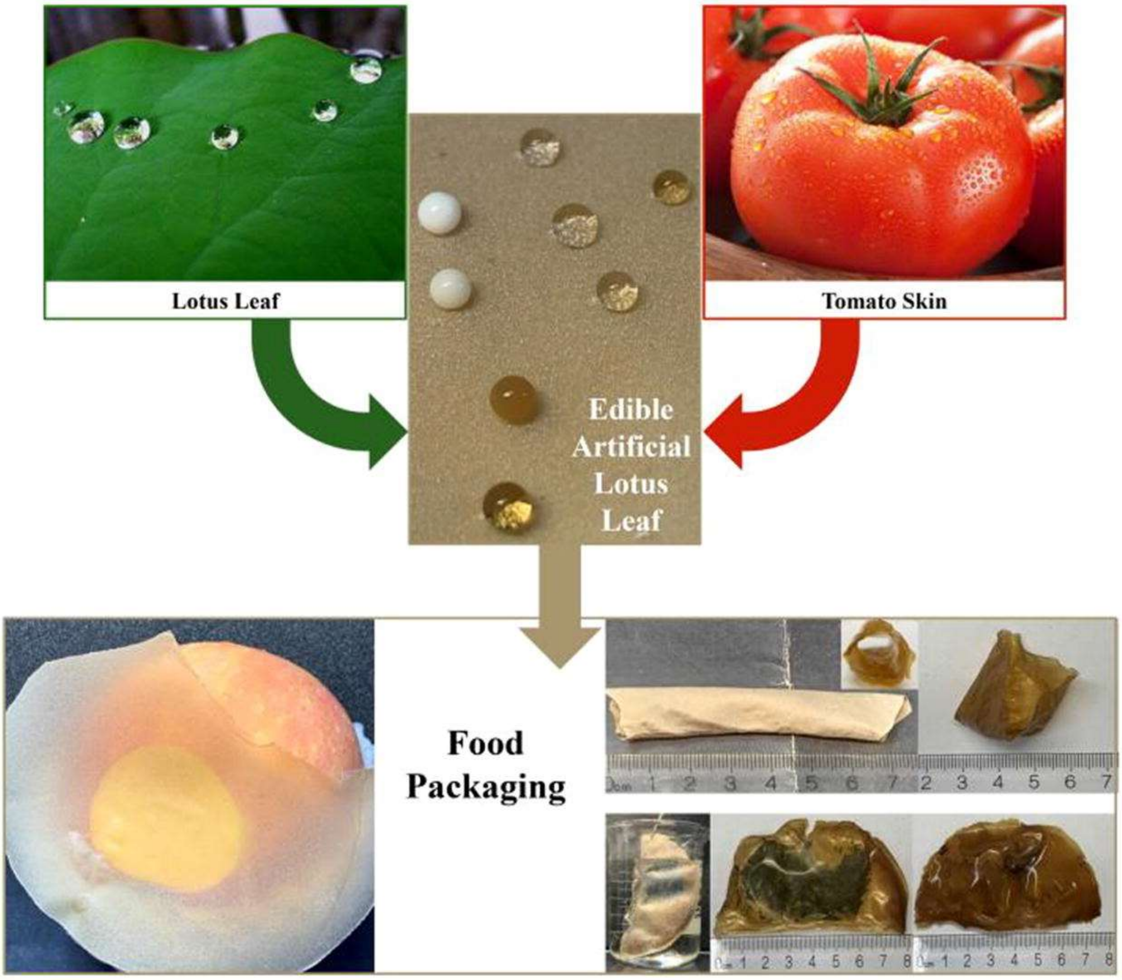


Figure 5. superhydrophobic membrane produced from tomato skin and mimic the lotus leaf (Wang et al. 2020).

5 Materials and Methods

This study is aimed to investigate whether commercially available paper cups and plates are super/hydrophobic. There is not much literature showing the wettability of commercial paper cups and plates. In practical usage, commercial paper cups might face different factors (time, temperature, date of manufacture, physical damage, humidity) which reduce the hydrophobicity of the paper cups. Therefore, it was important to study the wettability of commercial paper cups and plates. Orange juice was used as a main study liquid since it is a commonly used beverage at parties or get together. This study is important because this study shows the wettability of commercial paper plates and cups and calculates the amount of food that can be saved by superhydrophobicity.

5.1 Equipment and materials used in the study

The following equipment was used in this study.
This study was conducted using hydrophobic-coated paper cups, Beakers, Pipettes, Test tubes, heaters, ovens, thermometers, glass rods, pH meters, etc.
Reagents: Sodium hydroxide (NaOH), Hydrochloric acid (HCL), Ethanol (C_2H_6O).

A Membrane was made with tomato peel in our laboratory, and commercially available paper cups were purchased from Prisma. The size of the cup was 200 ml. The name of the company was Kartonkipikari ("Fig. 6"). Walki Paper plate was received from a company called Walki for the test and its biodegradability test. Duni 10 Bio paper plates and Biopak plates were purchased from the shop (Prisma). ("Fig. 7"). The Walki plate and Duni paper plate were made from wood fiber and the BioPak plate was made of sugarcane fiber. For experiments, orange juice, water, olive oil, milk, and Zero Sugar Coke were used for contact angle measurement and wettability test. Liquids like orange juice, milk, and Zero sugar Coke were kept in the refrigerator at a temperature of 4^{o}c. The paper stripes cut for the wettability test were 4*7cm and the contact area was 3*5 cm.

Figure 6. Paper cup kartonkipikari.

Figure 7. Biodegradable paper plates sample.

5.2 Cutin and Pectin preparation process

Cutin was produced from tomato peel extract according to the procedure used by Wang et al.(2020) in the Arcada UAS, laboratory.

Commercial apple pectin was bought from the Ruhonjuuri shop ("Fig. 8"). Cutin and pectin membrane forming solution (MFS) preparation obtained cutin was then dispensed in deionized water to form a cutin solution at 10% w/v concentration through ultrasonication. The commercial pectin was dissolved in deionized water at room temperature to form a 6% w/v solution ("Fig. 9"). The 50/50 wt ratio cutin-pectin mixture solution ("Fig. 10") was made and left in the oven at a temperature of 45 ^{o}c for 24 hours similar to that described by Wang et al. (2020), ("Fig. 11").

To make the membrane Superhydrophobic, Beeswax solution was sprayed on the surface of the membrane according to the procedure used by Wang et al. (2020).

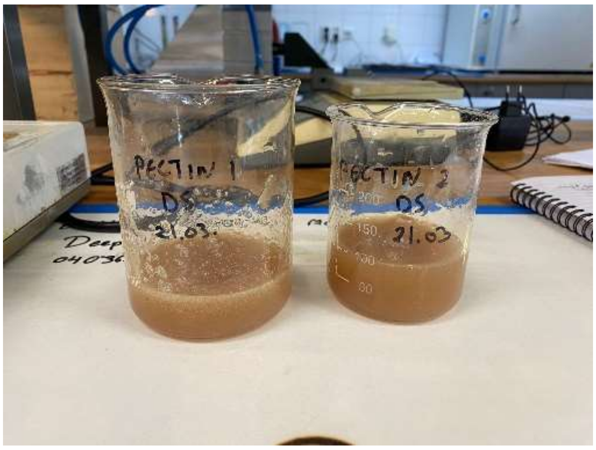


Figure 8. Apple pectin. *Figure 9. Apple pectin mixed with water (6% w/v).*

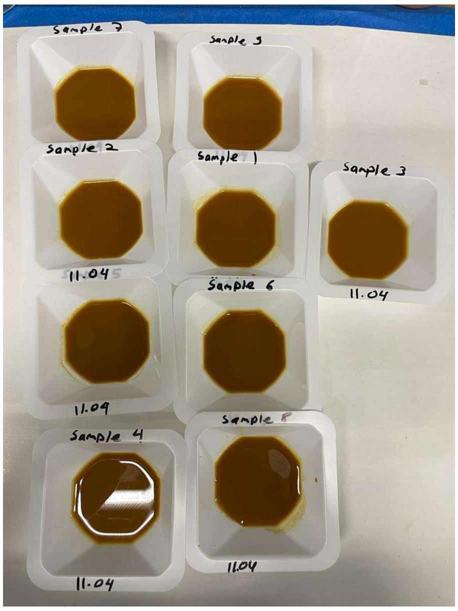


Figure 10. Cutin and Pectin mixed solution. Figure 11. Final cutin, pectin member after drying. (Fig.source. Dinesh Acharya) .

5.3 Process of Measuring Contact Angle

The bottom surface glass plate was cleaned with isopropyl alcohol before placing the strips. Water, orange juice, and olive oil as samples were poured into the beaker and the temperature of the orange juice was noted. The sample was mounted in a jack and the back lighting was adjusted. With the help of a syringe, a drop was added to the paper cup strips, plate stripes, and membrane sample cut pieces. The mobile phone was adjusted at the same height as the sample and a picture was taken ("Fig. 12 (a, b, c, d))". Then, the Contact angle was measured using ImageJ software ("Fig. 13")

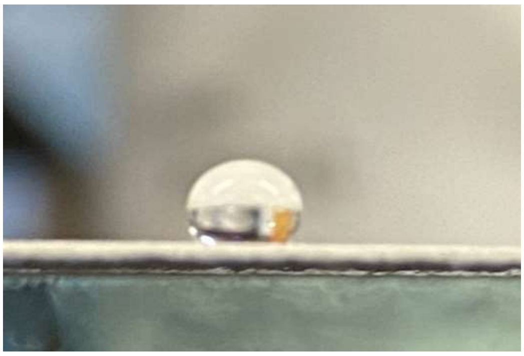


Figure 12(a):water sample in paper plate stripe stripes *Figure 12(b):orange juice in paperplate*

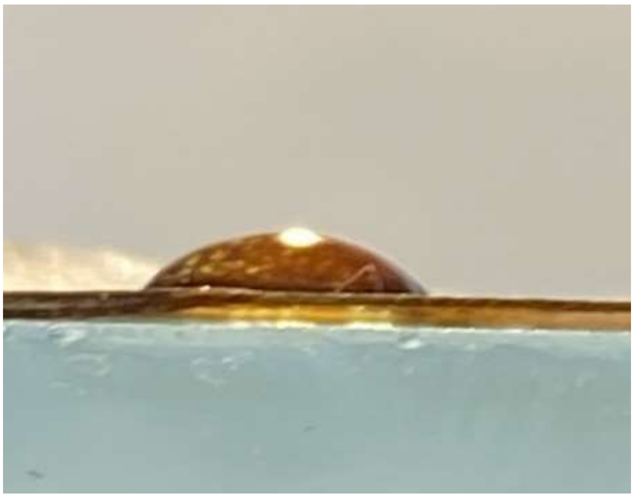
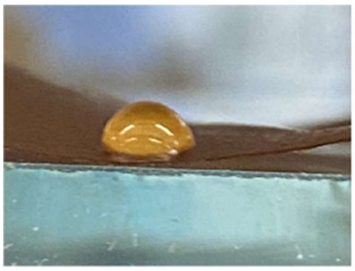
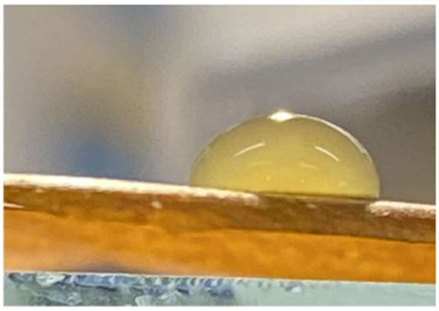


Figure 12 (c): sample olive oil in membrane



membrane without beeswax spray

mebrane beeswax sprayed



membrane with beewax sprayed- juice

Figure 12 (d). Contact angle calculated in beeswax sprayed and not sprayed.

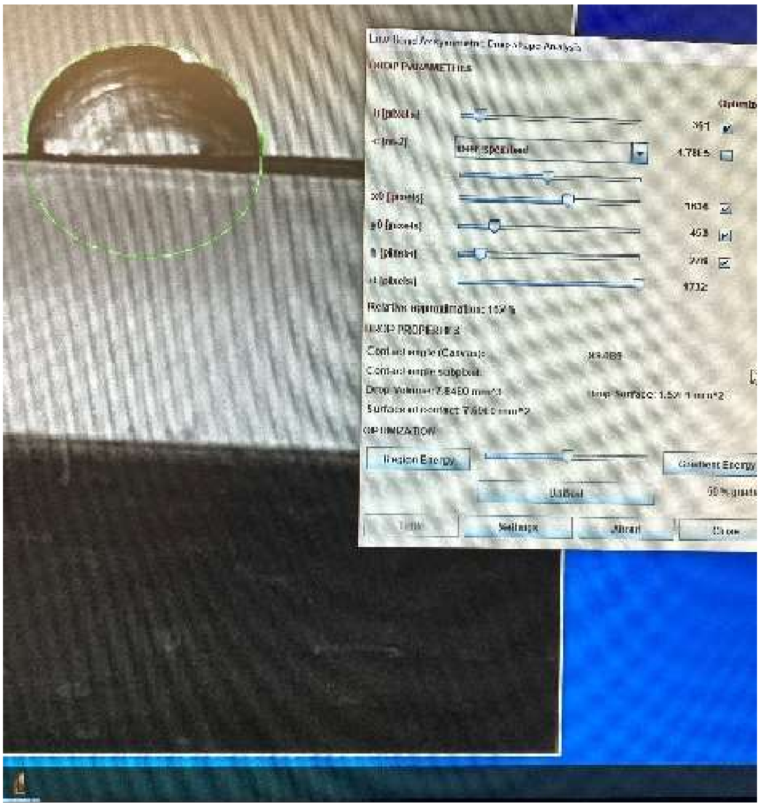


Figure 13. Contact angle in Imagej software.

5.4 Wettability/absorption test

Wettability is the ability of a liquid to spread over or adhere to a solid surface. It is determined by the balance between the adhesive forces between the liquid and the solid surface, and the cohesive forces within the liquid. A liquid that spreads easily over a surface is said to have high wettability, while a liquid that beads up or does not spread well has low wettability. The wettability can be evaluated by the contact angle. That is to say, the wettability is recognized to be good when the contact angle is smaller than 90°. On the other hand, the wettability becomes bad when the contact angle is larger than 900. Paper wettability was studied by contact angle measurement and an absorption test was done in the laboratory.

To analyze the practicality and wettability of the liquid were tested. Orange juice was selected as a testing liquid sample as it contains more surface-active components such as sugars, acids, and proteins. These components adsorb at the interface between the orange juice and the surface, causing an increase in the interfacial tension and the contact angle.

5.4.1 Experiment 1

The paper cup was cut into a specific size stripe and the specific measure of the inner area (2×4 cm) was drawn by measurement ("Fig. 14"). The weight of the stripes was scaled before adding liquids. Two ml of each liquid was poured carefully into the area indicated for absorption. These strips with specific liquid were kept for 5, 10, 15, 30, and 50 minutes of contact time. After each time interval, the liquid in the strip was poured and shaken 3 times to remove the liquid and take its weight as strip+ absorbed liquid. All the strips were treated and measured similarly to reduce them. The absorption of liquid was calculated by the equation:

Absorbed liquid (mg) = (weight of strip+ absorbed liquid)- wt of strip only

The data were collected in the laboratory book and transferred to the Excel file. The data was collected as weight and converted for volume and analyzed the result. The experiment was conducted at room temperature with 3 replications.

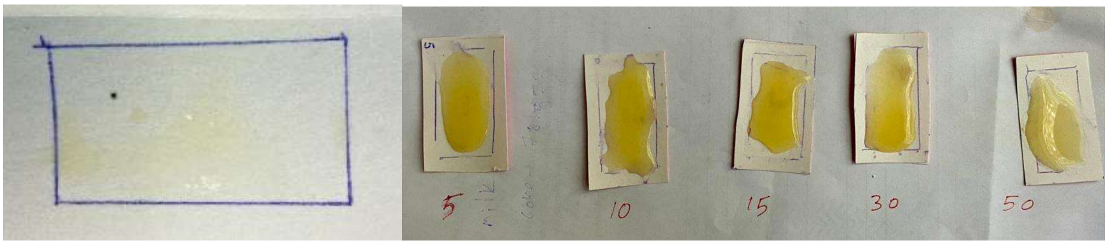


Figure 14: Cut paper stripes with the inner contact area measured.

5.4.2 Experiment 2

The membrane prepared at our laboratory was measured and cut into specific sizes (3×5 cm) stripes. Took the weight of the stripes before pouring water and orange juice as a liquid sample. 1 ml of each liquid was added carefully. The added liquid was removed carefully at the specific contact time i.e., 0.45 min, 1 min, and 5 min and the weight of the strips was noted. ("Fig. 15"). Data were collected in the laboratory book, transferred to the Excel file, and analyzed to interpret the result. The experiment was conducted with 2 replications at room temperature.

Figure 15: Membrane 9-sample, Wettability test with orange juice, (0.75 min,1 min,5 min).

6 Results and analysis

6.1 Contact angle

Contact angles of different liquids to different materials were measured as described in the method section. Although there is a rule of thumb about contact angle and hydrophobicity, several other factors such as temperature, pH, and contact time might affect the hydrophobicity. In our study, contact angle and hydrophobicity did not correspond as expected.

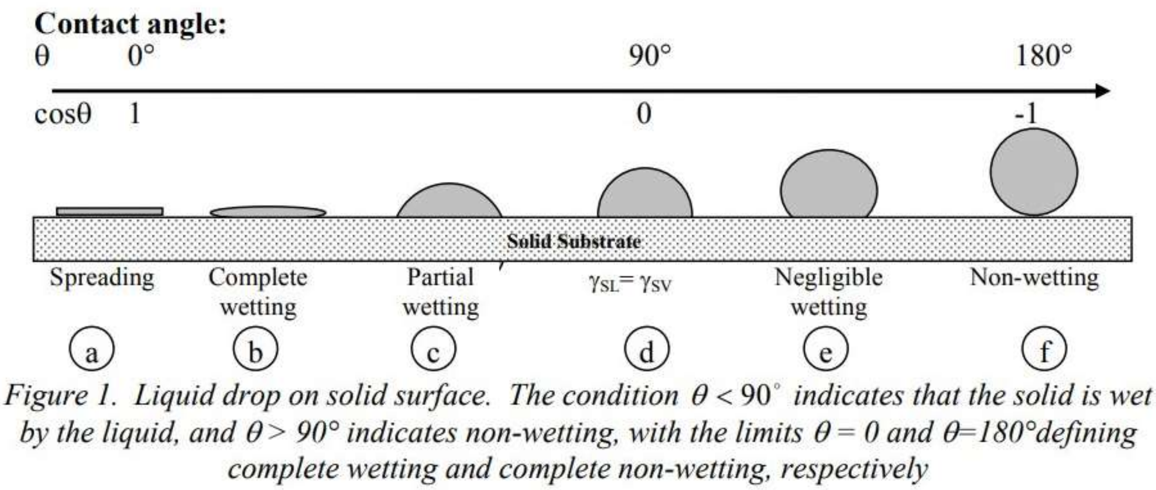


Figure 16. Liquid drop on the solid surface. (Njobuenwu et al. 2007)

Paper cup

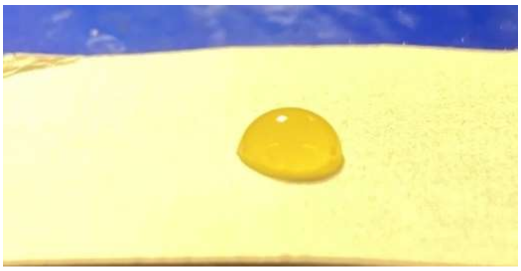


Figure 17: orange juice in paper cup stripes

Figure 18. water in paper cup stripes

The contact angle of orange juice in paper cup stripes was 83.15° and the contact angle of water drop was 71.864° (table 1). The pH value of orange juice was 3.5 and the pH of water was 6.5. The temperature of the juice and water was room temperature. Both liquid samples had a contact angle of less than 90°. That shows paper cup does not have a very good hydrophobic coated material. Orange juice showed a more contact angle than water because it contains more surface-active components such as sugars, acids, and proteins.

These components tend to adsorb at the interface between the orange juice and the surface, causing an increase in the interfacial tension and the contact angle. Additionally, the presence of pulp and other particulate matter in orange juice can also contribute to an increase in the contact angle.

Paper plate

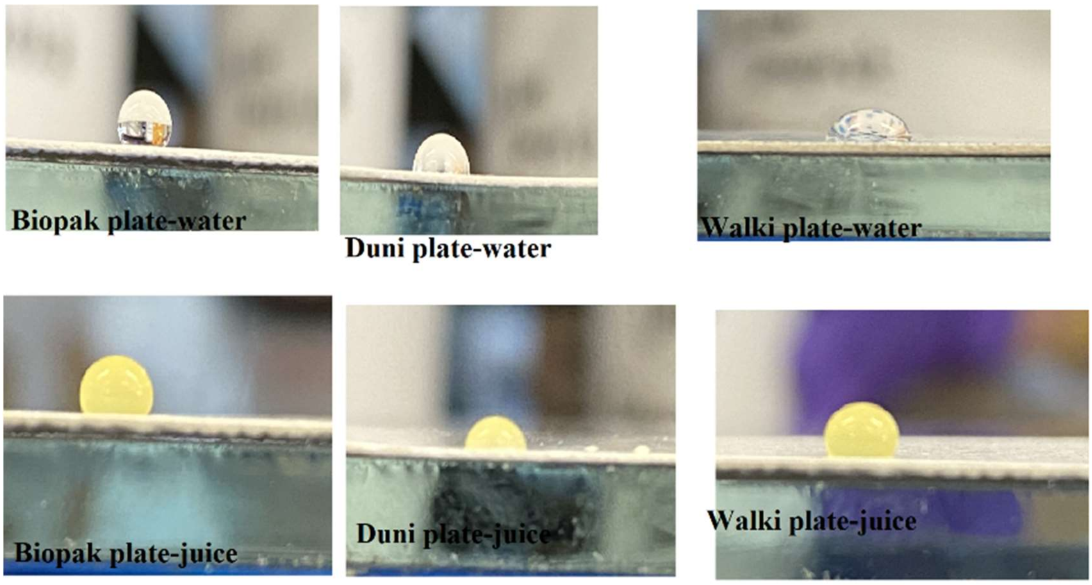


Figure19. Contact angle calculated with water sample in the paper plate.

Three different paper plates were tested for measurement of Contact angle (“Fig. 19”). Two paper plates (BioPak and Duni) were purchased from the shop and the Walki plate was sent by a company called Walki Group for Biodegradability which was done in the same lab. As shown in Table 1, the contact angle of water was 99^{o} in the BioPak plate, 78^{o} in the Duni plate, and 93^{o} in the Walki plate. The contact angle for orange juice in the Biopak plate was 104^{o}, it was 85^{o} in the Duni plate, and 106^{o} in the Walki plate. Biopak paper plate has the highest contact angle among all three paper plates. The walki plate’s contact angle was not as expected because it was told that it was a superhydrophobic coated plate, but it did not show the superhydrophobic characteristic based on the contact angle measurement. There could be several reasons why the contact angle is less even if the plate is superhydrophobic coated, for example, if the surface of the plate was contaminated with dust, oils, or other substances, it can reduce the contact angle. This can happen over time due to exposure to the environment, or during handling and storage. Superhydrophobic coatings also rely on a combination of surface roughness and low surface energy to repel water. So, if the roughness is not uniform, it can reduce the contact angle.

The quality of the superhydrophobic coating can also affect the contact angle. If the coating was not applied evenly or if there were defects in the coating, it can reduce the contact angle. Superhydrophobic coatings can degrade over time due to exposure to UV light, chemicals, or other factors. This can also reduce the contact angle and make the surface less water-repellent. This could be the reason why the contact angle of Walki paper was not more than 150º to be superhydrophobic.

Membrane

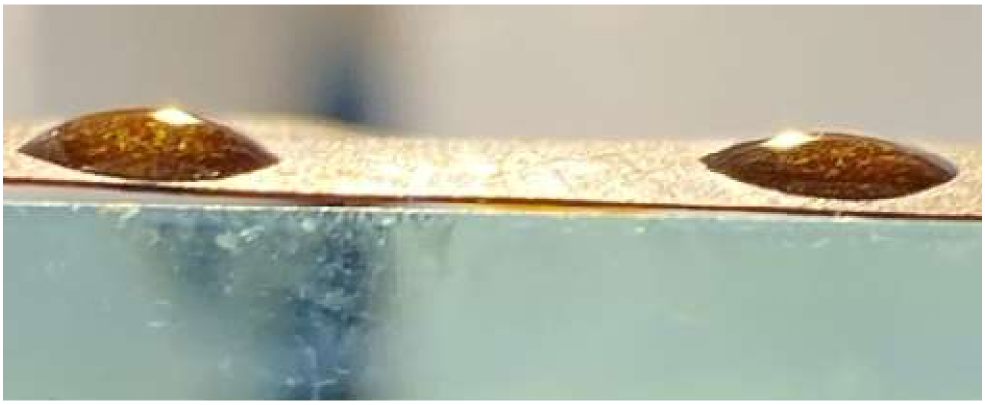
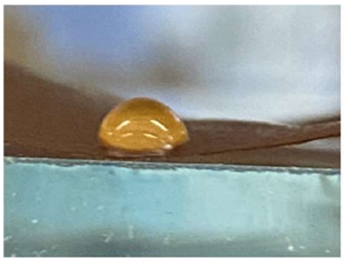


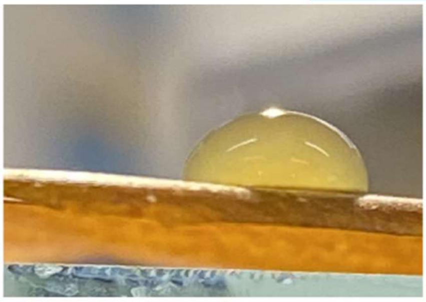
Figure 20: sample -olive oil.

Figure. 21: water drops in Teflon with bees-waxes-prayed.



membrane without beeswax spray

mebrane beeswax sprayed



membrane with beewax sprayed- juice

Figure 22. contact angle measurement in Membrane (beeswax sprayed, without sprayed).

The measurement of the contact angle of samples (Membrane 2) without beeswax sprayed is given in Table 2. The contact angle of the beeswax sprayed Membrane was between 95^{o} to 97^{o} (table 2) in our study. Wang et al (2020) found a contact angle of water 153^{o} which is significantly higher than our contact angle result which might be because we had used commercially bought Pectin. So the composition of the pectin might be different. Another reason can be the inappropriate concentration of the prepared beeswax spray used in our study.

In the membrane where beeswax was not sprayed, the Contact angle is lesser than in the membrane which had beeswax sprayed. Membrane with beeswax sprayed were more than 90^{o}, which shows the membrane is hydrophobic ("Fig. 22").

Table 1. The contact angle of different liquids in paper cups and plates.

Sample	Contact angle	pH
Paper cup		
Orange juice	83.2	3.5
Water	72	6.5
Olive Oil	48	
Milk	73.2	
Coke (zero sugar)	79	
Walki plate	Contact angle	
Water	93	

Orange juice	106.3	
Biopak plate		
Water	99	
Orange juice	104.2	
Duni 10 plate		
Water	78.2	
Orange juice	85.4	

Table 2 Contact angle of water in membrane prepared from tomato peel.

Membrane 2 (without beeswax spray)	73
Membrane 8 (without beeswax spay)	81
membrane 9 with Beeswax sprayed	97
Membrane 6 with a beeswax spray	95
Beeswax sprayed in Teflon	101.3
Teflon without beeswax spray	94.1

6.2 Result of Wettability

When we did an absorption test in a membrane that was not sprayed with beeswax for 1 min, 5 min, and 10 min, the membrane started to crumble already in the 1 min test. In 5 min, the membrane was already wet, soft and stuck in the tray ("Fig. 23"). The membrane did not have a hydrophobic coating, so it is likely to be hydrophilic. This means that the membrane is attracted to water and other polar molecules, rather than repelling them. As a result, the membrane absorbed water easily. The absence of a hydrophobic coating means that the membrane is not designed to repel water and may not be suitable for applications where water absorption is undesirable.

There is no standard method to conduct a wettability study. We tried several methods like dipping the sample paper in liquid and floating the paper cup and plate strip in liquid. Deeping the strip was not a good idea since the inner coating and outer coating were different. Eventually, we used a strip of cup and plate and pour liquid into a specific area. We found this method is more reliable so this method can be used to study wettability in the future.

Figure 23. Wettability test in the membrane without beeswax sprayed with water for 1 min, 5 min, and 10 min respectively.

6.3 Result of juice absorbed by the cup

Although the experiment for the juice absorption by cups was done using a small strip, the result was calculated and presented for a whole cup. The contact angle result showed that the used paper cup was not hydrophobic, and the absorption result also validate this result. Although some results were not clear overall result showed that the juice absorption increased with increasing contact time. The juice absorption was lower in contact times at 15 and 30 minutes but it was increased with the time and high at 60 minutes of contact time. Figure 24 showed that contact time of 5 to 10 minutes is increasing but 15 minutes contact time showed less contact time this might be because of evaporation. But contact times 15 minutes to 60 minutes again follow a similar trend i.e., increasing the absorption with increasing contact time. A cup absorbed more juice over time because the liquid can penetrate the surface of the cup and fill the empty spaces within the material. As more time passed, the liquid continued to be drawn into the cup, filling up more and more of the available space. As the cup was not hydrophobic coated (Table 1), that means the cup was made of a hydrophilic material which will absorb even more liquid due to its attraction to water molecules. The linear line showed that juice absorption is increasing overall.

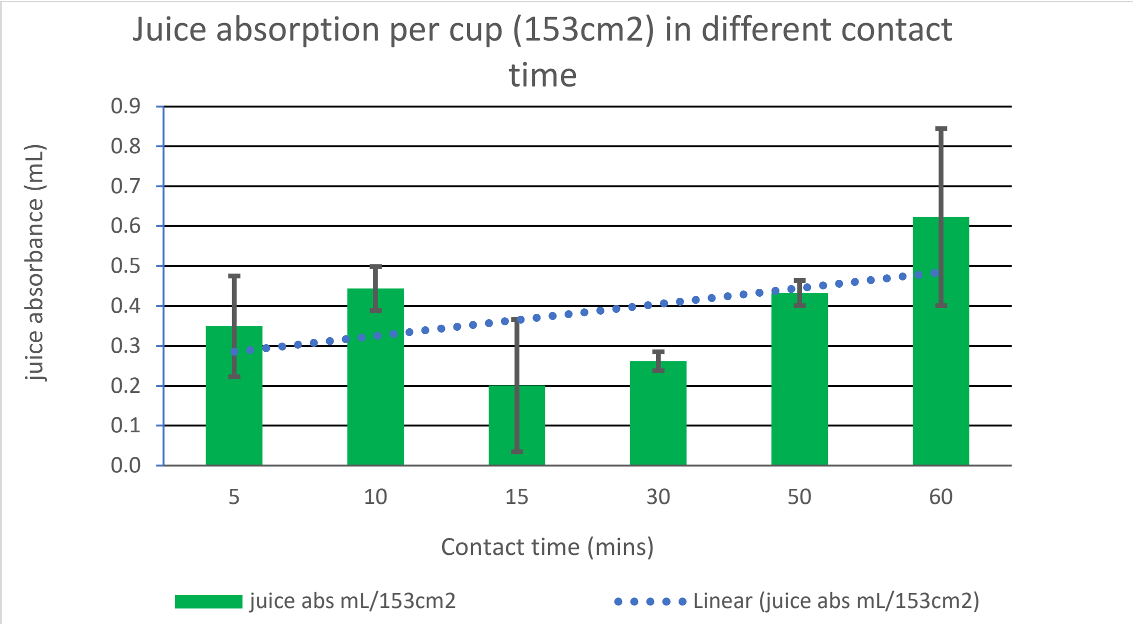


Figure 24. Juice absorption by a paper cup.

6.4 Result of Juice absorbed by paper plate

The contact angle result showed that the tested paper plate was hydrophobic. Although the plate showed hydrophobic it still absorbs the juice. The juice absorption was increasing with increasing contact time. The absorption of some juice in this plate might be due to the porosity of the plate. Higher temperatures and longer contact times could have reduced the effectiveness of the coating. Additionally, it can be because of the liquid surface tensions. However, the absorption increasing pattern with contact time was not very high.

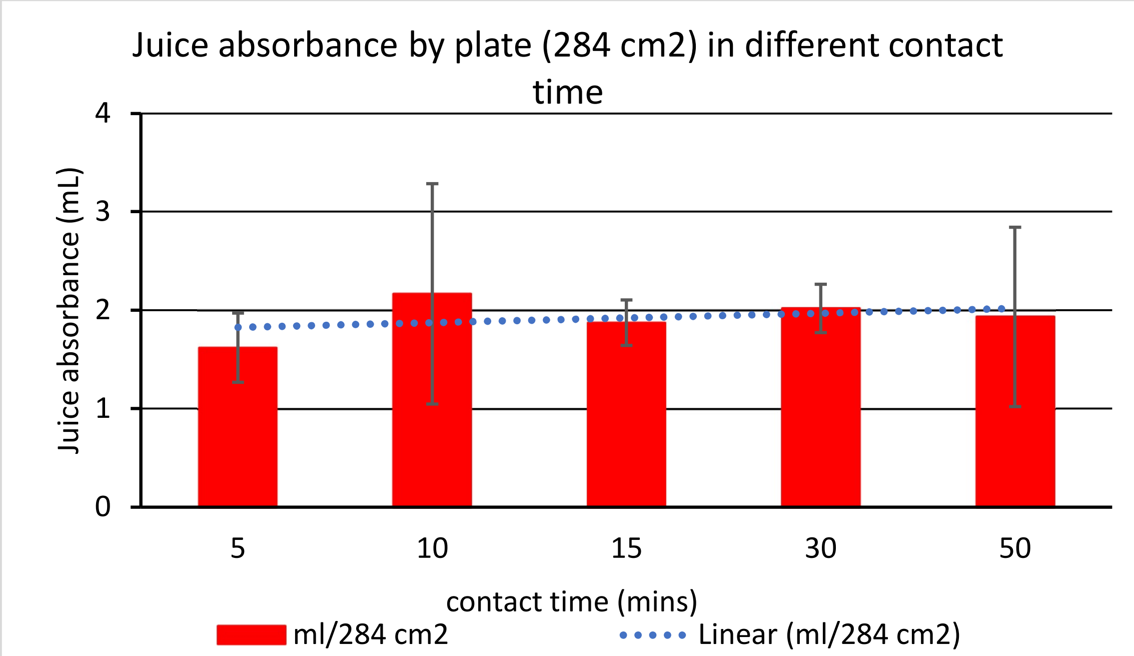


Figure 25. Juice absorption by a paper plate.

6.5 Result of water absorbed by a prepared hydrophobic membrane.

The contact angle showed that the prepared membrane is hydrophobic. Surprisingly, the membrane absorbed a significant amount of water ("Fig. 26"). After It may be due to the not well-processed membrane. while mixing with Pectin, there were a significant amount of air bubbles. The air bubbles in the mixture could have affected the texture and consistency of the membrane. It could be the reason for uneven surfaces. It was also found to be more porous when looked at under the magnification glass. A small part of the membrane melted in water, it is likely the material may have been too thin in some parts as the membrane was uneven and not properly treated to withstand exposure to water. Also, the temperature of the water may have been high, causing the membrane to melt. The membrane was solubilized in water and increased its solubility with an increasing contact time. The surface area of the membrane was not smooth which may have also affected the result of contact angle measurement. The hydrophobic coating on the membrane was not uniform and there may be some defects in the coating, so it may not be able to effectively repel water, leading to water absorption. Also, It was possible that the concentration of beeswax in the spray was too low and the temperature and humidity levels in the environment may have affected the effectiveness of the beeswax spray. It is also possible that the membrane material itself was not suitable.

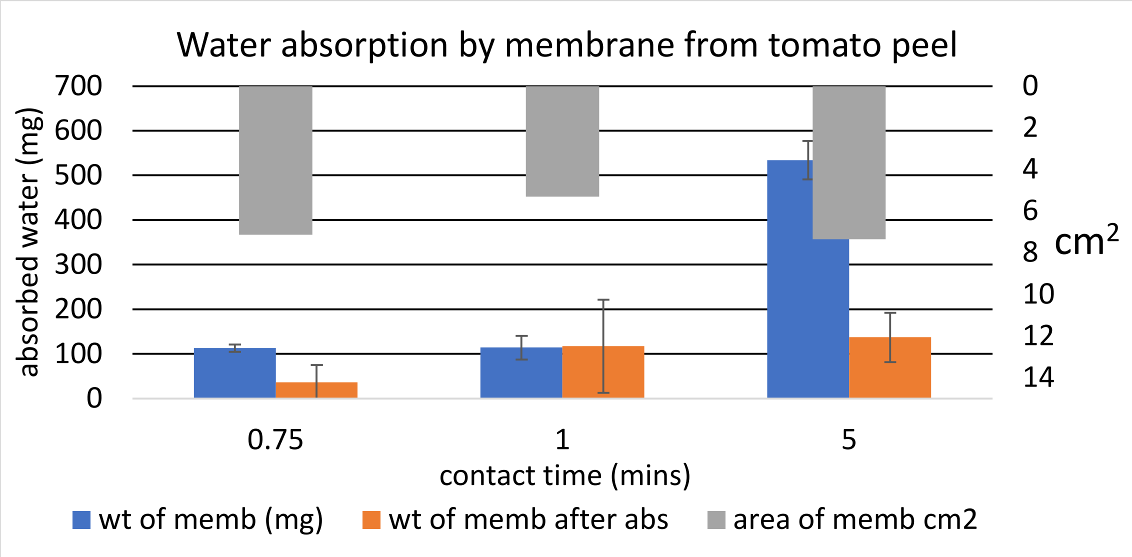


Figure 26. Water absorption by the membrane.

6.6 Comparison of absorption between plate and cup

Even though the plate was hydrophobic since its contact angle was more, it absorbed more liquid than the cup ("Fig. 27"). Besides the hydrophobicity, the surface might be different pore sizes, surface tension, etc in the cup and plate which might have affected the wettability.

Contact angle measurement clearly showed that the studied cups and plates are not superhydrophobic. The wettability study also showed that these plates and cups are not superhydrophobic since they absorb a certain amount of juice on their surface ("Fig. 27"). Although it is not clear why juice absorption is higher at 5 and 10 minutes of contact time, absorption is increasing with time in all figures.

Superhydrophobic cups and plates reduce food waste but there is several constrain to producing commercial superhydrophobic paper cups and plate such as it will be expensive, and it will not be as effective as superhydrophobic coated in other materials. Superhydrophobic coating in paper plates and cups is a little complicated due to the need for high temperatures. Although the plate had high contact angle compared to the paper cup still the absorption was higher in the paper plate this might be due to the surface area of the paper plate similar result is presented by Sadeghinezhad et al (2020).

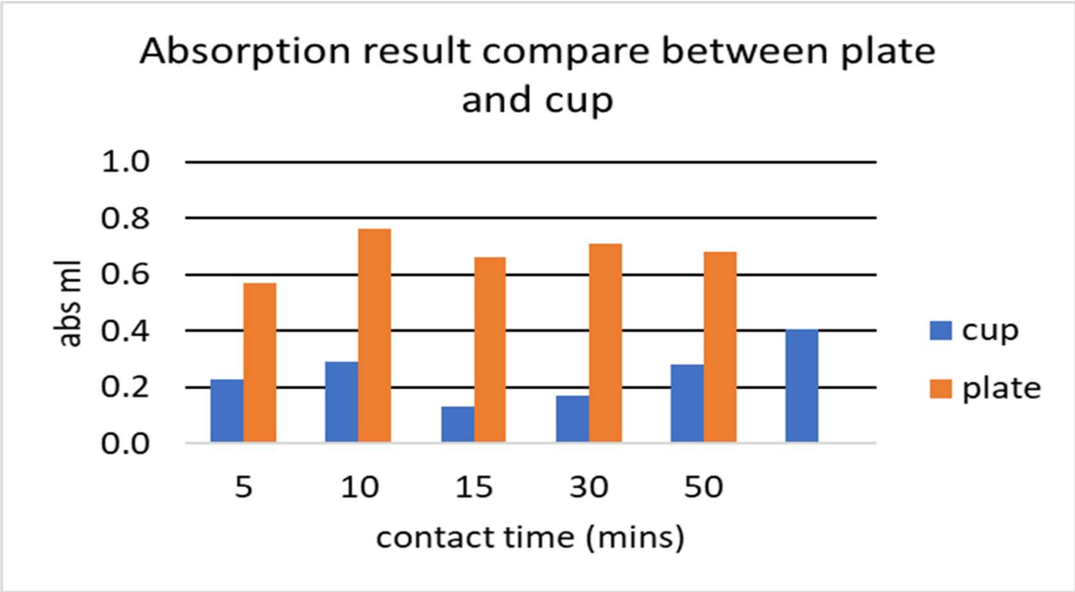


Figure 27. Absorption result compares between plate and cup.

7 Conclusion

Hydrophobic coating cups can play an important role in improving food security and reducing environmental impact by preventing spills and leaks and minimizing waste. The hydrophobic coating repels liquids, making it easier to transport and store food without the risk of spills. This also helps to reduce the amount of waste generated and minimize the environmental impact of food production and distribution.

Our experiment showed that different paper-based cups and plates have different hydrophobic characteristics. The cup was not hydrophobic, but the used plate was hydrophobic based on the contact angle analysis. Cup absorbed less juice compared to the plate. In both, plate and cup, absorption of used beverages was increased with contact time. Of course, both paper cups and paper plates were somehow hydrophobic which anyway saves the food compared to not coated paper cups and plates. However, paper-based cups and plates are environmentally friendly compared to plastics so the use of paper-based table utensils will be good for the environment. The superhydrophobic coating might be expensive but it will reduce food waste and improve food security.

Since contact angle measurement is the best procedure to understand the hydrophobicity of the materials and we also measure the contact angle of the different study materials. The wettability study in a small strap showed a good result but a larger strap or use of a whole cup or plate and a large amount of liquid might reduce the error and resemble the real-life experiment. Furthermore, we tested only orange juice for the wettability study but replicating this study using other liquids such as milk, and coffee would have given us a better understanding of the wettability of the study cup and plates. We successfully produced a membrane from tomato peel in our laboratory. This membrane was sprayed with beeswax to make it hydrophobic. It turned into a hydrophobic membrane, but it dissolved in water very quickly. These membranes sprayed with and without Beeswax were dissolved within 15 mins in seawater and biodegraded within 3 days. (Biodegradation output from Sapana Thesis). Perhaps, we needed more practice to produce a high-quality thin and smooth membrane. In addition, we could have used other spray to make the membrane better hydrophobic.

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