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作品編號　**200004**

參展科別　**環境工程**

作品名稱　**Process of making a new environmental friendly straw**

得獎獎項　**大會獎：二等獎**

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關鍵詞　**straw、seaweed gel、black tea straw**

作者簡介

當初我們為了想解決塑膠吸管對海洋生態環境造成的衝擊與因應政府的限塑計畫當作目標，才提出可以研發環保的新型吸管；我們從零開始，沒有參考的數據與文獻，大家不斷的腦力激盪提出想法，經過不斷的實驗、數據分析、討論修正與研發成型機器來來回回耗費將近快 1 年的時間，儘管途中有許多失敗不如意，我們都會把失敗當作養分，為成功的路上多加點色彩，最後希望我們的作品能在更大的舞臺展覽，成為眾所皆知的新型吸管。

摘要

本研究首先製作「蔬菜紙吸管」，其耐水性及吸飲功能不佳，改以海藻膠製作吸管，經歷多次改良後的「第三代海藻膠吸管」其質地近似塑膠吸管，但吸飲功能仍然不佳。接著，以海藻膠為膠著劑；紅茶粉為骨材，成功製作出耐水性、吸飲功能較佳且可散發紅茶香氣的「紅茶吸管」。提高添加紅茶粉之比例，能有效提升吸管硬度，可應用在飲料封口膜之戳入，在冰水、熱水中均可長時間維持吸飲功能，製作大口徑「紅茶吸管」，可輕易吸飲波霸珍珠，徹底解決吸飲波霸珍珠之難題。自製擠出成型機械，可控制出料速度維持穩定，在滑軌上以直線移動，可製作出粗細一致且筆直的吸管，最後試製綠茶、咖啡、檸檬等調味吸管，均會飄出天然原料之香氣，頗具商品化之潛力。

Abstract

Our research started by making “vegetable fiber straw”, but since the straw was not waterproof and with less strong structure, so we tried again with seaweed gel. After multiple trials and improvements, the texture of our “Seaweed Gel Straw Gen.3” had become similar to that of plastic straws. Unfortunately, the structure wasn’t strong enough as expected. Therefore, we used seaweed gel as the cementing material and black tea leaf powder as the aggregate. With these materials, we came up with the “black tea straw”, which has stronger structure with a bit of black tea fragrance. Increasing the percentage of the tea leaf powder can increase the hardness of the straw, so the straw can penetrate the films covered on the drinks. The straw can even maintain its structure for a long period of time，regardless of the conditions, dry, wet, cold or hot. Increasing the diameter of the straw allows users to drink larger objects such as Bubble tea, and solves the problem of consuming any kinds of drinks. We have made an auto shaping machine that can control the speed of (compressing the gel mixture into the forming bath,) and can produce perfectly straight straws with the same diameter. We also tried to make the straw with green tea, coffee, lemon and some other materials, so the straw would have natural fragrance. This would make it easier for our product with potential to be launched into the market.

1 Research motivation and purpose

1.1 Motivation

1.1.1 Sea turtles and straws [1]

The science team of Texas A&M University posted a shocking video on the Internet when they traveled to Costa Rica to study Ridley sea turtles. While examining one male turtle, they found a long plastic straw stuck in the turtle's nostril. After several trials, they finally succeeded in pulling out the straw, but by then the turtle had started to bleed painfully. The video, with over 5.5 million reviews, made the world rethink about the problem of plastic garbage.

1.1.2 Plastic straws [4] [5] [7] [9] [12]

These years, the world has started to face the problem of plastic pollution in oceans. On June 8th, 2018, the **Environmental Protection Administration (*EPA*)** of Taiwan announced a draft banning the use of plastic straw, which is in reference to how western cities bar the use of plastic straws. The law indicates no more plastic straw should be made available to customers in public sectors, including schools, department stores, malls and fast food chains. Now, the EPA even plans to expand the law to other food businesses in 2020. However, this draft raises a concern on how inconvenient it is for customers to take handmade drinks, like "Bubble tea", with the EPA simply urging people to drink it with spoons. So, how do we resolve this problem?

1.2 Purpose

- This research is plastic free, aiming at inventing straws that are ecologically-friendly, meaning it can be recyclable.
- Making straws with creative ways.
- Inventing straws with practical values that are applicable to any kinds of drinks.

2 Research process and methods

2.1 Literature review

2.1.1 Straws [5] [8]

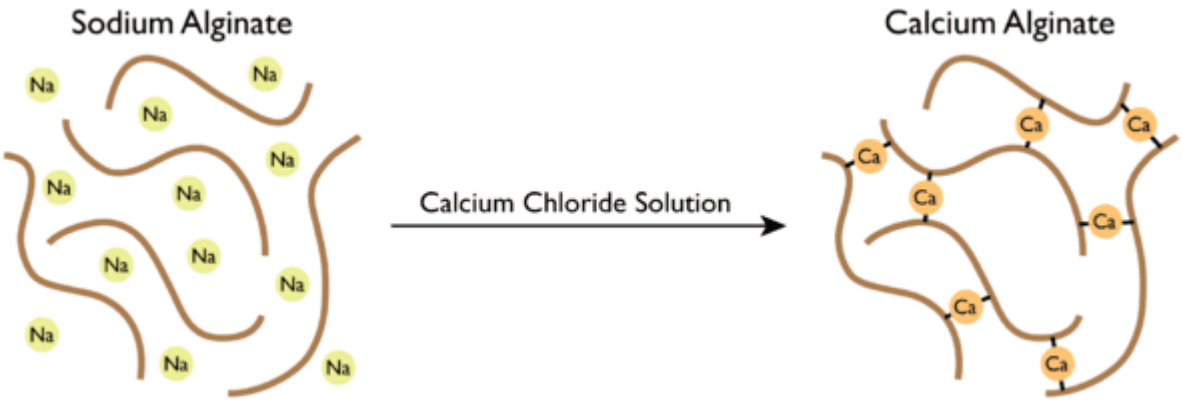
Materials of current market straws: plastic, paper, stainless steel, glass, silicon, sugar cane, bamboo and flavored straws, etc. Below display the pros and cons of the various types of straws:

Types of straws	*Pros*	*Cons*
Plastic	Easy for processing, inexpensive, high practicality	poor heat resistance, harmful to the environment
Paper	Slightly more eco-friendly, one-time use	poor heat resistance and persistence
Stainless steel	Heat resistant, reusable, shockproof	Hard to clean, dangerous to kids
Glass	Acid- proof, heat resistant, easy to check the cleanness inside	Fragile, dangerous to kids
Silicon	Soft, safe for kids	Hard to clean, can't penetrate the cover film on cups.
Sugar cane	Polylactide are fully breakable by the environment, faster at better soil conditions	Weak against heat, polylactide are harder to be broken down, compared with other green-plastics
Bamboo	Natural, easy to be decomposed	Left over smell, hard to clean, easy to get moldy.
Flavored	Flavorful straws give fresh feeling about the drinks	Still made by plastic

2.1.2 Sodium Alginate [10] [11] [13]

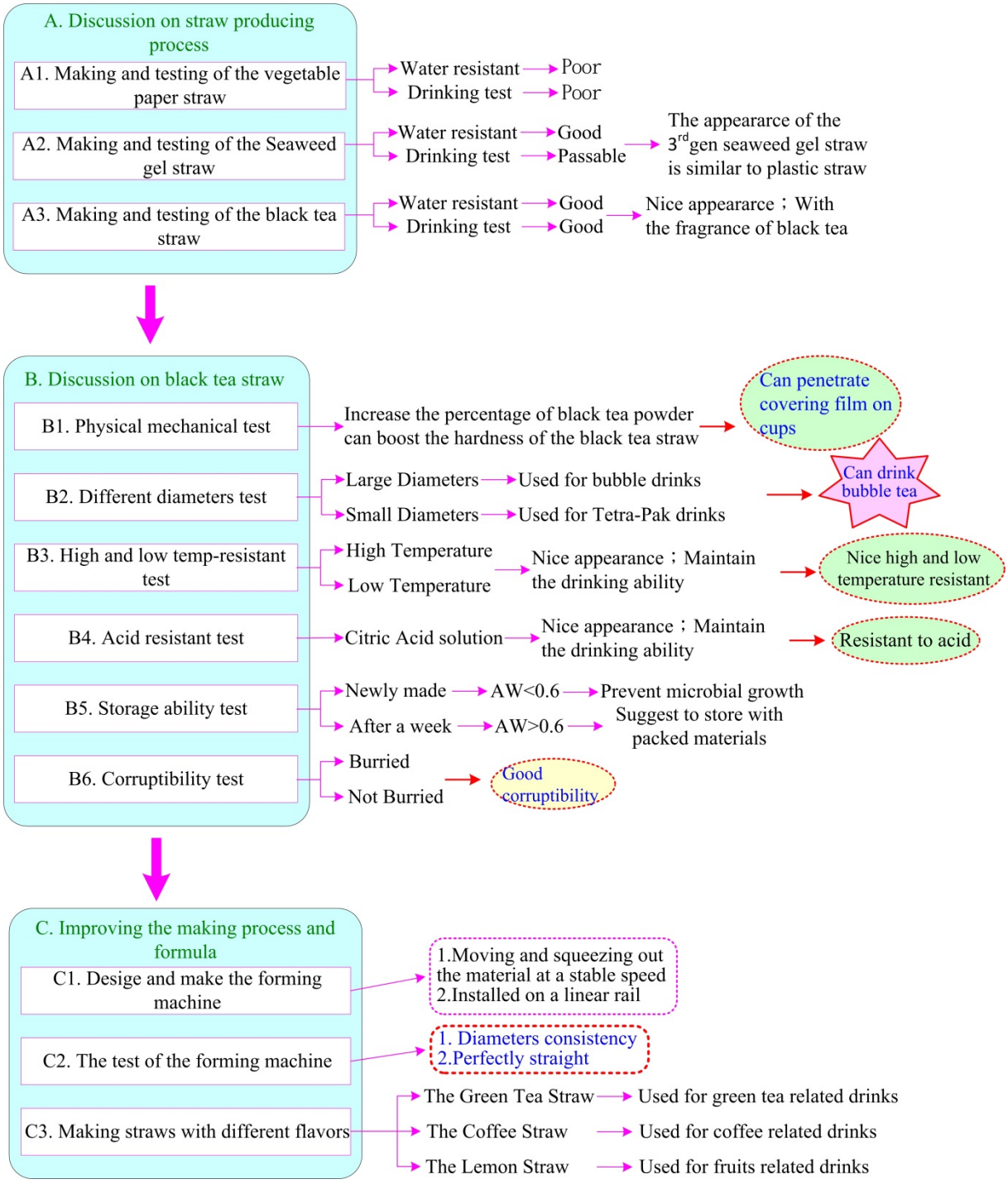
Sodium Alginate is linear polysaccharide containing β-(1→4)-linked D-mannuronic acid and α-(1→4)- inked L-guluronic acid. Its viscous aqueous solution will lower the viscosity by slowly decomposing under long-term storage, which is most stable at pH 6-9.

The gel principle of sodium alginate requires divalent cations, among which calcium ion is the most frequently used. Calcium ion bonds with the oxygen atoms of nearby molecules, forming a three-dimensional colloidal network structure, which is the so-called “egg-box model.” When sodium alginate aqueous solution is added into calcium chloride aqueous solution, the calcium ions will replace the sodium ions, performing cross-linking, thus turning into translucent gel. The gel principle of sodium alginate is shown in the following figure.



Gel principle of sodium alginate [13]

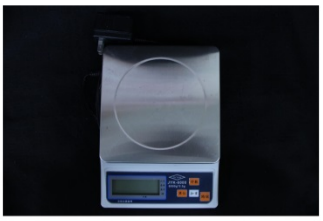
2.2 Architecture



2.3 Equipments and materials

2.3.1 Equipments

Thermometer
TES 1310-TYPE-K
(Taiwan)



Electronic Scale
Jin Yuan JYK-6000
(Taiwan)

Water Activitymeter
AquaLab AL1503
(USA)

Disintegrator
RT-02A
(Taiwan)

Juicer
Panasonic MX-V188
(Taiwan)

Homogenizer
SHIN KWANG MACHINER
HM-0025 (Taiwan)

DC Power Supply
GWLN STEKGPS-4303
(Taiwan)

Force Gauge
Lutron FG-5005
(Taiwan)

3-Axis CNC Milling Machine
SH-850
(Taiwan)

pH meter
430
(USA)

Dehumidifier
Panasonic F-Y12ES
(Taiwan)

Bread Fermentation Room
Jendan
(Taiwan)

Ovens
KC-900 Memmert
(Germany)

Freeze Dryer
FDU-1200
(China)

Vacuum Packaging Machine
FUSERJOY
(Taiwan)

2.3.2 Materials

Sodium alginate (Sin Long Foods Additive INC.)
Calcium chloride (CHONEYE)
Fresh cabbage
Coffee beans (Yeuan Yeou Enterprise Co., LTD)
Black tea leaf (Fu Lin Food Materials Firms)
Green tea leaf (Fu Lin Food Materials Firms)
Lemon

2.4 Methods

A. Discussion on straw producing process

【Experiment A1】Making and testing of the vegetable paper straw

Introduction：

The process of making the Eco-friendly paper straws is simple, simply by using a machine to roll the paper with tape, and cut into straws (*As shown on the right*). For our experiment, we used over-produced seasonal cabbage. For starters, we had to make vegetable paper, cut it into strips and roll into a vegetable paper straw. We had tested the straw on its level of water resistance and drinking ability and proved the practicality of the straw.

Process：

Ⅰ. Steps of making the vegetable paper straw

1. Clean the cabbage and blanch it for one minute, after blanching, beat it with a rolling pin and boil it in the water for 5 minutes and cool it down to room temperature. After cooling, cut the fibers into 2cm strips and blend it into cabbage juice with water.
2. Add 1% sticky rice powder solution into the cabbage juice. (*Ratio of sticky rice solution and fiber juice is 1 : 1000*)
3. Use a filter to extract fibers from the cabbage juice, then spread the fibers on the filter cloth and dry it for 24 hours to become a vegetable paper sheet.
4. First apply vegetable paper to seaweed gum, then apply calcium chloride solution. Dry it using a hairdryer and then iron out the vegetable paper to make it flat. After flattening it, we cut the papers into strips and spread another layer of sodium alginate and roll it around a stick. After drying, a vegetable paper straw is done!


Cabbage


Blanching


Blending


Draining


Vegetable paper


Rolling

Figure 1. Steps of making vegetable paper and vegetable paper straw.

Ⅱ. Test on the vegetable paper straw

(i) Water resistant test

1. Put the vegetable straw into the water and soak it for 24 hours.
2. After soaking for 24 hours, observe and take figures of its changes.

(ii) Drinking ability test

1. Put the vegetable straw into a cup with (eight cents) full of tea.
2. Drink the tea with the vegetable straw and observe the whole process by filming it.

Results：

Ⅰ. Steps of making the vegetable straw

1. Our experiment used over-produced cabbage as ingredient and followed the process of making papers, and successfully made the vegetable paper. (*As shown on figure 2-A*)
2. Cut, roll and dry the vegetable paper into straws, which resemble those purchased from the stores, but the structure and texture were still different. (*As shown on figure 2-B, 2-C*)


A. Vegetable paper


B. Vegetable paper straw

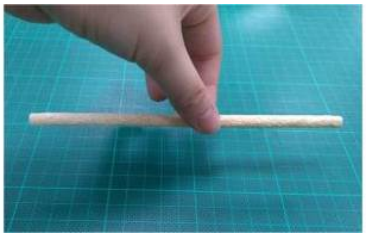

C. Handling the straw

Figure 2. Finished product of the vegetable paper and vegetable paper straw.

Ⅱ. Tests on the vegetable paper straw

(i) Water resistant test

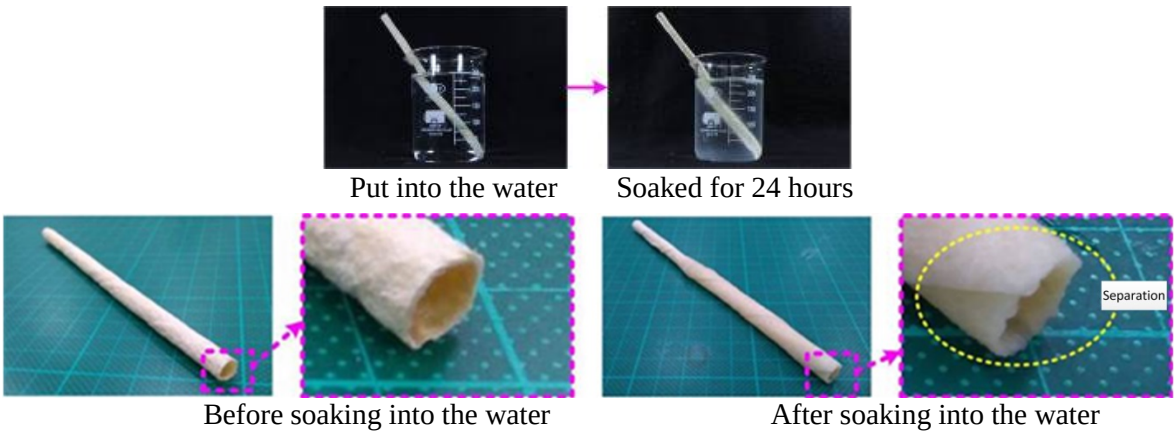


Figure 3. Water resistant test of the vegetable paper straw.

1. As figure 3 shows, the diameter of the straw stays the same when it was just put into the water. After 24 hours, the part soaking in the water had its diameter increased significantly.
2. As figure 3 shows. Before the soaking process, the straw had almost the same diameter through the whole straw. After soaking, the diameter of the straw became uneven. The part without contact stays its shape, but the part that had contact with water expanded and caused structural separation.

(ii) Drinking ability test

1. Multiple snap shots from the drinking test (*Figure 4*) revealed that the straw maintained the drinking ability at the beginning of the test.
2. After multiple uses, the straw slowly lost its drinking ability.

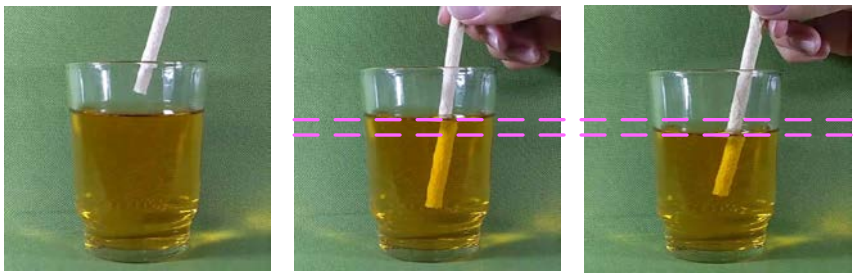


Figure 4. Drinking test of the vegetable straw.

Discussion：

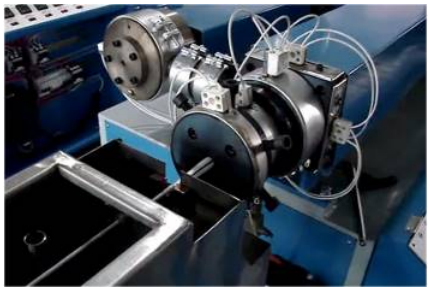
1. As shown in the experiment results, although our handmade vegetable paper straw looks like market paper straws, the texture and structure are not as good.
2. In our experiment, the strength of the vegetable paper isn't strong enough. In the rolling process, the paper broke easily, which we assumed was because the cabbages are edible vegetables, so the fibers are soft.
3. As shown on the water-resistant test, our vegetable paper straw isn't quite good enough. We

speculated that the reason might be that vegetable paper only rely on a thin layer of edible seaweed glue as adhesive between vegetable paper, its sticky strength is obviously not enough to cope with prolonged immersion in the water.

4. As shown in the drink test, after multiple usages, the part that has contact with the mouth absorbed saliva and therefore softened, the pipe wall of the straw shrank and folded because of the pressure, and the straw slowly lost its drinking ability.
5. As the goal was to invent an edible and eco-friendly straw, we didn't use any stronger chemical adhesive. Therefore, we must think out of the box and find new ways to make the straws.

【Experiment A2】Making and testing of the seaweed gel straw

Introduction：



The steps of making plastic straws started by melting the plastic grains, molding it through injection tool, and then cut it into straws after cooling down. (*As shown on right figure*)

In our experiment, we designed a brand-new molding machine to make our straws. Inspired by "Spheres" in molecular cuisines, (*As shown on figure 5*) instead of making them into drops, we molded the seaweed gel into a long tube, which is a new way to mold a straw. (*As shown on figure 6*)

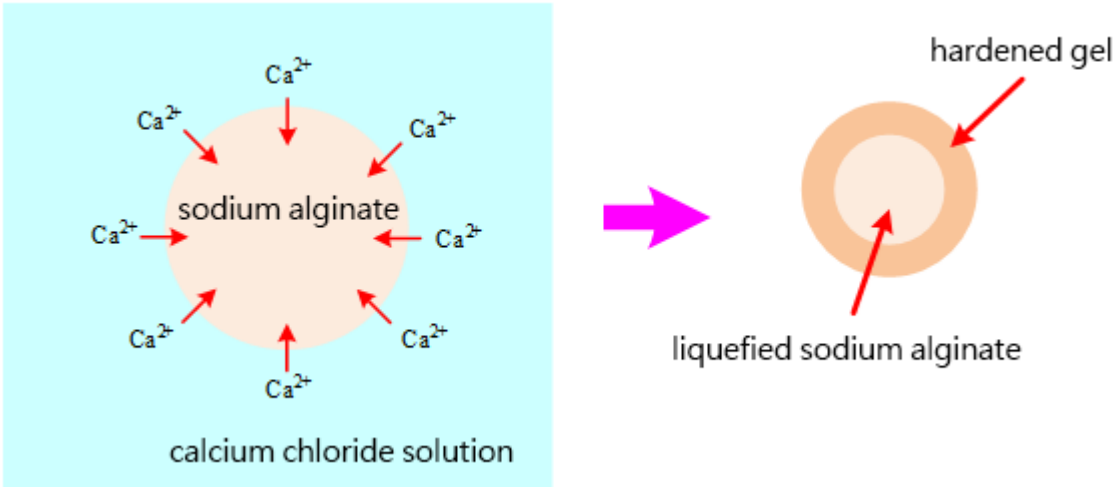


Figure 5. The theory of making seaweed gel "Spheres".

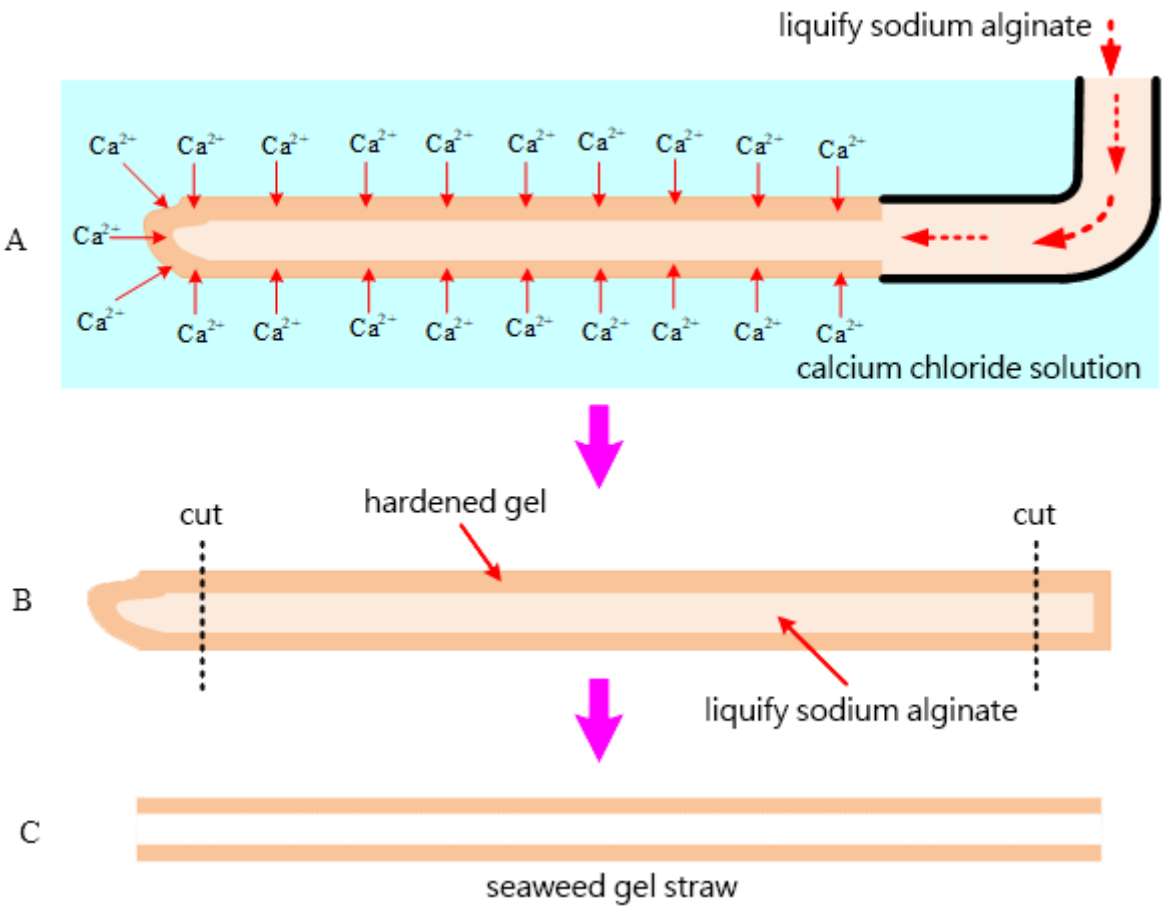


Figure 6. Theory of forming the seaweed gel straw.

Process：

Ⅰ. Making the conditions for forming

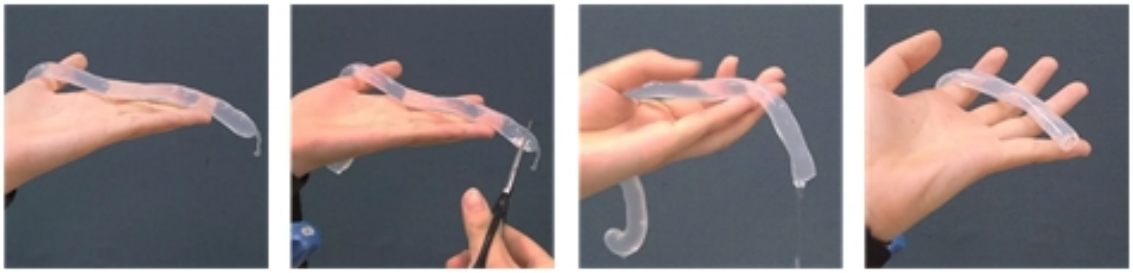
1. **Independent variables:** The time of soaking seaweed gel into calcium chloride solution.
2. Make 200ml of 2% sodium alginate solution and 1000ml of 10% calcium chloride solution.
3. Use a syringe to contain the sodium alginate solution and squeeze it with tube shape in the calcium chloride solution.
4. Change the independent variables of the experiment. Soak the tube-shaped seaweed gel in the calcium chloride solution.
5. Take the tube-shaped seaweed gel out of the solution, cut off the end and the front, and then clean it with water. After drying, make the seaweed gel straw hollow.
6. Cut the straws into 0.5cm long, take figures, observe, measure and record the thickness of the cross-cut pipe wall.
7. We used Excel to organize the experimental data, and SigmaPlot tool to plot and perform linear regression, creating a graph of the thickness of the straw as a function of time spent in calcium chloride solution.

Ⅱ. Steps of making the seaweed gel straw

Making the seaweed gel straws wasn't as easy as we thought, we had remade our product two times and came up with the best way to make the seaweed gel straws.

(i) 1st generation

1. Make 200ml of 2% sodium alginate solution and 1000ml of 10% calcium chloride solution.
2. Use a syringe to suck up the sodium alginate solution and squeeze it in the calcium chloride solution.
3. After 25mins, take the formed gel out of the solution, cut off the end and the front, and clean it with water. After drying, we then made the seaweed gel straw hollow.
4. This is 1st gen seaweed gel straw. We observed it and tested it.



(ii) 2nd generation

1. First, make the 1st gen seaweed gel straw, then hang the straw in a dryer. (*There is no supporting material inside of the hallow)*
2. After 24hrs of drying, the 2nd gen of seaweed gel straw was made, which was then observed and tested.

(iii) 3rd generation

1. First, make the 1st gen seaweed gel straw. But this time, we used a Teflon tube to support the straw before putting it in the dryer.
2. After 24hrs of drying, the 3rd gen seaweed gel straw is made, which was then observed and tested.

III. **Tests on the seaweed gel straw**

(i) Water resistant test

1. Put the 3rd gen seaweed gel straw into water and soak it for 24hrs.
2. After 24hrs of soaking, take some figures and observe its changes.

(ii) Drinking ability test

1. Put the 3rd gen seaweed gel straw into a cup with eight cents full of tea.
2. Drink the tea with the 3rd gen seaweed gel straw and observe the whole process by filming it.

Results：

Ⅰ. Making the condition for forming

1. As shown in **Figure 7, 8, Table 1**. The longer time the seaweed gel is in the calcium chloride solution, the thicker the pipe wall will be.
2. The thickness of the pipe wall and the time in calcium chloride solution are in a linear relationship. Use SigmaPlot tool for linear regression, we get the equation:

$$y = 0.0849x+0.9685 \text{，}(R^2=0.9940)$$

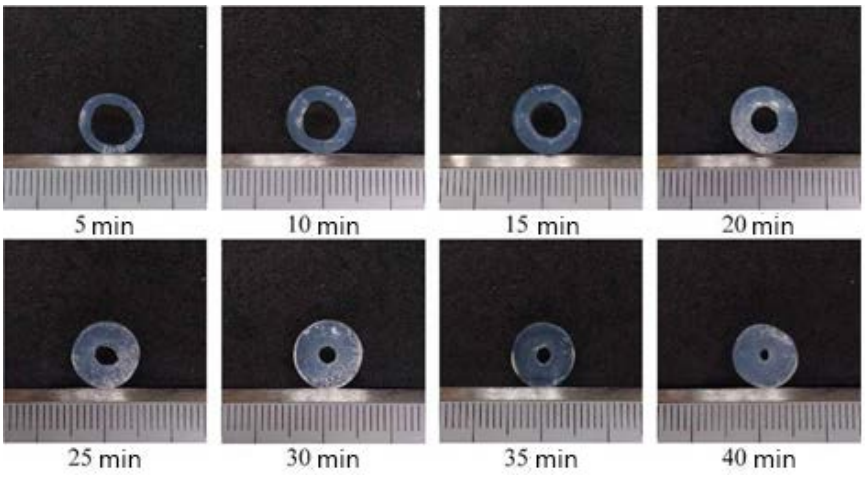


Figure 7. Time in calcium chloride solution effecting the thickness of the pipe wall

Table 1. Time in calcium chloride solution effecting the thickness of the pipe wall

Soaking time(min)	Thickness (mm)				
	Test 1	Test 2	Test 3	Avg	SD
5	1.25	1.30	1.40	1.32	0.08
10	1.60	1.80	1.90	1.77	0.15
15	2.20	2.30	2.40	2.30	0.10
20	2.55	2.70	2.85	2.70	0.15
25	3.25	3.10	3.40	3.25	0.15
30	3.40	3.60	3.50	3.50	0.10
35	3.85	4.00	3.90	3.92	0.08
40	4.40	4.15	4.30	4.28	0.13

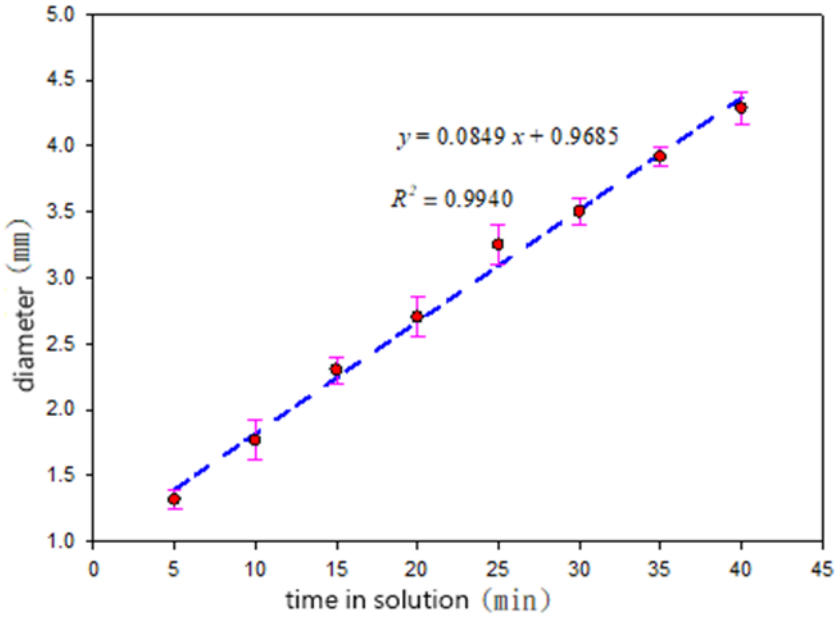
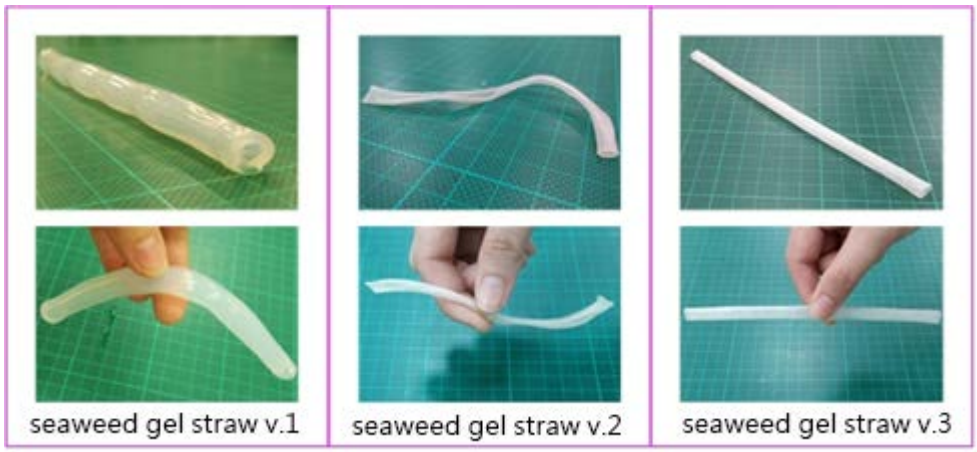


Figure 8. Time in calcium chloride solution effecting the thickness of the pipe wall

Ⅱ. Steps of making the seaweed gel straw



1st *2nd* *3rd*

Figure 9. 1st, 2nd, 3rd gens of seaweed gel straw

1. As figure 9-*1st* showed, the 1st gen seaweed gel straw had the same thickness through the whole straw, but since the straw contained a lot of water, the texture was soft and hanged down naturally while holding it up by hand.
2. As figure 9-*2nd* showed, after 24hrs of drying, the 2nd gen seaweed gel straw shrunk and curved into a uneven tube. The straw didn't contain too much water, the texture was harder, and it would not hang down when held up.
3. As figure 9-*3rd* showed, after drying, the 3rd gen seaweed gel straw (*with support*) had the same thickness through the whole straw with a perfect straight tube shape. The 3rd gen seaweed gel straw had low water content, the wall were strong and would not hang down when held up.

III. Tests on the seaweed gel straw

(i) Water resistant test

1. As shown on figure 10, when we put the straw in a cup of water, the thickness stayed the same. After 24hrs, the part soaking in the water slightly increased its thickness.
2. As shown on figure 10, before soaking it in water, the straw had the same diameter from top to the bottom, the nozzle of the straw stays the same, the transparency is low, and the straw is hard. After soaking for 24hrs, the part contacting with water had slightly increased its diameter, the nozzle of the straw stays the same, and the straw became transparent and soaking in water made the straw soften a lot.

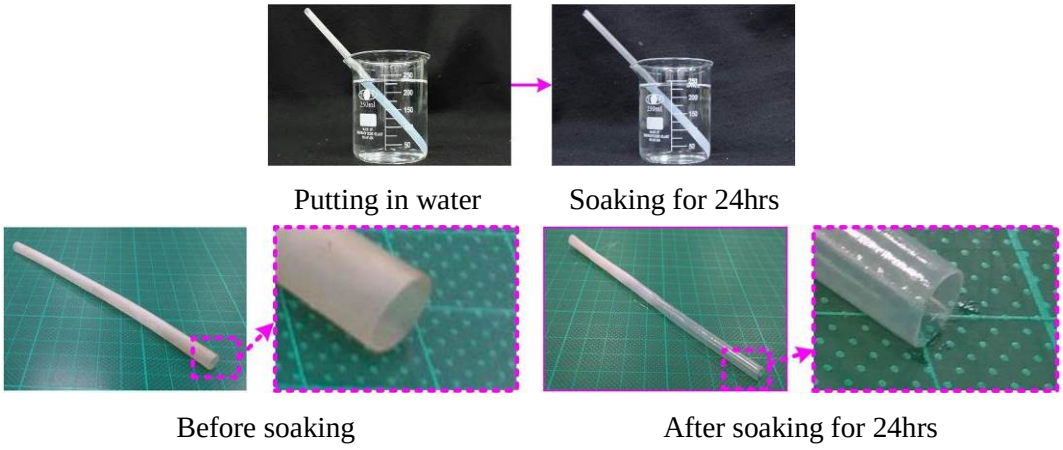


Figure 10. 3rd gen seaweed gel straw water resistant test

(ii) Drinking ability test

1. Multiple snap shots of drinking tea with 3rd gen seaweed gel straw (*Figure 11*) showed that at the beginning of the test, the straws worked fine.
2. The 3rd gen seaweed gel straw's drinking ability was better than that of vegetable paper straw. But after a longer time of use, the straw also lost its drinking ability.

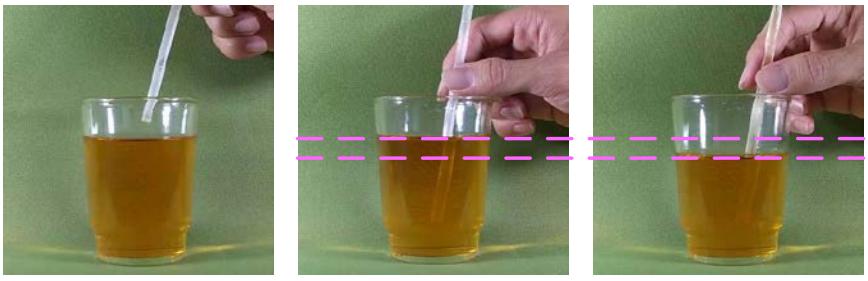


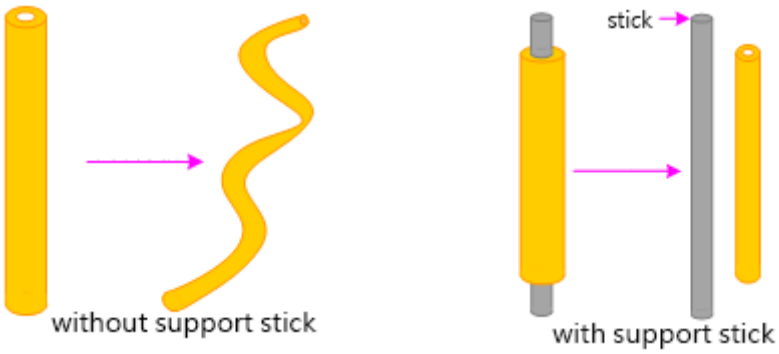
Figure 11. Drink test of the 3rd generation seaweed gel straw

Discussion：

1. According to our experiment, the soaking time in calcium chloride solution strongly effected the thickness of the tube. Changing the soaking time in the solution can control the thickness of the tube effectively.
2. According to our experiment, if the soaking time were not enough, the walls would be too

thin, and the structure would be weak. If the soaking time were too long, the walls would be too thick, and the pipe wall would be too narrow. After lots of evaluation, we believed that soaking for 25mins worked the best. After soaking for 25mins, the straw had the best structure and the pipe wall worked just fine.

3. The 1st gen seaweed gel straw's tube was way too thick, and the structure was soft, which made it hard to drink with. The high percentage of water also made it hard to preserve. So, we had to find methods to get rid of all the cons so as to make one with practical value.
4. When making the 2nd gen seaweed gel straw, we solved the high water containing problem, but the straw had shrunk and lost its shape, which forced us to find a way to maintain its shape.
5. When we made the 3rd gen seaweed gel straw, after 24hrs of drying, the walls had shrunk, but with the support of the Teflon tube, it helped the straw stay its shape, which looked just like a regular plastic straw.



Gen 2 Gen 3

Figure 12. Comparison between 2nd gen and 3 gen of seaweed gel straw

6. When we made the sodium alginate solution, we used a homogenizer to combine the mixture, which created too many bubbles in the mixture. And if we used this mixture to form the straw right away, there would be bubbles everywhere in our straw. So we vacuumed the mixture before forming it, and this method can get rid of the bubbles fast and quick. (*As shown on figure 13*)

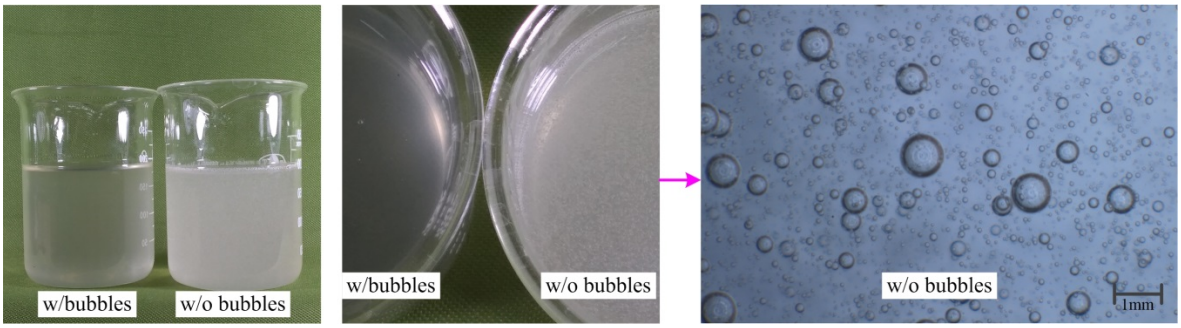


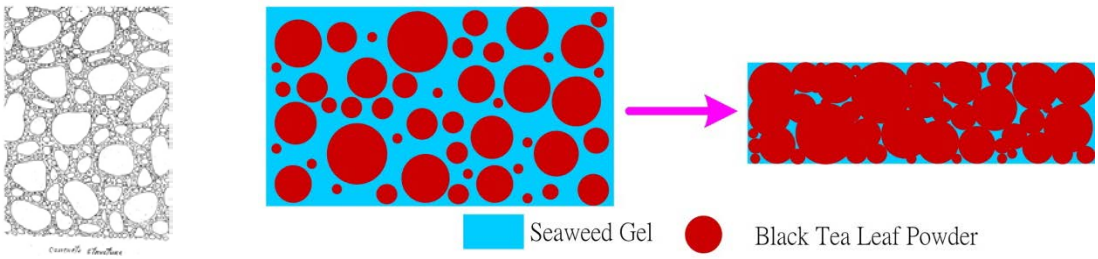
Figure 13. The bubbles in sodium alginate solution can be removed by vacuuming the mixture

7. The 3rd gen seaweed gel straws had better drinking ability than the vegetable paper straws. However, after multiple uses, the nozzle of the straw still got softened by saliva, and the pressure made the walls wrinkle and the straw slowly lost its drinking ability.
8. Before soaking in water, the 3rd gen seaweed gel straw had similar appearance and structure, compared with plastic straws. But after soaking in water, the seaweed gel straw softened and slowly lost its drinking ability. We needed a solution to fix this problem.

【Experiment A3】Making and testing of the black tea straw

Introduction：

1. The only ingredient of 3rd gen seaweed straw seaweed gel. Even when it is flexible and won't be dissolved in water, it still gradually softened and lost its drinking ability. This dealt a severe blow to the 3rd gen seaweed straw.
2. Concrete was made by grout and sandstones, while grout was the adhesive and the sandstones was the aggregate. When mixed with the right ratio, the strength gets a lot stronger. (*As shown on figure 14-A*)
3. Inspired by the concept, we used seaweed gel as the adhesive and food particles as the aggregate and tried to improve the strength of the straw.
4. As previously discussed, people still needed plastic straws to drink bubble tea, and this remained big problem to the environment. So we thought that if we used seaweed gel as adhesive and black tea leaf powder as aggregate, we probably could make the black tea straw with strong structure.



A. Concrete (6)　　B. Black tea straw

Figure 14. The structure of black tea straw

Process：

Ⅰ. Steps of making the black tea straw

1. Combine 200ml of 2% (*w/w*) sodium alginate solution with 1% black tea leaf powder. And 1000ml of 10% (*w/w*) calcium chloride solution.
2. Use a syringe to suck up the sodium alginate and black tea mixture and squeeze it in the calcium chloride solution.
3. After 25mins, take the formed gel out of the solution, cut off the end and the front, and clean it with water. After drying, we then made the straw hollow.

4. Use a Teflon stick to support the black tea straw when drying it in a dryer.

5. After 24hrs of drying, the black tea straw was made, which was observed and tested.

Ⅱ. Tests on the black tea straw

In our experiment, we tested the water resistance and drinking ability of the black tea straw and tried to prove the practicality of the straw.

(i) Water resistant test

1. Make a 5% black tea straw and soak it in water for 24hrs.

(ii) Drinking ability test

1. Put the black tea straw into a cup with eight cents full of tea.

2. Drank the tea with the black tea straw and observed the whole process by filming it.

Results：

Ⅰ. Steps of making the black tea straw

1. As shown on figure 15-A, after 24hrs of drying, the straw had an even thickness and the straw was straight and hollow.

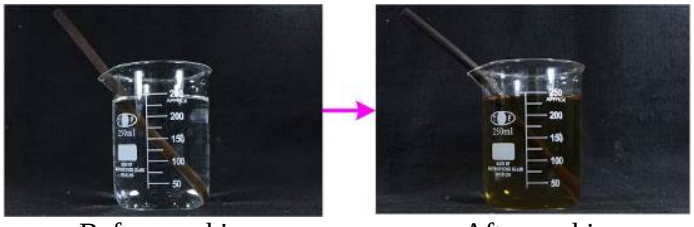
2. As shown on figure 15-B, the black tea straw had low content of water, which made it hard and would not hang down when held.

A. Black tea straw　　B. Holding the straw

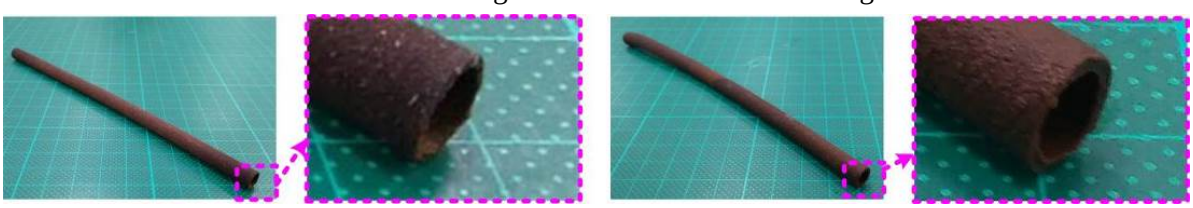
Figure 15. The Exterior of the black tea straw

Ⅱ. Tests on the black tea straw

(i) Water resistant test



Before soaking　　After soaking



Befor soaking　　After soaking

Figure 16. Water resistant test of the black tea straw

1. As shown on figure 16, at the beginning of the test, the straw maintained its shape. After 24hrs of soaking, the straw still remained unchanged, only the part soaking in the water softened a little bit.
2. As shown on figure 16. Before soaking, the straw had even thickness through the whole straw, the straw was hard but flexible, and with a bit of black tea fragrance. After soaking, the diameter didn't change a lot, only the part soaked in the water had swollen and softened a little bit, but overall, the structure was still in a great condition.

(ii) Drinking ability test

1. Multiple snap shots of drinking with the black tea straw showed that the drinking ability of the black tea straw was great.
2. The drinking ability of the black tea straw was way better than the 3rd gen seaweed gel straw. After multiple uses for a long period of time, the drinking ability was still great.

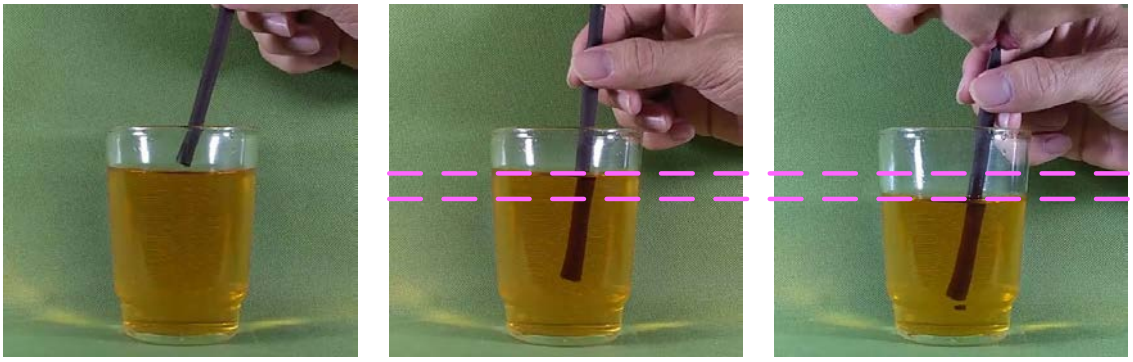


Figure 17. Drinking ability test of the black tea straw

Discussion：

1. After drying the black tea straw for 24hrs, the pipe wall had shrunk a bit. But it was still slightly thicker than the 3rd gen seaweed gel straw, and slightly harder, and still with flexibility.
2. The black tea straw had seaweed gel as adhesive and black tea leaf powder as aggregate which increased its strength.
3. Before putting it into the water, the black tea straw had thicker pipe walls, slightly harder but still flexible, comparing with the plastic straws.
4. When using the black tea straw multiple times, the nozzle of the straw did not shrink, and the pipe wall did not wrinkle because of the pressure, hence the drinking ability remained great.
5. According to the results, our assumption was right. Using seaweed gel as adhesive and black tea leaf powder as aggregate can effectively increase the strength of the straw.

B. Discussion on black tea straw

【Experiment B1】Physical mechanical test

Introduction：

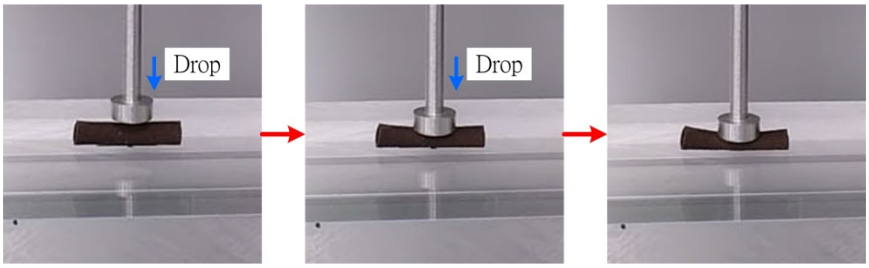
In experiment A3, using seaweed gel as adhesive and 1% black tea leaf powder as an aggregate can form a straw with stronger structure, increasing the hardness but still maintaining the flexibility. In this experiment, we are going to increase the percentage of black tea leaf powder. We suspect this will increase the hardness but decrease the flexibility of the straw.

Process：

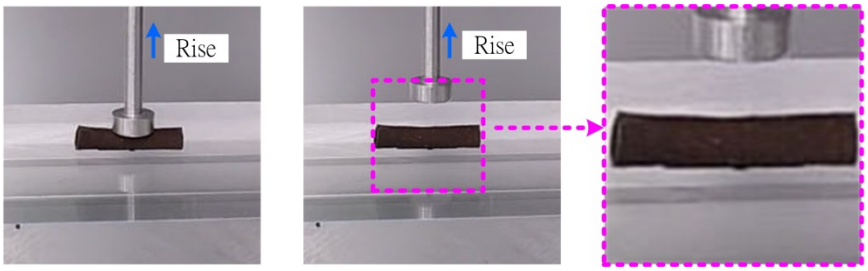
1. **Independent variables:** The percentage of black tea leaf powder. (*1%, 2%, 3%, ---- 8%, 9%, 10%*)
2. Make the black tea straws separately and cut into 2cm straws. We used a hardness tester we built (*CNC + Force gauge*) to test the physical properties of the straws and record down the data.

Results：

1. As shown on figure 18, when the straw was made with 1%~5% of black tea leaf powder, the pressure would deform the tube. But after the pressure being released, the tube would bounce back to its original shape. This proved with 1~5% of black tea leaf powder, the straw still had enough flexibility.
2. As shown on figure 19, when the straw was made with 6%~9% of black tea leaf powder, the pressure would deform the tube, which caused the wall cracked. This proved with 6~9% of black tea leaf powder, the straw would lack flexibility.

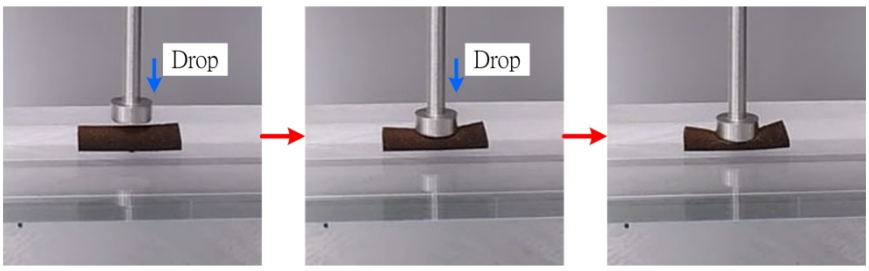


A. Pressure will squeeze down the tube

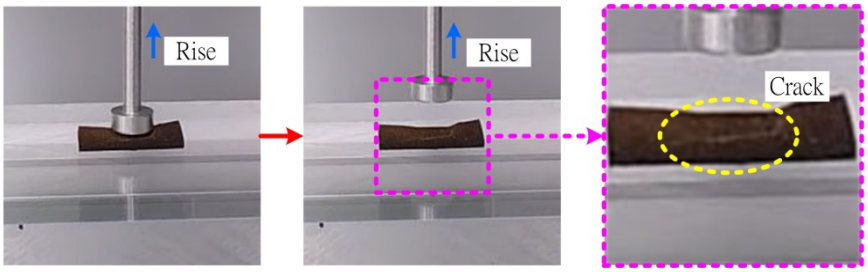


B. Returns its shape after the pressure has released

Figure 18. 1~5% of black tea leaf powder will maintain great flexibility



A. Pressure will squeeze down the tube



B. The tube cracked because of the pressure

Figure 19. 6~9% of black tea leaf powder will lose too much flexibility

3. As shown on Figure 20, 21 and Table 2, the higher the percentage of black tea leaf powder was, the harder the straw would be. The percentage of black tea leaf powder and force (*gw*) were in a linear relation. Using SigmaPlot tool for linear regression, we obtained the equation: ***y = 396.2500 x + 495.2604***，（R^2=0.9867）。

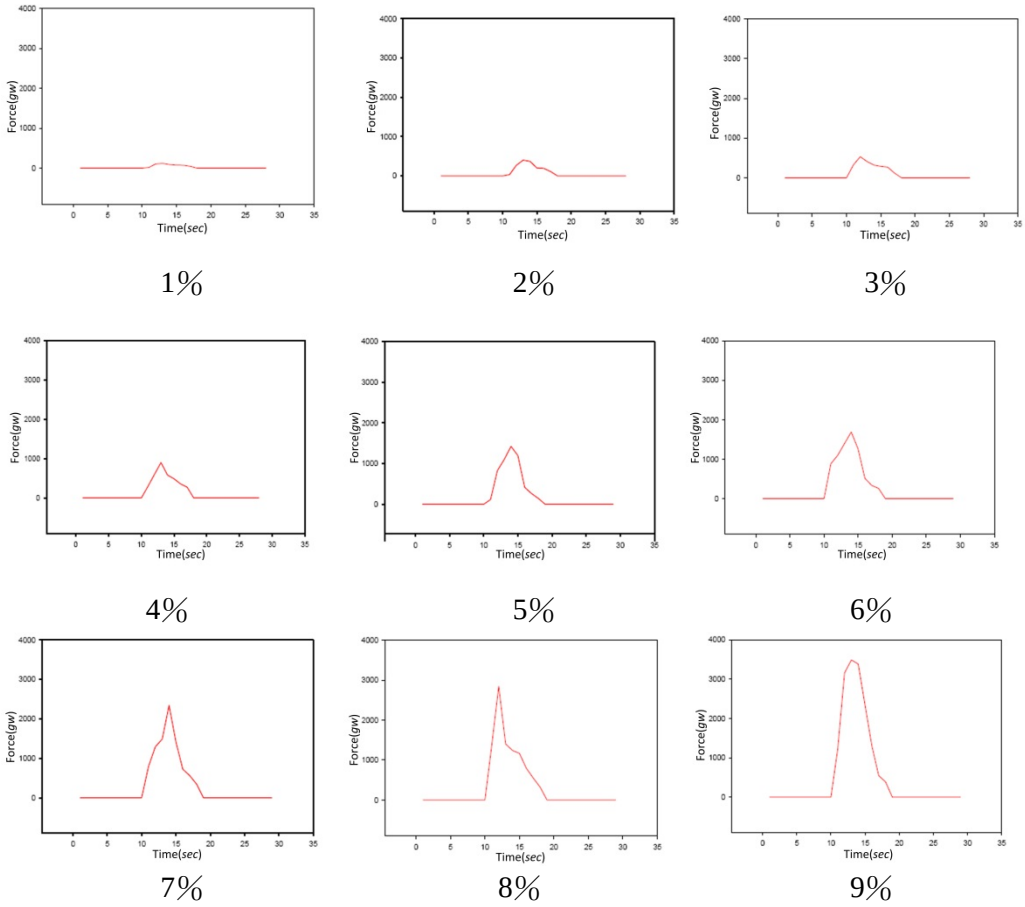


Figure 20. The different percentage of black tea leaf powder effecting the hardness

Table 2. The different percentage of black tea leaf powder effecting the hardness

Tea Powder(%)	Force (gw)				
	Test 1	Test 2	Test 3	Avg	SD
1	118	86	107	103.7	16.3
2	402	310	275	329.0	65.6
3	530	360	695	528.3	167.5
4	1147	900	1013	1020.0	123.6
5	1423	1548	1394	1455.0	81.8
6	1589	1687	1877	1717.7	146.4
7	2341	2185	2482	2336.0	148.6
8	2845	2694	2442	2660.3	203.6
9	3489	2987	3186	3220.7	252.8

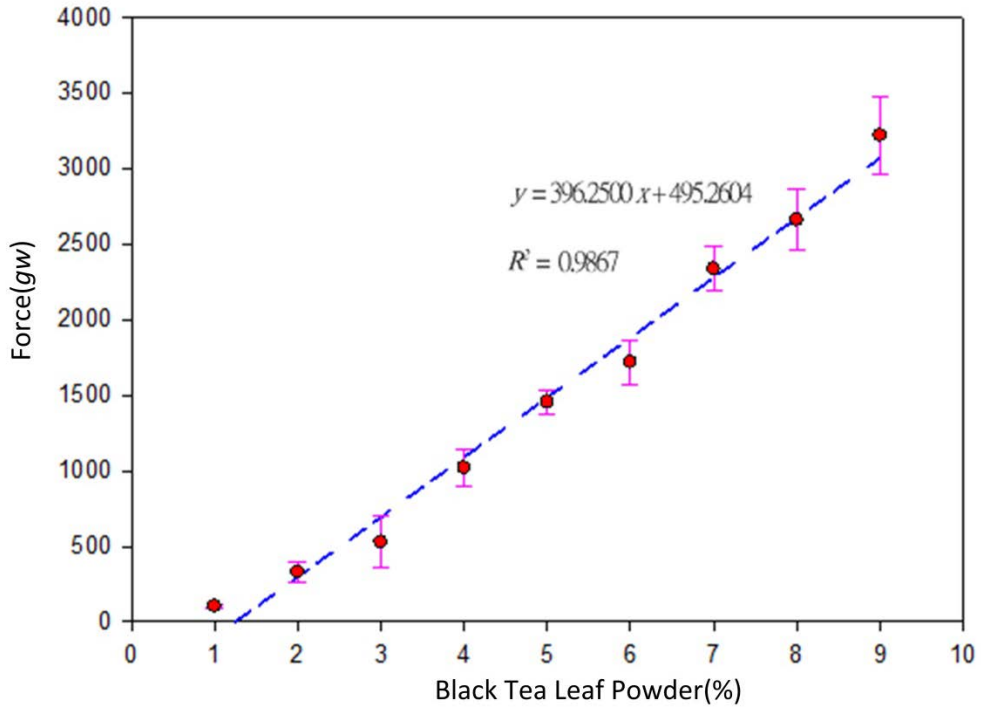


Figure 21. The different percentage of black tea leaf powder effecting the hardness

Discussion：

1. The highest percentage of black tea leaf powder that we had was 10%, but after 24hrs of drying process, the straw cracked badly. So 10% of black tea leaf powder couldn't get the job done.
2. Hand shake drinks and Tetra Pak drinks are usually covered by a thin film, so people need straws to penetrate the film. As increasing the percentage of black tea leaf powder could effectively increase the hardness of the straw, this could be used to penetrate the film cover on the drinks. Considering the flexibility and the hardness, we believed that with 5% of black tea leaf powder, it would work the best for the straw.

【Experiment B2】Different diameters test

Introduction：

1. In out next experiment, we tried to change the diameter of the straw, also the diameter of the Teflon tube, and hoped to make the straws with different diameters so that it could be used on all kinds of drinks.
2. We tested the black tea straws with different diameters on all kinds of drinks with covering films. We hoped the straws were strong enough to penetrate the covering film.
3. We also aimed to make the straws with bigger diameter tubes, so people could drink bubble tea with it.

Process：

1. **Independent variables:** Different diameters of black tea straw. (*Small, medium, big*)
2. Apply different diameters (*8mm / 10mm / 25mm*) on the syringe, and with different diameters of Teflon tube (*3mm / 6mm / 13mm*) to make 5% black tea straws with different diameters.
3. Covering film penetration test: used the small, medium, big black tea straws to penetrate the plastic coverings in the drinks. We filmed the whole process and observed the result.
4. Bubble drink test: Used the big straw to drink bubble tea. We also filmed the whole process and observed the result.

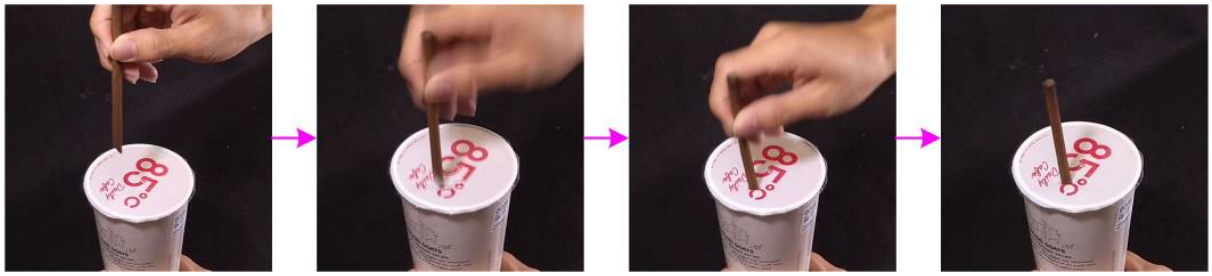
Results：

1. As shown on figure 22, the black tea straws with different diameters had the same diameter through the whole straw. The straws didn't have much water inside, and the structure was hard and would not hang down when held.
2. When doing the covering film penetration test, all diameters of straws passed the test. (*As shown on figure 23*)
3. As shown on figure 24, with the biggest black tea straw, we were able to drink Bubble tea easily.

A. Big, medium, small black tea straw

B. Helding the straws

Figure 22. Black tea straws with different diameters.



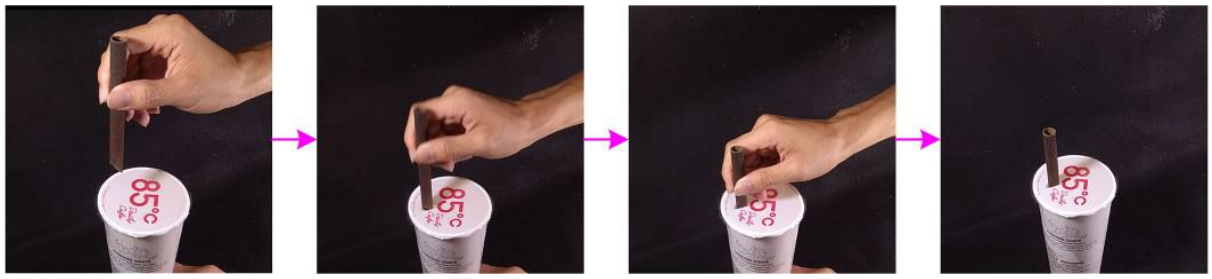


Figure 23. Covering film penetrate test on different diameter black tea straws.

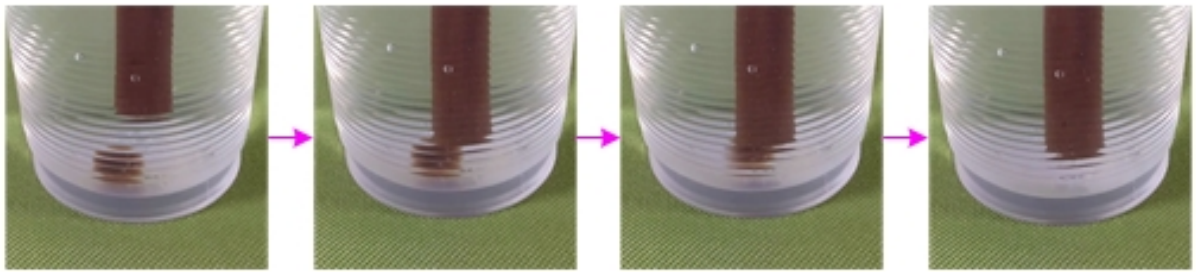


Figure 24. Bubble tea drink test with the biggest diameter black tea straw.

Discussion：

1. In this experiment, it showed that by changing the output diameter of the straw and the diameter of the Teflon tube, we successfully made the straws with different diameters.
2. Different diameters of straws all passed the covering film penetration test, which showed that the black tea straws should have great value when it comes to commercialization.
3. The biggest model of the black tea straws allowed users to drink Bubble tea easily, which means once it’s been launched into the market, it can solve the problem of drinking Bubble tea with eco-friendly solution.

【Experiment B3】High and low temp-resistant test

Introduction：

In this experiment, we were going to put the straws into cups filled with water with different temperature to test the high and low temperature resistance ability of the black tea straws, which could prove the practicality of the black tea straw under different temperatures.

Process：

1. **Independent variables:** Put the black tea straws in water with different temperature. (*0°C low, 100°C high*)
2. Put the black tea straws into cups filled with 0°C and 100°C water respectively, and then measure the water temperature after inserting the straw.
3. Soaked the straws in hot and cold water for 24hrs, and filmed and observe the changes.

Results：

1. As shown on figure 25, after soaking in cold water for 24hrs, the appearance didn't show obvious changes and the structure was still strong. It still had black tea fragrance, and the straw still remained hard but flexible.

Figure 25. Low temperature resistant test of the black tea straws

2. As shown on figure 26, after soaking in hot water for 24hrs, the part not touched with water didn't change, but the nozzle which had been contacted with water had slightly expanded. The structure was still strong, but the texture became softer.

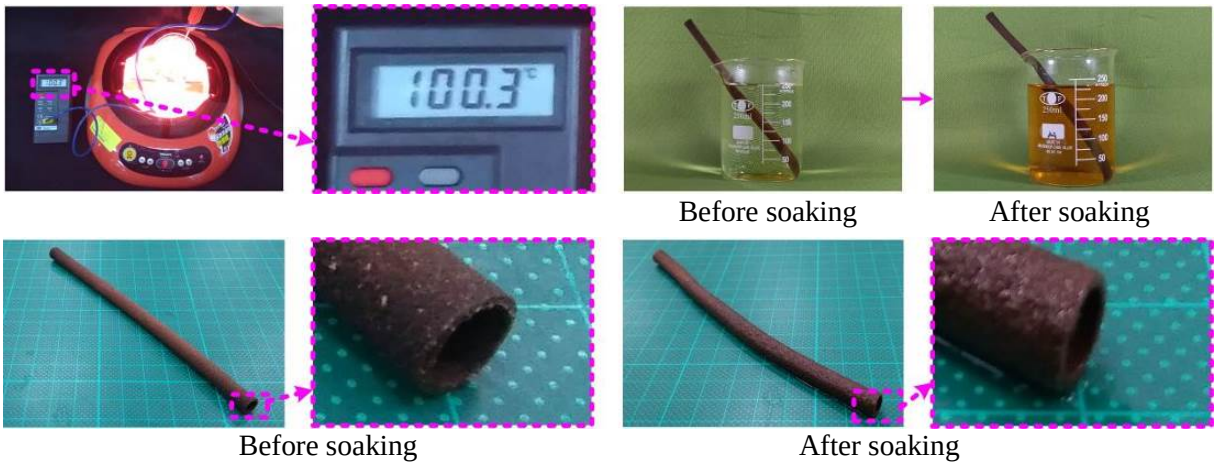


Figure 26. High temperature resistant test of the black tea straw

Discussion：

1. No matter how temperature is of the drink, hot or cold, the pipe wall of the straws will not be shrunk even after repeated usages and can still maintain its drinking ability, which has potential market value.

【Experiment B4】Acid resistant test

Introduction：

It is common to have sour drinks everywhere. Thus, in our next experiment, we attempted to soak a black tea straw in acid water to test its acid-resistance ability.

Process：

1. Put the black tea straw into a cup filled with 5% citric acid solution. Use a pH meter to note the pH value of the solution.
2. After soaking for 24hrs, we filmed and observed the changes.

Results：

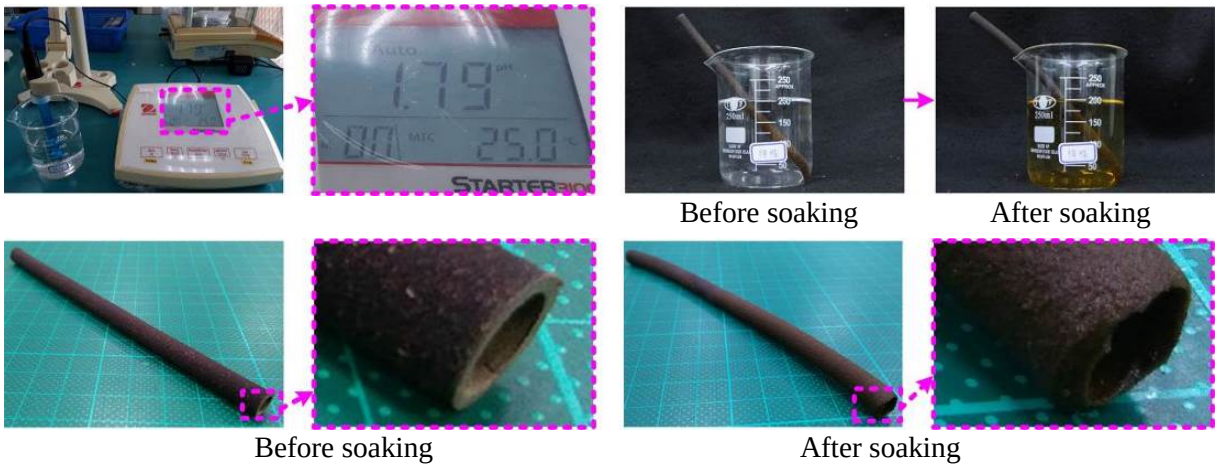


Figure 27. Acid resistant test of the black tea straws

1. As shown on figure 27, after soaking in critic acid solution for 24hrs, the appearance of the black tea straw didn't display any obvious changes.
2. As shown on figure 27, after soaking in critic acid solution for 24hrs, the structure was still great. The straw still had black tea fragrance and remained hard but flexible.

Discussion：

1. After soaking in critic acid solution and with multiple uses, the nozzle of the straw would not shrink and the pipe wall would not collapse because of the pressure, either. This shows that the drinking ability of the black tea straws was great.
2. As shown on the results, the black tea straw could maintain its drinking ability in critic acid solution. In the future, it can be used on sour beverages and with great value on commercialization.

【Experiment B5】Storage ability test

Introduction：

Since the black tea straw is made by natural ingredients like seaweed gel and black tea leaf powder, once people used it on a regular basis, we needed to consider how to preserve it. In this experiment, we attempted to test the water activity of the black tea straws and prove its storage ability with quantitative data.

Process：

1. **Independent variables:** New formed black tea straw and straw formed a week ago. (*Without packaging*)
2. Made two 5% black tea straws for two samples. (*Newly formed and formed for a week*) Tested the water activity of the two samples.
3. Used a water activity meter to measure the Aw changes of the two samples and recorded the humidity of the air.

Results：

1. As shown on table 3, figure 28-A, 29, the newly formed straw's Aw was 0.344□0.020. At the same time, the humidity inside the drying box was 36%.
2. As shown on table 3, figure 28-B, 29, the straw formed a week ago, the Aw was 0.733□0.003. At the same time, the humidity of the air was 74%.

A. The humidity of the drying box

B. The humidity of the air in a week

Figure 28. The water activity valve and humidity of the straws

Table 3. 「The black tea straw」Water activity test

samples	Water activity value(Aw)				
	Test 1	Test 2	Test 3	Avg	SD
Just finish process	0.324	0.346	0.363	0.344	0.020
1 week without packaging	0.735	0.734	0.729	0.733	0.003

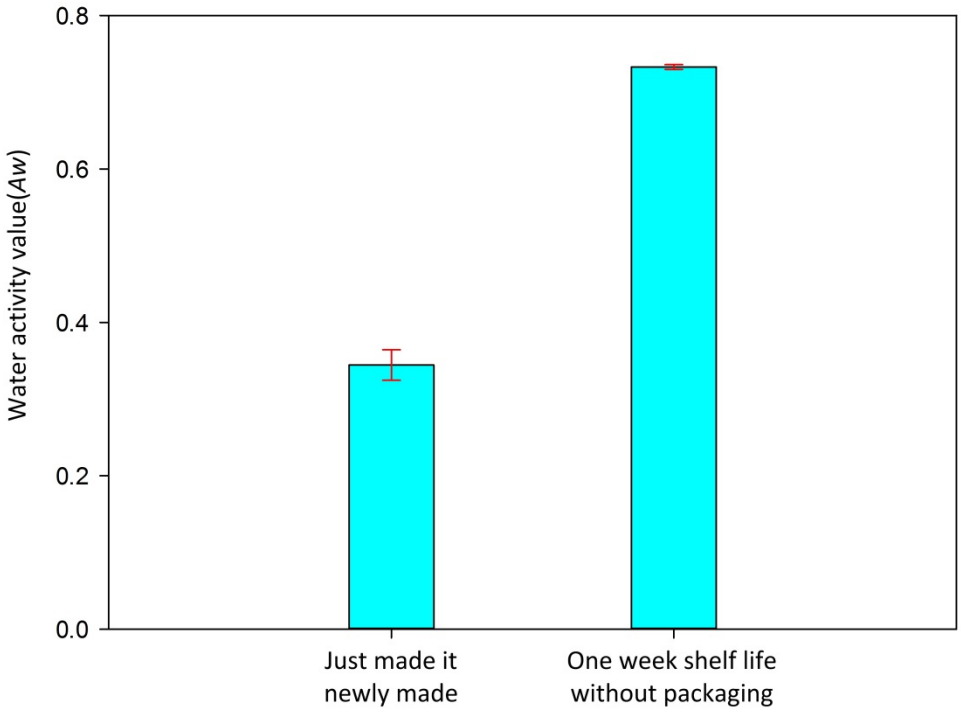


Figure 29. The changing of black tea straw's water activity value

Discussion：

1. To prevent microbes from growing, the water activity value had to be under 0.6. The newly formed black tea straw averaged Aw of 0.344, which showed that Black tea straws had decent storage ability.
2. After a week without packaging, the humidity of the air changed the Aw of the black tea straw, as the value increased more than 0.6, reaching 0.733, which means the black tea straw needed to be packed before use to avoid hygiene issue.

【Experiment B6】Corruptibility test

Introduction：

Since the black tea straw is made by natural ingredients like seaweed gel and black tea leaf powder, once people use it in regular basis, we need to consider the corruptibility of the straw. In this experiment we attempted to compare the corruptibility of the black tea straw with the ones available in the market and expected to prove that our black tea straw was eco-friendly.

Process：

1. **Independent variables:** Black tea straw, plastic straw, paper straw, sugar cane straw
2. Split the black tea straw, plastic straw, paper straw and sugar cane straw into two groups of samples, (*Buried / Not buried*) and test their corruptibility.
3. After 4 weeks of corruptibility test, we filmed and observed the changes of the 4 straws.

Results：

1. As shown on figure 30, after 4 weeks, whether or not we buried the straws, the plastic straw and the sugar cane straw still had the same appearance and showed no obvious corruption status.
2. As shown on figure 30, after 4 weeks, whether or not we buried the straws, the black tea straw and the paper straw had their structure damaged and the black tea straw deformed and corrupted significantly.

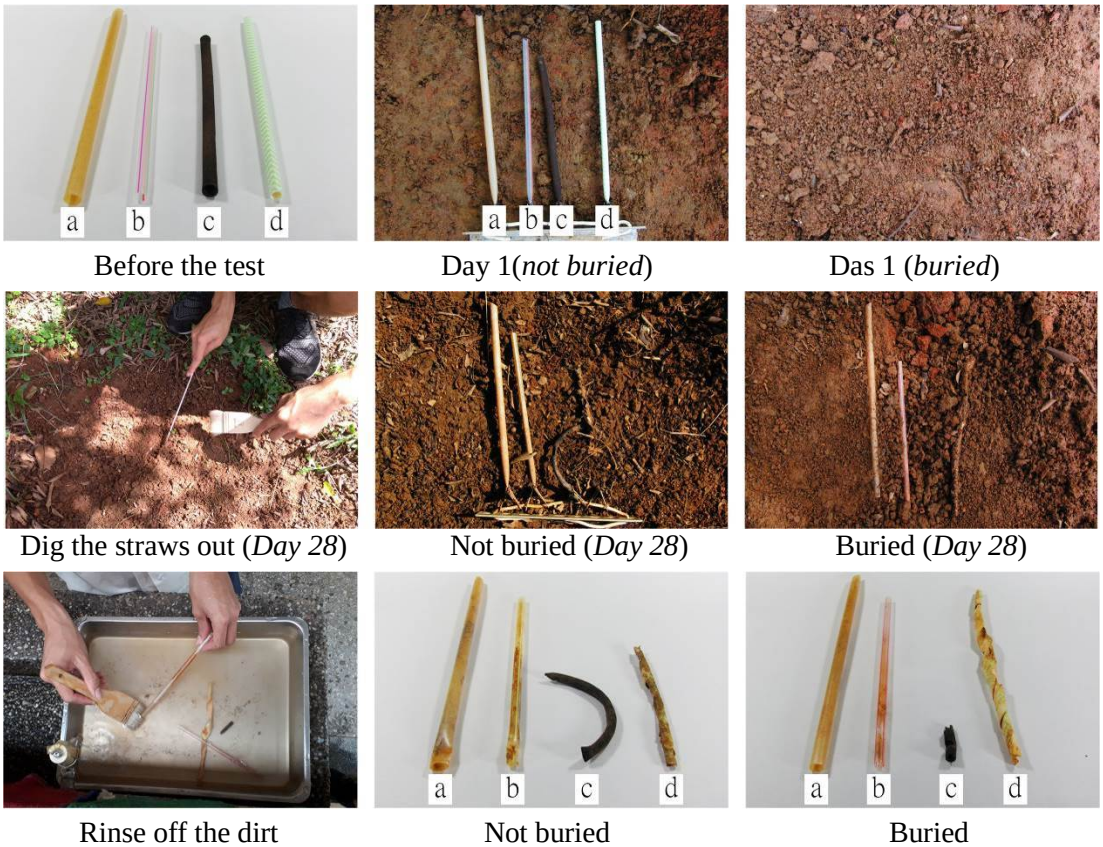


Figure 30. The corrupting changes of the black tea straw.

(a. Sugar cane straw, b. Plastic straw, c. Black tea straw, d. Paper straw)

Discussion：

1. In this experiment, we found that the paper straw had better corruptibility than the plastic and sugar cane straws, so the paper straws were eco-friendlier.
2. The black tea straw that we invented in our research were made by natural ingredients such as seaweed gel and black tea leaf powder. The corruptibility test showed that the black tea straw was the most eco-friendly straw.

C. Improving the making process and formula

【Experiment C1】Design and make the forming machine

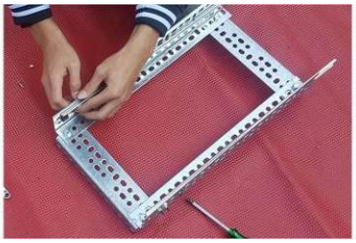
Introduction：

In previous experiments, those are all handmade straws. Before drying, the diameter of the straw wasn't even enough, and the straw was not perfectly straight. Therefore, we planned on building a machine to squeeze out the sodium alginate mixture with steady diameter and speed.

Process：

1. Use a circular saw to cut the angle iron.
2. Assemble the stand with angle iron.
3. Install the rail on the stand, for the squeezing device to move on.
4. Installed recycled power window regulator onto fixed iron shelf.
5. Worked on circuit installation on power window switch.
6. Placed the squeezing device on the block of wood.
7. Placed the recycled DC geared motor on the squeezing device to operate the squeezing spiral and move the squeezing device at the same time.
8. Used a sponge as shock absorber placed under the motor to reduce the vibration when operated.
9. The squeezing machine was built.


Cut the materials


Assembleing the stand


Rail assembleing

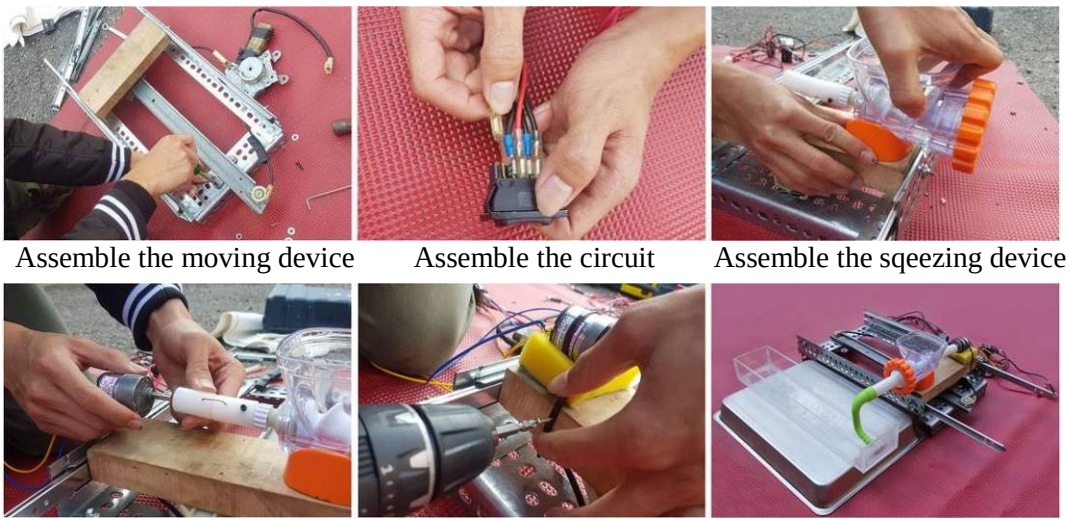


Figure 31. The process of making the squeezing machine.

Results：

1. As shown in *figure 32*, adjusting the speed of the motor could change the speed of the spiral, effecting the squeezing speed of the machine and the moving speed of the device.
2. As shown in *figure 32*, movement motor could control the ingredient output device to move to left or right straightly.

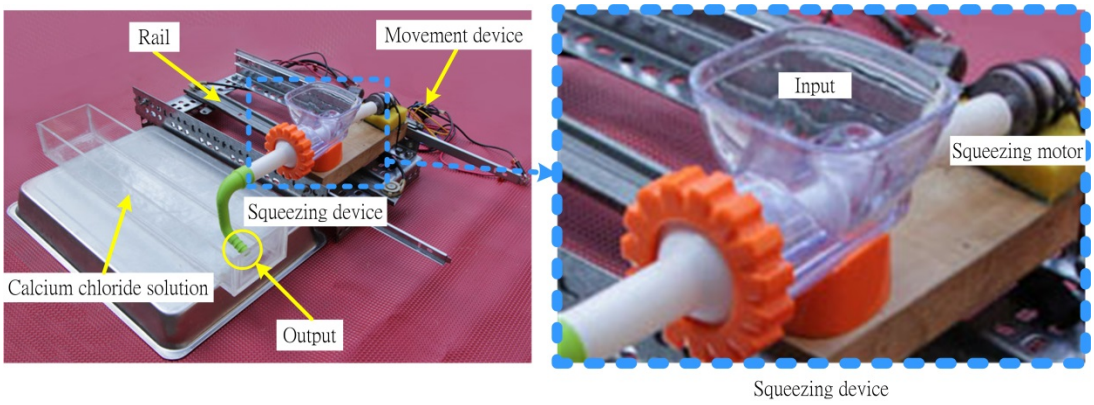


Figure 32. Handmade squeezing machine.

Discussion：

1. When assembling the squeezing machine, the principle of this machine is to provide stable Volt by power supply to control the RPM of the motor. It can control the speed of squeezing the ingredients and the speed of the output device.
2. Changing the motors' speed can control the speed of the device moving and the speed of squeezing the ingredients. When the speeds are stable, the seaweed straw made from the machine can have a stable diameter through the whole straw.
3. Due to the output device placed on the rail moving straight, therefore, the seaweed gel straw is perfectly straight.

【Experiment C2】The test of the forming machine

Introduction：

In is experiment, we will test the machine we made in【experiment C1】 to verify if it can make the seaweed gel straw with the same size and straight.

Process：

1. Compound 200ml of 2% sodium alginate and 1000ml of 10% calcium chloride. (*Add 5% of black tea powder to make black tea straws.*)
2. Put the sodium alginate mixture and black tea mixture into the squeezing machine.
3. Use the squeezing machine to form the straws in the calcium chloride solution.
3. After 25 minutes, take out the straw, cut off the end and the front of the straw. Put the straws into water for cleaning and make them hollow.
4. Insert the Teflon tube in the hollow (*to support the tube*), then hang them in the dryer.
5. After 24hrs of drying, the 3rd gen seaweed gel straws and the black tea straws are made. Take figures and observe.

Result：

1. As shown on figure 33. Using the machine, we are able to make the straws even and straight.

Figure 33. Straws made by our machine

Discussion：

1. Adjusting the motor speed of the output and moving can form the straws in an even diameter.
2. Due to the output device placed on the straight rail, the straws can be produced perfectly straight.

【Experiment C3】Making straws with different flavors

Introduction：

【Experiment A3】(*Black tea straw*) In this experiment, we are trying to use other ingredients to replace black tea powder see if we can make straws with different flavors.

Process：

1. Mix 200ml of 2% sodium alginate solution with 5% of powder (*green tea powder/coffee powder/lemon powder*), and make 1000ml of 10% calcium chloride solution
2. Use a syringe to squeeze the mixtures with different flavor into the calcium chloride solution in a tube shape.
3. After 25 minutes, take the tube out of the solution, cut off the tube's end and front. Put the tube in some water for cleaning and make it hollow.
4. Use a Teflon tube and insert it in the tube (*for support)* and hang it in a dryer.
5. After 24hrs of drying, we get different flavors of seaweed gel straws. Film the straws and observe them.

Results：

1. As shown on figure 34. After drying the green tea, coffee and lemon straws for 24hrs, the water content is very low. The structure remains hard and it will not hang down when held.
2. The three kinds of straws all have their own fragrances. Green tea straw with green tea fragrance, coffee straw with coffee fragrance and lemon straw with lemon fragrance.

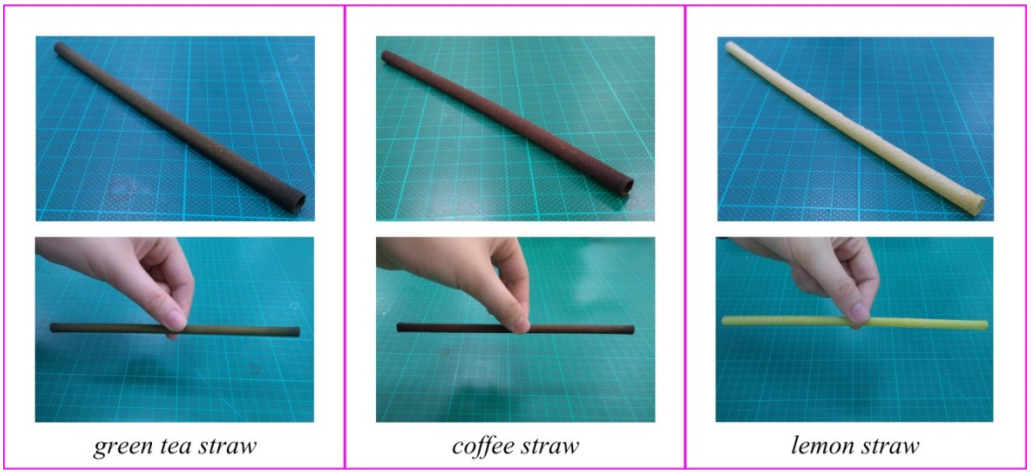


Figure 34. The finished product of green tea/coffee/lemon straws

Discussion：

1. According to the experiment results, we found that by adding different flavors into calcium chloride solution, straws could have their own fragrances.
2. Because different flavors of straws have different smells, the green tea straw can be used to drink green tea, coffee straw for coffee, lemon straw for fruit drinks. Developing different flavors of straws can increase the applications of the seaweed gel straws.

3. Conclusions

3.1 Conclusion

A. Discussion on straw producing process

【Experiment A1】Making and testing of the vegetable paper straw

Although the appearance of the vegetable paper straws we made is similar to the paper straw, the texture is obviously worse.

【Experiment A2】Making and testing the seaweed gel straw

The first-generation seaweed gel straw is too thick on side wall and too soft to be held on hand when sipping. It also contained too much water which made it hard to be preserved.

The second-generation seaweed gel straw (*with no structural support*) had improved its moisture content issue, but the tube had shrunk and bended.

The third-generation seaweed gel straw (*with structural support*), due to the Teflon tube's support when drying, the pipe wall became thin and even. The appearance is similar to plastic one.

【Experiment A3】Making and testing the black tea straw

The experiment proved that our assumptions are right. When using seaweed gel as adhesive and black tea powder as aggregate to form the Black tea straw, it can have stronger structure and with water resistant ability improved.

B. Discussion on black tea straw

【Experiment B1】Physical mechanical test

When the black tea powder contents is at the percentage of 1~5%, it will get pressed by outer force, but after the pressure is released, the tube bounces back to its shape. When the powder contents is at the percentage of 6%~9%, the pressure will crack the tube. Considering that store bought drinks usually come with a covering film, so we think the balancing point of the black tea powder is 5%.

【Experiment B2】Different diameters test

In our experiment, we proved that changing the diameter of the ingredient output and the diameter of the Teflon stick can make the Black tea straws with different diameters. Different diameters of the Black tea straws all passed the covering film penetration test. The biggest

diameter of the Black tea straws could be used to drink bubble tea with ease, solving the problem of drinking hand shake drinks. This showed the commercialized value of the Black tea straws.

【Experiment B3】High and low temp-resistant test

Despite the temperature of the drink, hot or cold, the pipe wall of the straw would not collapse even after repeated uses and could effectively maintain its drinking ability.

【Experiment B4】Acid resistant test

Soaking the Black tea straws in citric acid solution and with multiple uses, the tube would not shrink, the pipe wall would not collapse, and the straws still maintained its drinking ability, increasing the value of commercialization. This shows that the straws can handle any sour drinks sold on market and can be widely used on any kinds of drinks.

【Experiment B5】Storage ability test

To prevent microbes from growing, the water activity value (*AW*) must be under 0.6. The Black tea straws that had just finished process has the AW of 0.344, the value is way under 0.6, which proved that the Black tea straws have decent storage ability. Without packaging for a week, the humidity of the air changed the water activity value of the straws, which increased more than 0.6. Therefore, the Black tea straws need to be packaged before use to avoid hygiene issue.

【Experiment B6】Corruptibility test

In this experiment, we found out that after 4 weeks of corruptibility test, with or without being buried, the plastic and sugar cane straw still had the same appearance and didn’t corrupt. And after 4 weeks, with or without being buried, the paper and Black tea straw had corrupted, the structure had collapsed and bent. This showed that the Black tea straws are very eco-friendly.

C. Improving the making process and formula

【Experiment C1】Design and make the forming machine

The idea of designing the forming machine is to control the RPM of the motor by the stable voltage provided from the DC power supply, which can control the speed of squeezing out the ingredients and the movement speed of the output device. Adjusting the motors’ speed can control the speed of the device moving and the speed of squeezing the ingredients. The sodium alginate gel tubes will be consistent in pipe diameter when the motors are at stable speed.

【Experiment C2】The test of the forming machine

The test result shows that the sodium alginate gel tubes squeezed out are consistent in pipe

diameter when both the feed motor and the moving motor are at stable speed. In addition, since the whole device is installed on a linear rail, the sodium alginate gel tubes squeezed out is perfectly straight.

【Experiment C3】Making the straws with different flavors

According to the experiment results, whether the straws are in green tea, coffee, or lemon flavor, not only are they consistent in pipe diameter, but they are also in moderate hardness after 24-hours drying. What's more, each of the three kinds of straws has their own fragrance, which endows them merchandising potential. For example, the green tea straw can be used in green tea related drinks, while the coffee straw can be used in coffee related drinks, and the lemon straw can be used in fruits related drinks.

3.2 Contributions

1. We invented a way to make plastic free straws that can be decomposed by environment easily.
2. Through our experiment, we adopted the process of making "Spheres" in molecular cuisines and invented a brand-new way to make the straw.
3. In our experiment, we took sodium alginate gel as the adhesive, and food particles as the aggregate, and successfully made a new type of straw with practical value. It can be used in all kinds of cold drinks, hot drinks, and bubble tea as well in the future, which has high commercialized value.

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本研究嘗試利用可食用的原料製作吸管，由蔬菜改良至海藻膠製作吸管，並討論其強度及彈性。由於台灣的飲用習慣多以膠膜封口，因此本研究另添加粉狀物作為骨材，增加吸管的強度，極具創意。實驗設計以及實驗過程完整，且均有嚴謹的討論，是一個具實用性的研究。