



Prize Winner

Science Investigation

Year 11 - 12

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From Kitchen to Material

Comparison of Fibre Structure and Tensile Strength in Vegetable-Derived Paper-like Materials

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Introduction

Petroleum-based plastics, particularly those contributing to marine plastic pollution, impose a significant environmental burden and have become a global issue. [1] Therefore, alternative materials that can decompose more easily in nature and be produced sustainably are increasingly required. Plants contain components involved in material formation, such as cellulose fibres and starch. Therefore, this study examined the potential and limitations of vegetable-derived materials by producing paper-like materials from several types of vegetables and comparing their strength and structure.

Background

Although petroleum-derived plastics are lightweight and easy to process, they decompose slowly in nature. According to UNEP, 19 to 23 million tonnes of plastic waste leak into aquatic ecosystems every year. [1]

An important component of plant-derived materials is cellulose. Cellulose is a major structural component of plant cell walls and consists of linear molecular chains of β -glucose. These molecular chains are connected by hydrogen bonds and form highly crystalline microfibrils. Because this fibrous structure contributes to the tensile strength of plant cell walls, cellulose fibres remaining after processing may affect the strength of the paper-like samples. [2] However, its biodegradability varies depending on the fibre structure, the number of other components such as lignin and pectin, and environmental conditions. [3]

Starch is also a natural polymer involved in material formation. When heated with water, starch gelatinises, and the leaching of amylose forms a continuous network. Therefore, starch may help form film-like materials. On the other hand, starch-based films tend to become brittle after drying and are also easily affected by moisture. Thus, differences in cellulose fibres and starch between vegetables may affect sample structure and strength.

Research Question

How does vegetable type affect the fibre structure and tensile strength of paper-like samples?

Hypothesis

In vegetable-derived paper-like samples, internal structure after processing may depend on raw material. In particular, the way components such as plant fibres and starch remain in the sample is considered to affect how well the sample holds together and how resistant it is to tensile load. Therefore, this study predicted that differences in the internal composition of each type of vegetable may be related to the tensile strength of the paper-like samples produced.

Methods

The experiment was conducted in three stages: preparation of paper-like samples, microscopic observation, and tensile strength testing.

Variables are defined in Table 1.

Variable type	Variable in this study	Details
Independent variable	Type of vegetable	Four vegetables were compared: celery, potato, sweet potato, and carrot.
Dependent variables	Tensile strength	Tensile strength was calculated from the breaking load measured using the Vernier Structures & Materials Tester and the cross-sectional area of each test piece.
Controlled variables	Sample preparation conditions	For the preparation of the paper-like samples, the following conditions were controlled: • Mass of vegetable: 60 g • Size of vegetable pieces: 1cm cubes • Sodium hydroxide solution: 150 mL of 0.1 mol/L NaOH solution • Heating time: 35 minutes • Neutralisation process: 30 mL of 0.5 mol/L hydrochloric acid was used. • Grinding method: the collected solids were ground into a paste using a mortar and pestle. • Forming method: the paste was spread onto baking paper. • Pressing method: the samples were pressed with a total of 3 kilograms of weights twice for 3 minutes each. • Drying method: the samples were dried in a fume cupboard.
Controlled variables	Tensile testing conditions	The tensile testing conditions were also controlled. Each test piece was cut to a width of 10.0 mm, and a central unsupported section of 20.0 mm was left between the fixed sections. Both ends of each test piece were attached to cardboard supports using adhesive, and for all samples, the cardboard supports were clamped to the Vernier Structures & Materials Tester in the same way. The maximum load at the point of breaking was recorded using the measurement system.

Table 1. Independent, Dependent, and Controlled Variables in This Investigation

1. Preparation of paper-like samples

Each vegetable sample, weighing 60 g, was cut into 1 cm cubes and heated in 150 mL of 0.1 mol/L aqueous NaOH solution for 35 minutes. After heating, the mixture was neutralised with 30 mL of 0.5 mol/L hydrochloric acid, and the solid material was collected by filtration. The collected solids were ground into a paste using a mortar and pestle, spread onto baking paper, and pressed with weights twice for 3 minutes each to make the thickness more uniform. After excess water was removed, the samples were dried in a fume cupboard to reduce the risk of mould growth.

This method was based on Japanese washi papermaking, in which plant fibres are dispersed, formed into thin sheets, and dried. [5] [6] However, this experiment did not reproduce the raw materials or processes used in traditional washi production. Instead, it was a simplified method for producing paper-like samples using vegetable-derived fibres.

2. Microscopic observation

Optical microscopy was chosen because it allowed visible features, such as fibre-like structures, fibre

density, and granular structures, to be directly observed and compared between samples. Each sample was observed at magnifications of 40× and 100×. During the observations, attention was paid to features such as the remaining fibres and fibre density, and the structures were compared to determine whether differences could be observed depending on the type of vegetable.

3. Tensile strength testing

The Vernier Structures & Materials Tester was chosen because it could measure the breaking load more consistently and quantitatively than pulling the samples by hand. This made it possible to apply a controlled tensile load and compare the samples under fairer experimental conditions.

The prepared paper-like samples were cut into test pieces with a width of 10.0 mm, and both ends were fixed to cardboard supports using adhesive. A central section of 20.0 mm was left between the fixed parts, where the sample was not covered with adhesive.

A Vernier Structures & Materials Tester was used for the strength testing. The cardboard support was attached to the device, and a vertical tensile load was applied to the test piece. The maximum load at the point of breaking was recorded. The cross-sectional area was calculated from the width of 10.0 mm and the measured thickness, and the tensile strength per unit area was calculated by dividing the maximum load by the cross-sectional area. For each sample, three measurements were planned, and the mean value was used for comparison.

Materials, Chemicals, and Equipment Used

Table 2 lists the equipment used.

1. Vegetables • Celery: 60g • Potato: 60g • Sweet potato: 60g • Carrot: 60g 2. Chemicals • 0.1mol/L sodium hydroxide solution: 150mL per sample • 0.5mol/L hydrochloric acid: 30 mL per sample	3. Equipment used to make the paper-like materials • 250mL Beaker x4 • Measuring cylinder x2 • Burner x4 • Tripod x4 • Wire gauze x4 • Heat-resistant mat x4 • Filter paper x4 • Funnel x4 • Conical flask x4 • Mortar x4 • Pestle x4 • Baking paper x1 • Cutting board x1 • Knife x1 • Cutter x1 • 1 kg weight x2 • 250g weight x4 • Fume cupboard x1	4. Equipment used for microscope observation • Optical microscope x1 • Microscope slides x4 • Cover slips x4 • Tweezers x1 5. Equipment used for strength testing • A4 Cardboard x1 • Adhesive x1 • Scissors x1 • Cutter x1 • Ruler with 0.1 mm scale divisions x1 • Vernier Structures & Materials Tester x1 (Figure 1.)
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Table 2. Materials, Chemicals, and Equipment Used in This Investigation

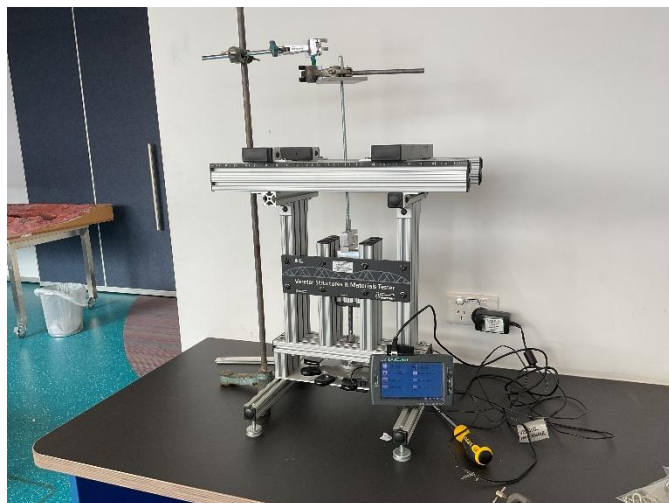


Figure 1.

Vernier Structures & Materials Tester used to measure the breaking load of the vegetable-based paper samples.

Risk Assessment

Risks were considered as shown in Table 3.

Material or Procedure	Main Risks	Control Measures
0.1 mol/L sodium hydroxide solution [7] [8]	Irritation to the skin and eyes; possible corrosive effects	Wear safety glasses, gloves, and a lab coat, and avoid contact with the skin and eyes. If the solution is spilled or comes into contact with the body, report it to the teacher immediately.
0.5 mol/L hydrochloric acid [9] [10]	Irritation to the skin and eyes; possible damage caused by acid	Wear safety glasses, gloves, and a lab coat, and handle the acid carefully in small amounts. If it comes into contact with the skin or eyes, rinse immediately with water and report it to the teacher.
Heating procedure	Burns, splashing of hot liquid, and contact with hot glassware	Use a heat-resistant mat, and do not touch equipment directly during or immediately after heating. Do not leave the area while heating is in progress.
Knife, cutter, and scissors	Cuts	Use them on a stable cutting board, and do not place hands in the direction of the blade. After use, place them in a safe location.
Glassware	Injury caused by breakage	Handle glassware carefully and avoid strong impacts. If glassware breaks, do not touch it with bare hands, and report it to the teacher.
Pressing with weights	Dropping weights and trapping fingers	Use weights on a flat surface, and do not place hands under the weights. Place the weights slowly and carefully.
Drying in a fume cupboard	Contact with mould or odour; contamination of samples	Avoid direct contact with the samples. If any abnormal changes are observed, confirm them with the teacher. Wash hands after observation.
Microscope observation	Breakage of microscope slides or cover slips; damage to equipment	Handle glass materials carefully, and do not allow the objective lens to press strongly against the sample or glass.
Vernier Structures & Materials Tester	Fingers being caught in moving parts; scattering of fragments when the test piece breaks	Keep hands and face away from the moving parts and the test piece during measurement. Operate the device according to the teacher's instructions.
Adhesive	Contact with skin; inhalation of vapour	Use the minimum necessary amount and handle it in a well-ventilated area. If it comes into contact with the

		skin, do not rub it forcefully, and check with the teacher.
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Table 3. Risk Assessment for the Experimental Procedures

Results

1. Results of paper-like sample preparation

Measurable paper-like samples were produced from celery, potato, sweet potato, and carrot. (Figures 2-5)

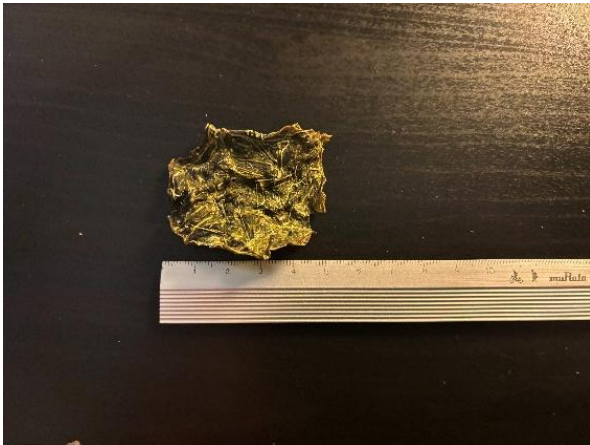


Figure 2.

Celery paper-like sample after drying. The sample maintained a sheet-like shape and showed visible fibrous texture.



Figure 3.

Potato paper-like sample after drying. The sample formed a sheet, but its surface appeared less fibrous than the celery sample.

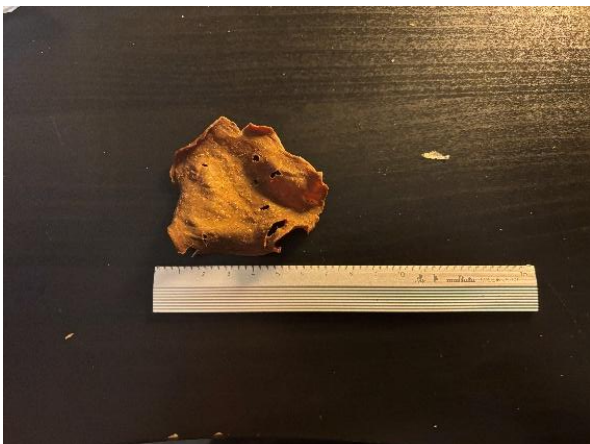


Figure 4.

The dried sweet potato sample formed a sheet-like material with a texture similar to the potato sample. It showed slight flexibility, while some fibrous texture was also observed.



Figure 5.

The dried carrot sample formed a thin, fibrous sheet-like material with a texture similar to the celery sample.

2. Results of microscopic observation

Microscopic observation showed differences in internal structure depending on the type of vegetable. In the celery sample (Figure 6), several fibrous structures remained and overlapped with each other. Similar fibrous structures were also observed in the carrot sample, although their amount and clarity were lower than those in celery (Figure 7). In the sweet potato sample (Figure 8), some fibrous structures were observed, but they were less abundant than in celery and carrot. In the potato sample (Figure 9), clear fibrous structures were limited, and many round granular structures, which were considered likely to be starch granules, were observed.



Figure 6.

Microscopic image of the celery sample at 100× magnification. The celery sample showed clear and overlapping fibre-like structures.

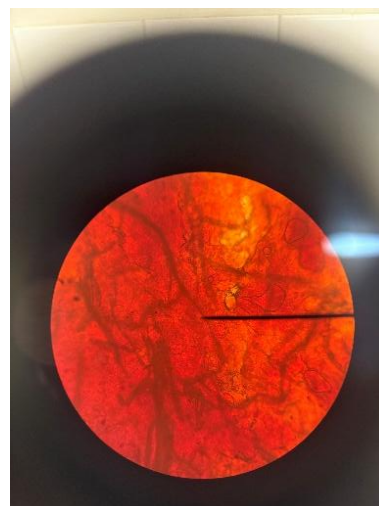


Figure 7.

Microscopic image of the carrot sample at 100× magnification. The carrot sample showed a thin, fibrous structure similar to that observed in the celery sample.

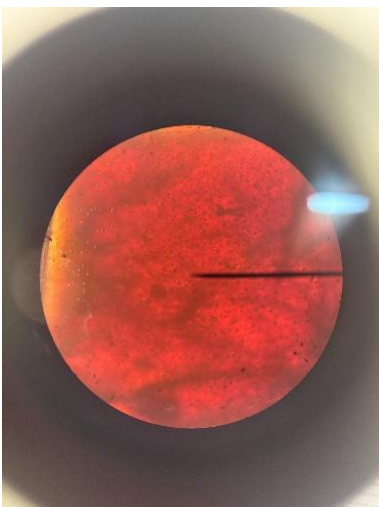


Figure 8.

Microscopic image of the sweet potato sample at 100× magnification. The sweet potato sample showed some fibre-like structures, but these were less clear than those observed in the celery and carrot samples.



Figure 9.

Microscopic image of the potato sample at 40× magnification. The potato sample showed many round granular structures, and clear fibre-like structures were rarely observed.

3. Results of tensile strength testing

Two valid measurements per sample were used. (Table 4.)

Sample	Thickness (mm)	Breaking Load 1 (N)	Breaking Load 2 (N)	Average Breaking Load (N)	Cross-sectional Area (mm ²)	Tensile strength (N/mm ²)
Celery	0.6	31.3	32.2	31.75	6	5.29
Potato	1.3	24.5	22.8	23.65	13	1.82
Sweet potato	1.0	26.1	27.0	26.55	10	2.66
Carrot	0.5	23.4	24.2	23.80	5	4.76

Table 4. Thickness, Breaking Load, Cross-sectional Area, and Tensile Strength of Each Sample

Discussion

1. Effects of differences in tissue and components among vegetables on the structure after processing

Although the same treatment was applied to all vegetables, clear differences in internal structure were observed under the microscope. NaOH treatment is used as a process to remove or modify non-cellulosic components such as hemicellulose and lignin in plant fibres, making it easier to extract the fibres. [11] In this study as well, heating and alkaline treatment may have softened the tissues and weakened the bonds between cells, allowing fibres to remain relatively clearly in vegetables that originally contained many fibrous structures.

In the celery sample, the clearest fibrous structures were observed. Since the edible parts of celery are the stem and leaves, and celery has string-like structures running along its length, long and continuous fibrous structures may have remained even after NaOH heating and grinding. Fibrous structures were also observed in carrot, but because carrot is a storage root, fewer long fibre bundles may have remained compared with celery.

In the sweet potato sample, a small number of fibrous structures were observed, but they were less abundant than in celery and carrot. Since sweet potato is a storage root, its starchy parts may have softened during heating and contributed to forming the sample into a sheet. [12] However, the formation of a continuous fibre network was likely limited. In the potato sample, clear fibrous structures were hardly observed, while many round granular structures, which were considered likely to be starch granules, were observed. In tubers such as potatoes, starch granules are abundant inside parenchyma cells, which may explain why granular structures remained prominent after processing.

2. Effects of the remaining structure on tensile strength

The tensile strength results generally corresponded with the differences in internal structure observed under the microscope. The highest mean tensile strength was observed in celery at 5.29 N/mm², followed by carrot at 4.76 N/mm², sweet potato at 2.66 N/mm², and potato at 1.82 N/mm². This order generally matched the clarity of the observed fibrous structures.

Cellulose microfibrils are considered to have high tensile strength and to contribute to the mechanical strength of plant cell walls. [3] Although the fibrous structures observed in this study cannot be identified as pure cellulose, the overlapping fibres observed in celery and carrot may have helped transmit tensile load over a wider area. If fibres are continuous and have many contact points, force concentrated in one area can be distributed to other fibres, making local cracks less likely to develop into complete fracture.

The highest tensile strength obtained in celery may be explained not only by the presence of remaining fibres, but also by the formation of an overlapping structure that distributed the applied load. In carrot, the mean breaking load was relatively small at 23.80 N, but because the cross-sectional area was 5 mm², the tensile strength per unit area was high at 4.76 N/mm². This result indicates that even a thin sample can show high tensile strength if a fibre structure capable of supporting the load remains.

In contrast, in sweet potato and potato, even though sheet-like samples were formed, the fibre network supporting the tensile load may not have been sufficient. In sweet potato, the starchy components may have helped form the sample. However, although starch gelatinises with water and heating and contributes to the formation of gel or film-like structures, starch-based films have also been reported to become brittle after drying. [4] Therefore, load distribution by fibres may have been limited, resulting in lower tensile strength than in celery and carrot.

In potato, many granular structures were observed, suggesting that there were fewer continuous pathways for transmitting tensile load. Stress may have concentrated at the boundaries between granules or in uneven areas, making these local weak points more likely to become starting points for fracture. This may explain why potato showed the lowest mean tensile strength. Overall, these results suggest that, for vegetable-derived paper-like materials, the important factor is not simply whether the material can be formed into a sheet, but whether a continuous fibre network capable of supporting tensile load can remain after processing.

3. Evaluation of the Experiment

In this study, samples in which more fibrous structures were observed under the microscope tended to show higher tensile strength. This suggests that differences in the internal structure remaining after processing may be related to the tensile strength of vegetable-derived paper-like samples. However, there were several limitations in this investigation. First, the amounts of cellulose and starch were not chemically quantified. Therefore, the differences in strength cannot be explained solely by the amounts of these components. In addition, the round granular structures observed in the potato sample could not be definitively identified as starch granules, as they were not confirmed using iodine solution or other identification methods.

The microscopic observations were also limited to qualitative comparisons. The number, length, and density of fibres were not measured numerically. Therefore, the relationship between fibre structure and tensile strength can only be discussed as a possible trend. There were also limitations in the tensile strength testing. In some trials, peeling at the fixed sections or breakage during measurement occurred, so only two valid measurements were used for each sample. Because the number of measurements was small, the results may have been affected by individual variation and random errors.

Outlook

In future work, the number of test pieces should be increased to improve the reliability of the mean values and variation. The fibre structure should also be quantified, and the amounts of cellulose and starch should be measured more directly. In addition, the origin of the granular structures should be confirmed using methods such as the iodine-starch test.

Furthermore, to evaluate these materials as possible alternatives to plastic, properties other than tensile strength should also be investigated. Practical use would depend on factors such as water resistance, flexibility, storage stability, and production cost. Future research should examine these additional properties and consider what types of applications vegetable-derived paper-like materials may be suitable for.

Conclusion

In this study, paper-like samples were produced from common vegetables, and their internal structures and tensile strengths were compared. Paper-like samples were successfully produced from celery, carrot, sweet potato, and potato. Microscopic observation showed that clear fibrous structures remained in the celery and carrot samples, a small number of fibres were observed in the sweet potato sample, and many

granular structures were seen in the potato sample. In the tensile strength test, samples with more fibrous structures tended to show higher tensile strength, suggesting that the fibre network remaining after processing may be related to the strength of the samples.

However, the amounts of cellulose and starch were not directly measured, and the microscopic observations were qualitative. Therefore, the differences in strength cannot be explained solely by the amounts of these components. In future work, it will be necessary to increase the number of measurements and quantitatively analyse both the fibre structure and component amounts to evaluate the relationship between internal structure and mechanical strength more accurately.

Appendix: Observation of mould in samples not used for strength testing

In this study, samples that showed changes after drying were observed separately from the samples used for strength testing. In some of the sweet potato and celery samples, white, cotton-like spots were observed. When these spots were examined under a microscope, thread-like structures spreading in a cotton-like manner were seen. These features were consistent with the appearance and microscopic images of mould, which is a type of fungus. Therefore, in this study, the white spots were identified as mould, specifically fungal mycelium. However, because culturing, detailed observation of spore-forming structures, and species identification were not conducted, the type of mould could not be identified.

The observation of mould growth during storage indicates that vegetable-derived paper-like samples can be affected by microorganisms. This suggests that they may be decomposed in the natural environment; however, biodegradability was not directly measured in this study. In future work, biodegradability should be evaluated more objectively by controlling temperature, humidity, and storage period, and by measuring changes in mass and structure.



Figure A1.

White spots observed on the sweet potato sample. White cotton-like spots were observed on part of the dried sweet potato sample.

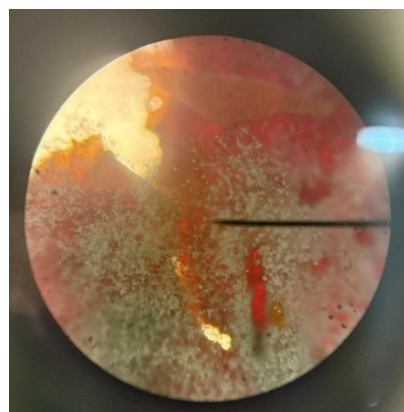


Figure A2.

Microscopic image of the white spot observed on the sample. Thread-like structures spreading in a cotton-like form were observed under the microscope.

(2199 words)

Acknowledgements

I would like to express my sincere gratitude to my teachers, Ms Mihelios, Mr Noack, Mr Lewis, and Mr Fisher, for their guidance and support throughout this research project. I also acknowledge the Tokyo Metropolitan Board of Education for providing financial support for my study abroad program.

In addition, I used ChatGPT and DeepL to support the translation of this report, and ChatGPT to help search for relevant reference materials. The final content, interpretation, and conclusions of this report are my own responsibility.

References List

- [1] Environment, UN. "Plastic Pollution." *UNEP - UN Environment Programme*, 2022, www.unep.org/plastic-pollution?utm.
- [2] Alberts, Bruce, et al. "The Plant Cell Wall." *Nih.gov*, Garland Science, 2025, www.ncbi.nlm.nih.gov/books/NBK26928/?utm.
- [3] Erdal, Nejla B., and Minna Hakkarainen. "Degradation of Cellulose Derivatives in Laboratory, Man-Made, and Natural Environments." *Biomacromolecules*, vol. 23, no. 7, 28 June 2022, pp. 2713–2729, <https://doi.org/10.1021/acs.biomac.2c00336>. Accessed 5 Feb. 2023.
- [4] "Strategies and Methodologies for Improving Toughness of Starch Films." *Mdpi.com*, 2026, www.mdpi.com/2304-8158/13/24/4036?utm.com. Accessed 21 June 2026.
- [5] "Washi, Craftsmanship of Traditional Japanese Hand-Made Paper - UNESCO Intangible Cultural Heritage." *Unesco*, 2026, ich.unesco.org/en/RL/washi-craftsmanship-of-traditional-japanese-hand-made-paper-02291?utm. Accessed 21 June 2026.
- [6] for, Agency. "Video Washi, Craftsmanship of Traditional Japanese Hand-Made Paper." *Unesco*, UNESCO, 2026, ich.unesco.org/en/video/22081?utm_source=chatgpt.com. Accessed 21 June 2026.
- [7] "Sodium Hydroxide | Medical Management Guidelines | Toxic Substance Portal | ATSDR." *Cdc.gov*, 2025, wwwn.cdc.gov/TSP/MMG/MMGDetails.aspx?mmgid=246&toxid=45&utm.
- [8] "Hazardous Chemical Information System (HCIS)." *Safeworkaustralia.gov.au*, 2018, hcis.safeworkaustralia.gov.au/HazardousChemical/Details?chemicalID=4177&utm.com.
- [9] "CDC - NIOSH Pocket Guide to Chemical Hazards - Hydrogen Chloride." *Cdc.gov*, 2019, www.cdc.gov/niosh/npg/npgd0332.html?utm.com.
- [10] "Hydrogen Chloride | Medical Management Guidelines | Toxic Substance Portal | ATSDR." *Cdc.gov*, 2026, wwwn.cdc.gov/TSP/MMG/MMGDetails.aspx?mmgid=758&toxid=147&utm. Accessed 21 June 2026.
- [11] "Analysis of the Characterization of NaOH-Treated Natural Cellulose Fibre Extracted from Banyan Aerial Roots." *Nih.gov*, 2024, pmc.ncbi.nlm.nih.gov/articles/PMC10400698/?utm.com.

[12] Choi, Jong Hyun, et al. "Flour and Parenchyma Cells from Sweet Potato and Potato: A Comparative Study of Their Physicochemical Properties and Digestibility." *Food Science and Biotechnology*, vol. 34, no. 6, 18 Dec. 2024, pp. 1327–1337, <https://doi.org/10.1007/s10068-024-01777-9>.

OSA RISK ASSESSMENT FORM

for all entries in ☒ Models & Inventions and ☒ Scientific Inquiry

This must be included with your report, log book or entry. One form per entry.

STUDENT(S) NAME: Tunichiro Arita

ID: 0233-001

SCHOOL: Hamilton Secondary College

Activity: Give a brief outline of what you are planning to do.

This investigate will compare the tensile strength and microscopic structure of paper-like materials made from different vegetables. Celery, carrot, potato and sweet potato will be cut, heated in dilute sodium hydroxide solution, neutralised with hydrochloric acid, filtered, mashed, pressed and dried to form thin samples. The dried samples will be observed using a light microscope and tested with a Vernier Structures & Materials Tester to compare

Are there possible risks? Consider the following: their tensile strength.

- Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.
- Thermal risks: Are you heating things? Could you be burnt?
- Biological risks: Are you working with micro-organisms such as mould and bacteria?
- Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?
- Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead?
- Radiation risks: Does your entry use potentially harmful radiation such as UV or lasers?
- Other hazards.

Also, if you are using other people as subjects in an investigation you must get them to sign a note consenting to be part of your experiment.

Risks	How I will control/manage the risk
<u>Risks of skin and eye irritation and corrosion associated with the use of 0.5 and 0.1 mol/L sodium hydroxide solution and 0.5 mol/L hydrochloric acid.</u> <u>Continued on the attached sheet.</u>	<u>Wear safety goggles, gloves and a laboratory apron, and avoid contact with the skin or eyes. If the solution is spilled or comes into contact with body, rinse immediately with plenty of water and report the incident to the supervisor.</u>

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out

RISK ASSESSMENT COMPLETED BY (student name(s)): Tunichiro Arita

SIGNATURE(S): 有田 淳一郎

☒ By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.

TEACHER'S NAME: Felicia Michalos

SIGNATURE: [Signature] DATE: 23/4/20

Risks ✓	How I will control / manage the risk
Burns, splashes of hot liquid and contact with hot glassware resulting from the heating of aqueous solutions using a burner	Use a heat-resistant mat, and do not touch equipment directly during or immediately after heating. Do not leave the area while heating is in progress.
Injuries caused by the use of knives, cutters, and scissors	Use them on a stable cutting board, and do not place hands in the direction of the blade. After use, place them in a safe location.
Injuries caused by glassware	Handle glassware carefully and avoid strong impacts. If glassware breaks, do not touch it with bare hands, and report it to the supervisor.
Bruises caused by the use of weights	Use weights on a flat surface, and do not place hands under the weights. Place the weights slowly and carefully.
The risk of encountering mould, unpleasant odours or contamination during sample drying	If any abnormalities are observed in the sample, report them to the supervisor and avoid touching directly. Wash my hands after observation.
Injuries caused by broken microscope slides and cover slips during microscopic observation	Handle glass materials carefully, and do not allow the objective lens to press strongly against the sample or glass.
The risk of finger injuries when using 'vernier structures & Materials Tester'	Keep hands and face away from the moving part and the test piece during measurement. Operate the device according to the supervisor's instruction.
Risks associated with skin contact with adhesives and inhalation of vapour	Use only the minimum necessary amount of adhesive and handle it in a well-ventilated area. If it comes into contact with skin, do not rub it vigorously; consult the supervisor.

From Kitchen to Material

2 February 2026

Name : Junichiro Arita

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Overview of the Research

- This research explores the possibility of using vegetables as alternative materials to plastic.
- Different vegetables and plant materials will be investigated to examine how they can be processed into paper-like materials.
- The research will explore the properties, limitations, and potential applications of these materials through experimentation and comparison.
- The aim of this study is to investigate whether vegetable-based materials could contribute to more sustainable alternatives to conventional plastics.

Background

① Marine Plastic Pollution

- Plastic pollution in the ocean has become a serious global environmental problem.
- According to UNEP, 19 to 23 million tonnes of plastic waste leak into aquatic ecosystems every year.
- Microplastics may also affect marine ecosystems and living organisms.

② Plant-Based Materials

- In recent years, biodegradable and plant-based materials have attracted attention as alternatives to conventional plastics.
(such as starch, cellulose, PLA, PHA) → p.10-11 p.51-53
- Plants contain natural fibres substances (e.g. cellulose) that may be useful for environmentally sustainable materials. p.10-11

③ Cellulose and Paper

- Cellulose is one of the main components of plant cell walls.
- It's commonly used in the production of paper and fibre-based materials.
- Because cellulose is renewable and biodegradable, it may have potential as a plastic alternative material.

2 February 2026

④ Research Connection

- This research explores the possibility of using vegetables and plant materials as alternatives to plastic through experimentation and material investigation.

Bibliography

- ① Environment, UN. "Plastic Pollution" UNEP-UN Environment Programme. 2022, www.unep.org/plastic-pollution?utm.

Experiment 1

Trial Production of Paper-like Material from Vegetable

23 April 2026

PLAN

1. Aim

- The aim of this experiment is to investigate whether vegetables can be processed into paper-like materials using methods inspired by traditional Japanese washi papermaking (→ Page 10)

2. Background of the Method

- Traditional washi papermaking uses plant fibres suspended in water and formed into thin sheet.
- This experiment was inspired by the general process of washi papermaking, including fibre extinction, sheet formation, pressing and drying.
- However, in this experiment, unlike traditional washi papermaking, the pulp is not dispersed in water before sheet formation in order to produce paper-like material through a simpler process. Instead, the pulp is directly spread into a sheet form.

3. Materials and Equipments

① Vegetables

Celery, carrots, apples, onions : each 30 g

② Chemicals

- 0.1 mol/L Sodium hydroxide solution (NaOH) each 110 ml
- 0.5 mol/L Hydrochloric acid (for neutralisation) (HCl)

③ Equipment

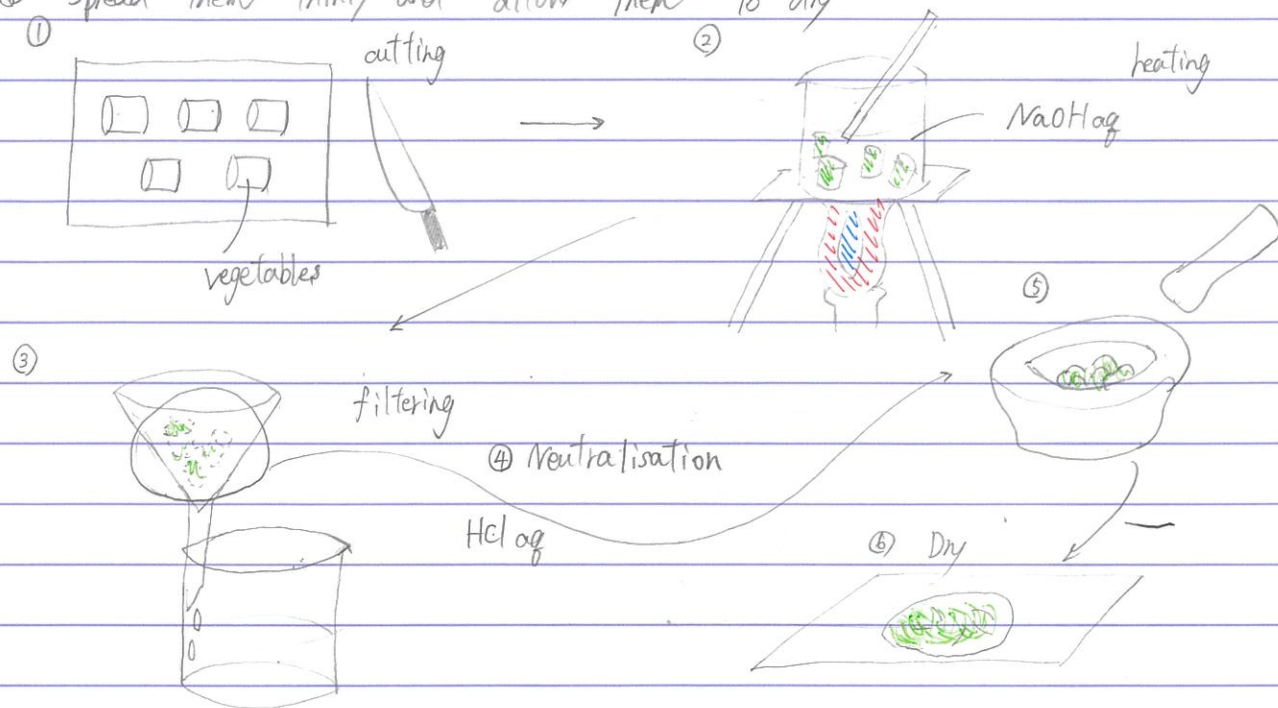
- | | |
|---|---------------------------------|
| • 250 mL Beaker × 4 | • Mortar and pestle × 1 |
| • Gas burner × 1 | • Lab Apron × 1 |
| • Tripod and wire gauze × 1 | • Safety goggles and gloves × 1 |
| • Filter paper and filtration apparatus × 1 | • Scale × 1 |

4. Method

- ① Chop vegetable waste (e.g. celery) into small pieces (about 30 g)
- ② Add dilute sodium hydroxide solution and heat while stirring. NaOH : 110 mL.
- ③ Filter the mixture to collect the remaining fibrous material. heating : 30 min

23 April 2026

- ④ Neutralise the residue with dilute hydrochloric acid and rinse thoroughly with water.
- ⑤ Grind the fibers with a mortar and pestle
- ⑥ spread them thinly and allow them to dry



5. Observation Points

- Whether the experimental method is suitable for producing paper-like material
- Whether the vegetable material can be processed into pulp.
- Whether the pulp can be spread into a sheet form
- What kind of paper-like material is produced
- Texture and appearance of the material
- Flexibility and thickness of the material
- Whether the material keeps its shape after drying
- Problems or limitation observed during the process.

6. Prediction

- It is predicted that some plant fibers including cellulose fibres, will remain after the processing steps and form a paper-like material when dried.

24 April 2026

Results / Experimental Log

Date : 24 April 2026

Log

11:25 AM Experiment started

Points / Observation

- For safety reasons, I wore a lab coat, rubber gloves and safety goggles

11:28 AM Vegetables were cut into small pieces.

- Different vegetables had different textures and water contents.

1cm x 1cm x 1cm

11:47 AM Heating of celery sample was started

Celery : 32.78g NaOH aq : 110 mL

11:54 AM Heating of the carrot sample was started.

Carrot : 31.11g NaOH aq : 110 mL

12:17 PM Heating of the celery sample was completed.

The material was filtered and formed into a sheet.

- The sodium hydroxide solution was deep green in colour and had strong smell of celery.

- Fibers were clearly visible
- The materials held together relatively well.

12:24 PM Heating of the carrot sample was completed.

The same filtering and sheet-forming processes were carried out.

- The sodium hydroxide solution was orange in colour and had a sweet smell.

- The material became softer after heating.
- It fell apart, so it was unable to examine fibers.

1:10 PM Heating of the apple sample was started

Apple : 30.57g NaOH aq 110 mL

1:19 PM Heating of the onion sample was started

Onion : 31.35g NaOH aq 110 mL

The production process for the celery sample

27 April 2026

1:40 PM Heating of the apple sample was completed.
The same filtering and sheet-forming processes were carried out.

The sample and the aqueous solution turned black and had a strong sweet smell. Apart from what appeared to be apple peel, the rest was quite soft, and no fibres were detected.

1:49 PM Heating of the onion sample was completed. The same filtering and sheet-forming processes were carried out.

The onion sample was more difficult to keep in shape.

Drying Process

Ceramic plates were used as the base for drying the paper-like materials.

After Drying Observation (27 April 2026)

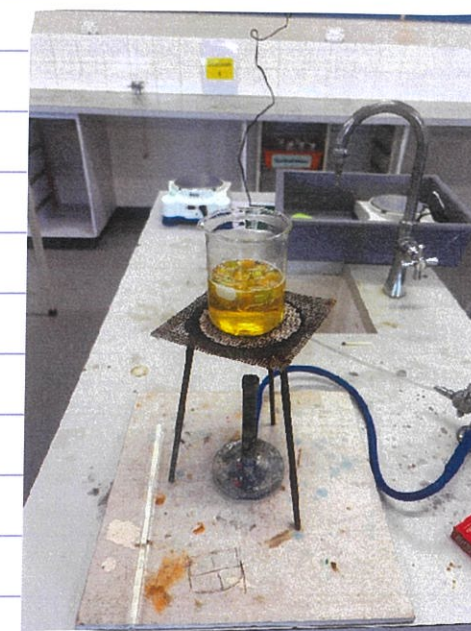
The samples were left to dry for three days before their condition checked.

However; all completed samples became strongly attached to the ceramic plates and could not be removed for detailed observation.

Despite this, when touched by hand, the surfaces of the samples felt rough and textured, similar to traditional nashi-paper.

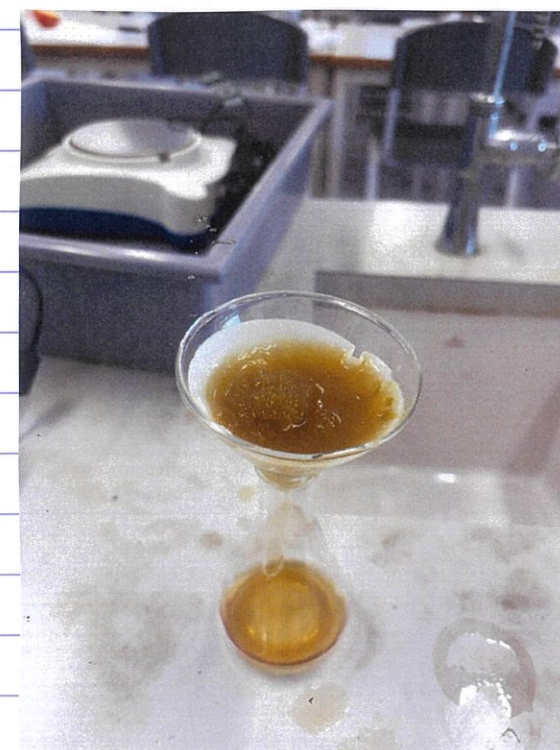


cutting

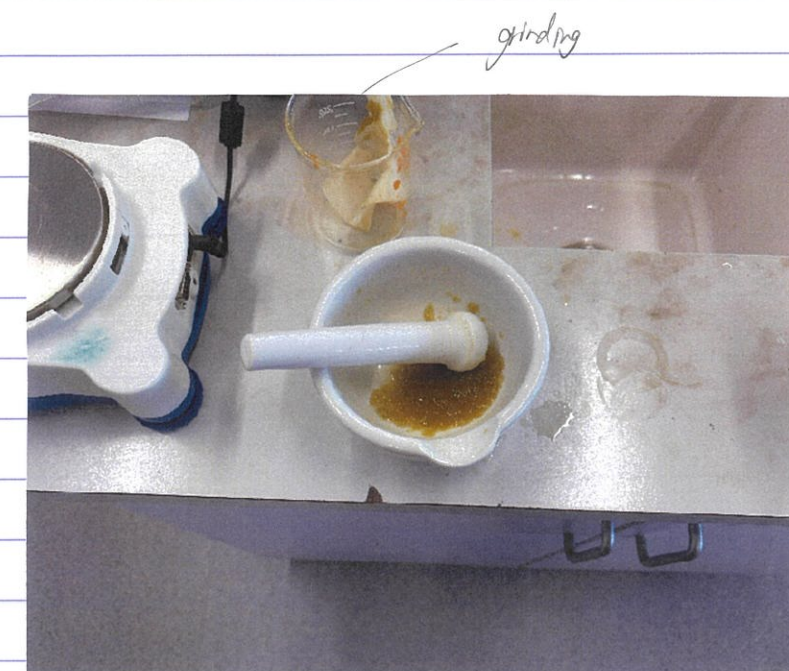


heating

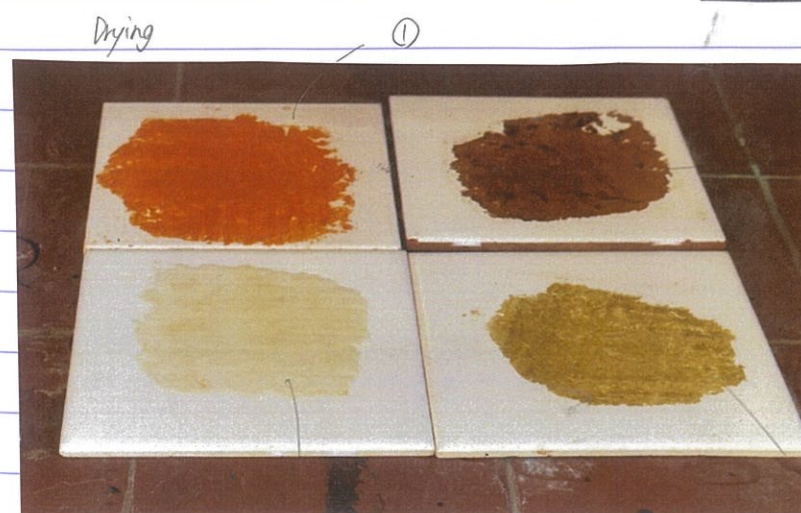
yellow green colour



filtering



grinding



Drying

- ① Carrots
- ② Apples
- ③ Onions
- ④ Celery

Discussion of the Results

① Validity of the experimental method

- Although the samples could not be removed from the ceramic plates, the texture and appearance suggested that paper-like materials may have formed successfully.
- The rough texture similar to washi paper suggested that plant fibers may have remained after processing and formed a connected structure during drying.
- The experiment suggested that simplified methods inspired by washi papermaking may still allow the formation of paper-like materials.



The basic process appears to be effective.

② Why did the sample stick to the ceramic plate?

What was the cause?

↳ Evaporation?

It's possible that, while the pulp was still in a liquid state, it adhered to the plate as it dried, with only the water evaporating from it, causing it to stick.

Hydrogen bonding via cellulose?

Cellulose readily forms hydrogen bonds. It's possible that the fibres have bonded not only with each other but also with the plate.

(→ Page 10)

Pectin or Sugar?

It's possible that natural substance such as pectin and sugars found in vegetables and fruits acted as an adhesive.

(→ Page 10)

③ How to improve the experimental method

Problem: sticking to the ceramic plate

Evaporation

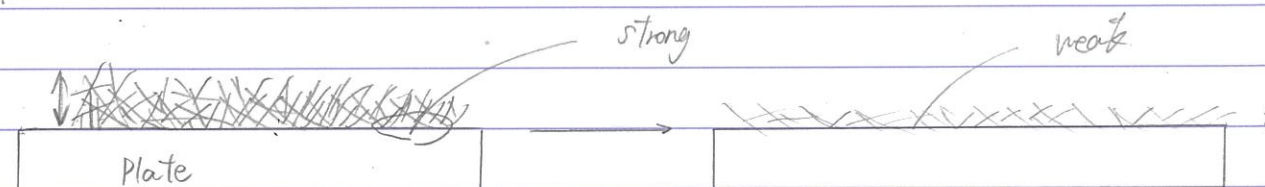
→ Using a material with non-stick surface as the base?

↳ Baking paper? Cooking tray?

Hydrogen bonding via cellulose

→ Spreading the pulp thinly may reduce hydrogen bonding in the longitudinal direction (The image below)

*



→ Rather than spreading the pulp directly onto the plate, it might be possible to produce a thinner paper-like material by dispersing it in water and then scooping it up with a mesh screen to spread it out.

Pectin or Sugar

→ Pectin reacts with sodium hydroxide, causing its adhesive strength to weaken

↳ wouldn't altering the concentration of sodium hydroxide make it less likely to bond with the substrate.



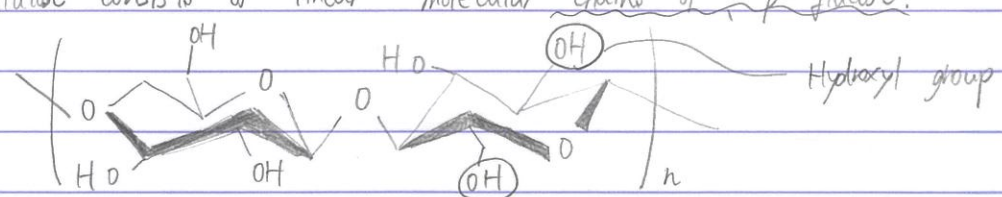
④ Outlook for the next experiment

- Line the base with baking paper
- Scoop up the mixture dispersed in water using a sieve and spread it thinly
- Investigate how the reaction differs depending on the concentration of sodium hydroxide.

1 May 2026

Background research 1 : Cellulose

- Cellulose is a major structural component of plant cell walls.
- Cellulose consists of linear molecular chains of β -glucose.



- This molecular chain is easy to connect by hydrogen bonding.
- And it's easy to form highly crystalline microfibrils.



- This structure contributes to the tensile strength of plant cell wall.

- ★ In terms of biodegradability, it varies depending on the fibre structure, the amount of impurities such as lignin and pectin, as well as the conditions under which decomposition take place.

Bibliography

- Britannica, T. Editors of Encyclopaedia. (Mar 21, 2025). Cellulose. Encyclopedia. britannica.com.
- Alberts, Bruce, et al. "The Plant Cell Wall." NIH.gov, Garland Science, 2025, www.ncbi.nlm.nih.gov/books/NBK26928/?utim.
- Erdal, Nejla B., and Minna Hakkarainen. "Degradation of Cellulose Derivatives in Laboratory, Man-Made, and Natural Environments" Biomacromolecules, vol. 23, no. 7, 28 June 2022 pp. 2713-2729, https://doi.org/10.1021/acs.biomac.2c00336.

Background research 2 : Pectin

- Pectin is a complex polysaccharide found in plant cell walls. It's one of the main components of the cell wall, together with cellulose.
- Pectin is also abundant in the middle lamella, which is the layer between neighbouring plant cell.

microfibril

1 May 2026

The main chemical component of pectin is galacturonic acid. It's not a single simple molecule, but a group of related polysaccharides.

In plants, pectin helps control the physical properties of the cell wall (adhesion, wall flexibility, softening of plant tissues). It's especially important for holding neighbouring plant cells.

Bibliography

- Daher, F. B., & Braybrook, S. A. (2015). How to let go : Pectin and plant cell adhesion. Frontiers in Plant Science, 6, 523.
- Shin, Y. Chane, A., Jung, M., & Lee, Y. (2021). Recent advances in understanding the roles of pectin as an active participant in plant signaling networks. Plants 10(8), 1712.

Background Research 3 : Washi paper

Washi is traditional Japanese handmade paper

- Plant fibre selection

Washi is commonly made from fibres from plants such as kozo, mitsumata, and gampi.

- Heating in alkaline solution

The fibres are heated in a mild alkaline such as wood ash or soda ash, to remove non-cellulose materials (e.g. lignin)

- Washing and removing impurities

After heating, the fibres are washed to remove the alkaline solution and remaining unwanted materials.

- Beating the fibres

The fibres are beaten to separate and loosen them. This helps the fibres spread more evenly in water and bond with each other during sheet formation.

- Mixing fibres with water

- The beaten fibres are mixed with water

- Sheet formation

The fibre suspension is scooped using a mould and screen.

- Pressing and Drying

The wet sheets are pressed to remove excess water. Then, the sheets are dried.

Bibliography

- UNESCO. (n.d.) Washi, craftsmanship of traditional Japanese hand-made paper. Intangible Cultural Heritage.
- The Japanese Paper Place. (n.d.) Papermaking in Japan.

Experiment 2: Improving the Production Method for Vegetable-Based

Paper Materials

7 May 2026

PLAN

1. Aim

To improve the production method for vegetable-based paper materials based on the problems observed in Experiment 1.

2. Background of the method.

In Experiment 1, paper-like materials appeared to form from vegetable pulp.

However, the samples strongly adhered to the ceramic plates after drying and could not be removed properly. Therefore, the production method needed to be improved.

In this Experiment 2, to improve the production process, several modification is made.

First, baking paper is introduced between the samples and plates to reduce adhesion.

Second, the concentration of NaOH is adjusted to make the pectin dissolve more easily.

Finally, a water-dispersion step is introduced before sheet formation in order to spread the fibers more thinly.

3. Materials and Equipments.

① Vegetables : Celery each 30 g.

② Chemicals

• 0.5 mol/L Sodium hydroxide solution (NaOH) • Distilled water 150 mL

• 0.5 mol/L Hydrochloric acid (HCl)

150 mL

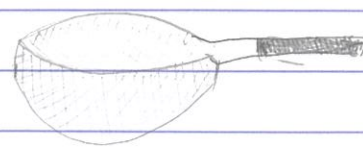
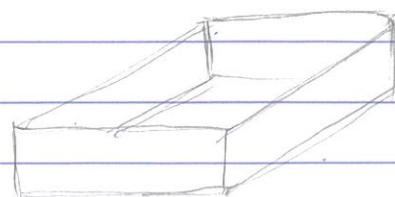
③ Equipments

• Same as Experiment 1 with the following addition:

• Baking paper x1

• Cooking tray x1

• Cooking grill (net) x1



7 May 2026

4. Method

①~⑤ Same as Experiment 1

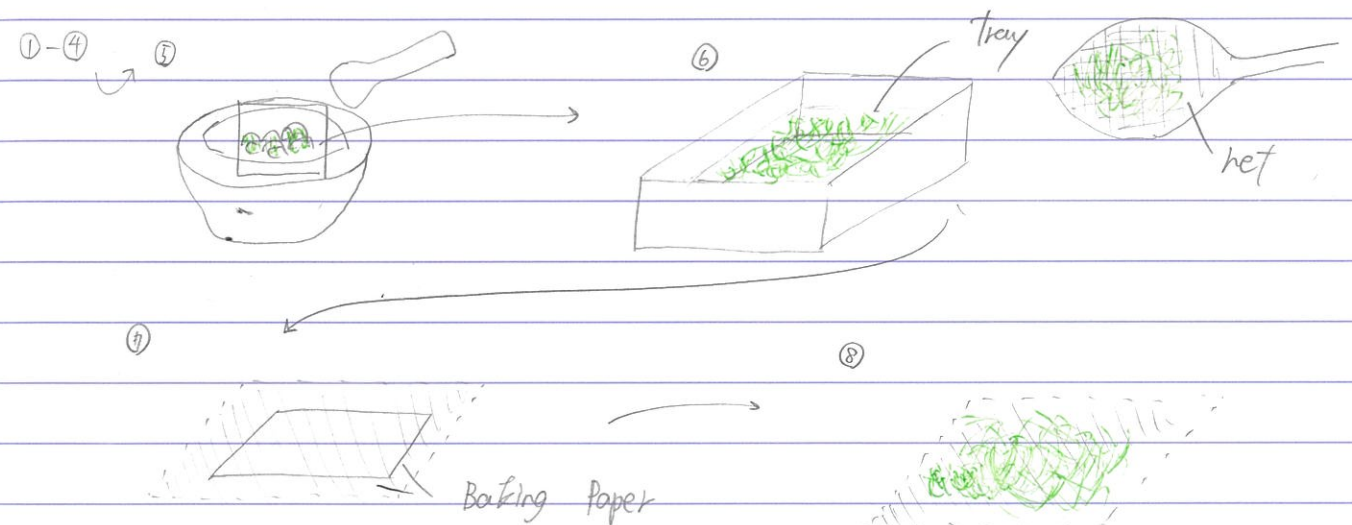
The following modifications are introduced:

⑥ Disperse the pulp in water and scoop it up with a net.

⑦ Line the plate with baking paper

⑧ Place the sample collected with the net on the base and leave them dry

⑨ Replace the aqueous solution used in step ② with distilled water instead of sodium hydroxide, and repeat steps ① to ⑧. (Omit the neutralization step).



5. Observation Points

• Whether the improved method prevents strong adhesion

• Whether the samples can be removed after drying

• Whether paper-like materials form successfully

• Texture, thickness, flexibility and appearance of the samples

• Differences in strength, tackiness and paper properties resulting from variations in the concentration of sodium hydroxide

• Problems or limitations of the improved method

6. Prediction

It's predicted that using baking paper as a drying surface will reduce adhesion and allow the samples to be removed more easily after drying. If the basic production process is suitable, the vegetable pulp should still form paper-like materials.

8 May 2026

Results / Experimental Log

Date: 8 May, 2026

Log

9:05 AM Experiment started

Points / Observation

For safety, I used a lab coat, rubber gloves and safety goggles

9:09 AM Finish preparing the equipment for the experiment.

9:15 AM Celery was cut into small pieces

9:31 AM Heating of celery sample with NaOH aq was started
→ 0.5 mol/L.

Celery: 28.85 g NaOH: 150 mL

Let this be sample 1

9:48 AM Heating of another celery sample with distilled water was started

Celery: 32.40 g H₂O: 150 mL

Let this be sample 2

10:01 AM Stop heating sample 1
The sample 1 was filtered

After straining, crushed using a pestle

Perhaps due to the increased concentration of NaOH aq, the mixture became thicker thicker than in the previous experiment and took on a more liquid-like consistency

10:05 AM Filled a cooking tray with water and attempted to disperse the pulp in the water

The amount of water in cooking tray: 2L

When the sample crushed with a pestle was dissolved in water, the liquid portion dispersed throughout the water, whilst the remaining fibrous material sank immediately without floating to the surface, making it difficult to scoop up with net.

★ Problem

8 May 2026

10:18 AM

changing plans due to the problem

After filtration, the sample was crushed using a mortar and pestle

The plan has been revised to produce paper-like material directly from pulp, with the exception of step ⑥

Unlike previous samples the shape of the celery remained almost unchanged compared to before heating, and could clearly feel its firmness when crushing it.

10:36 AM Rolled out the sample onto base lined with baking paper and left it to dry.

It seems to be related.

★ Points I noticed

In Sample 1 (using sodium hydroxide), as in the previous experiment, the liquid in the beaker turned green, in contrast, in sample 2 (using distilled water), the liquid remained colourless and transparent showing no change.

The experiment took longer than planned

★ Results of the sample after drying (11 May 2026)

A material resembling a transparent film has been produced.
Thanks to the baking paper, it was easy to peel it off the base
There are transparent sections and areas where something resembling celery fibres spreads out in all directions.
It measures approximately 9cm x 5cm.
It's strong enough that it does not deform or tear even when pulled gently by hand.

11 May 2026

Discussion of the Result

① Was the baking paper effective?

- It was possible to peel off the sample and observe it.
- ↳ Managed to resolve the issue from last time.

• Why does baking paper not stick?

- ↳ Baking paper has a non-stick surface, which may have reduced adhesion between the sample and drying surface.

↓
★ It's highly likely that the baking paper served as a drying surface.

② Was the water dispersion process effective?

- When the sample containing NaOH was dissolved in water, it immediately formed a precipitate; it did not disperse through the solution, and it was impossible to scoop it up with a net.

• Possible causes

- The fibres were too short?
- Unlike materials normally used in papermaking, there were too many impurities?
- The concentration of cellulose, which forms the paper, was too low?

★ Taking into account the possible causes and the fact that using baking paper made it easier to peel off, it seems that in future experiments it would be better to spread the pulp as it is rather than dispersing it in water.

③ The effect of changing the NaOH concentration

- I. In sample 1, sodium hydroxide was used at a concentration five times of the previous experiment.

11 May 2026

- ↳ After heating for 30 min, many parts had turned quite watery.
- This was likely another reason why dispersion in water was unsuccessful.

• Why has the proportion of liquid increased?

- This may have occurred because a greater amount of pectin and hemicellulose was removed, causing the plant structure to break down more extensively.
- As a result, the fibres became more dispersed and the pulp retained less of its original structure.

↓
★ A 0.5 mol/L sodium hydroxide solution is likely to be too concentrated to be suitable for the experiment.

- ↳ In the next experiment, use the same 0.1 mol/L aqueous solution as in the previous experiment.

II. Sample 2 was used as an aqueous solution in which distilled water was heated.

- During heating, almost no change in colour was observed in the aqueous solution.
- The material was noticeably harder than the other samples and difficult to grind.

★ These may indicate that little decomposition or extraction of the plant components took place.

• Succeeded in producing a "film-like material":

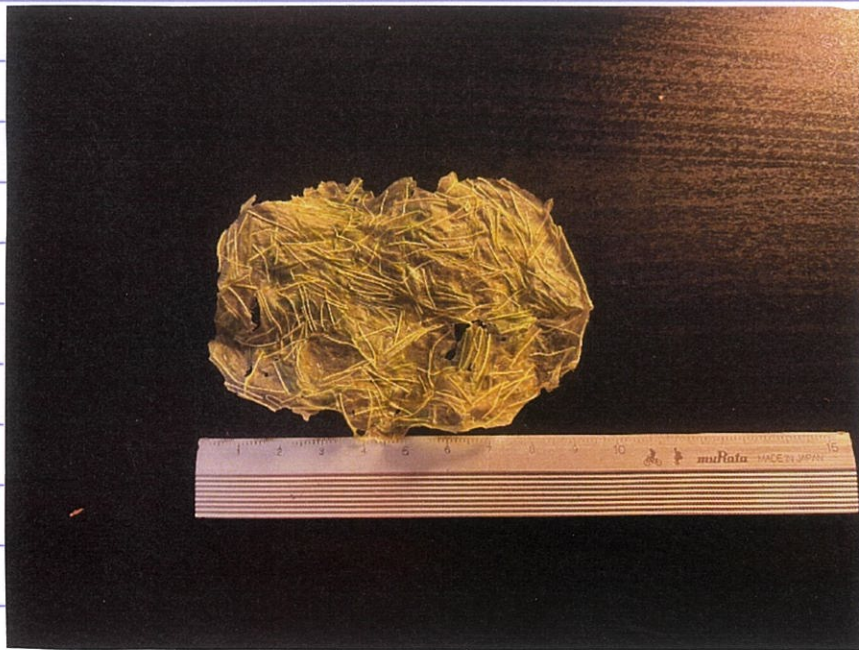
- ↳ However, many areas were observed where the celery fibres remained intact.
- These areas were more prone to tearing than the surrounding areas.
- The strength of the material was also not considered sufficient.

↓
★ Distilled water is unable to break down plant fibres and is therefore unlikely to be suitable for use as an aqueous solution in experiments.

11 May 2026

④ Outlook for the next experiment

- the concentration of Sodium hydroxide used for heating should be kept at 0.1 mol/L
- Conduct the experiment using other plants.



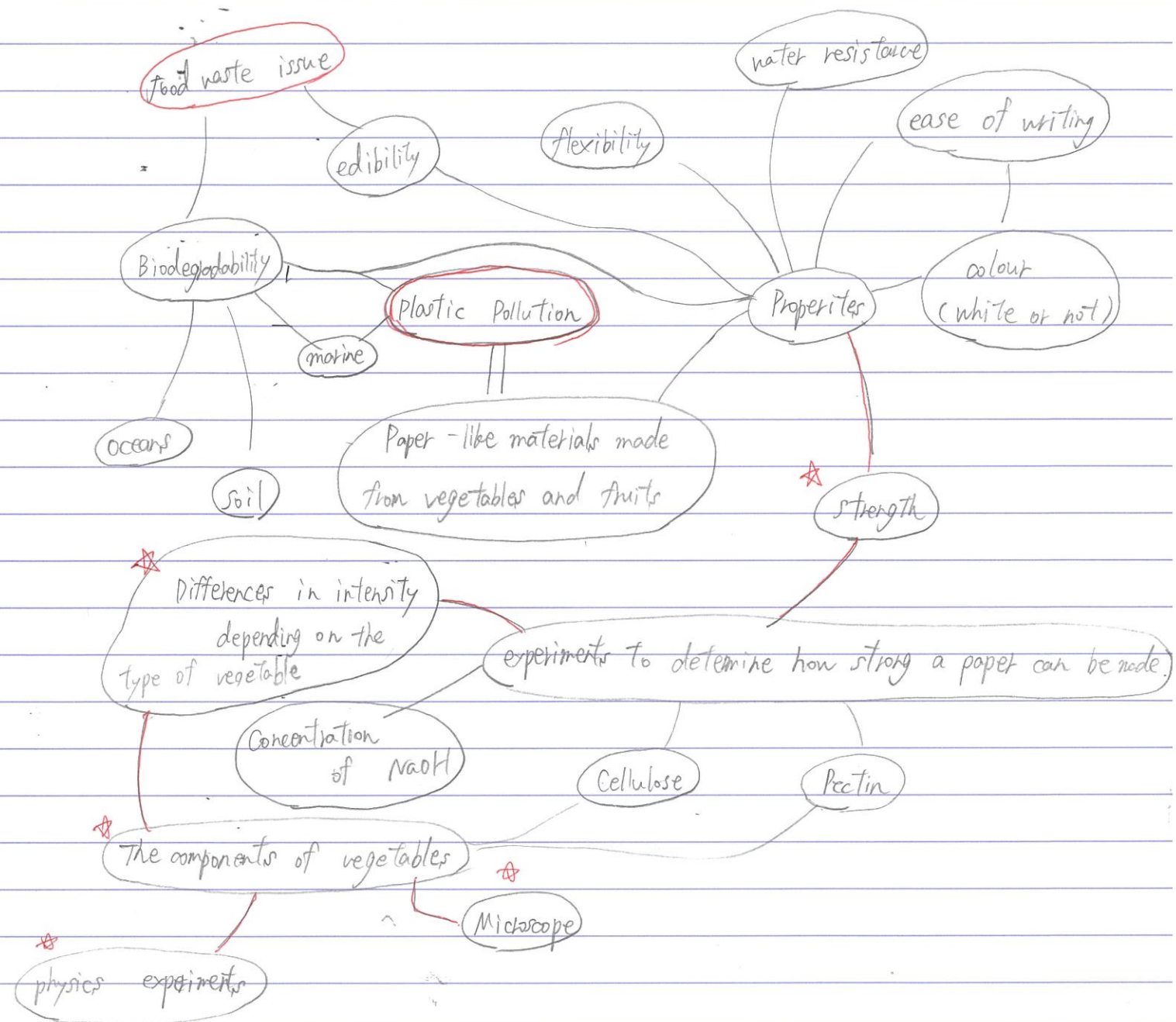
Sample created

- A sample with a texture resembling a thin film was produced.
- Fibre that appear to be from celery itself can be seen.

Review of the Research Direction

12 May 2026

Ideas for research directions



★ Future Research Plan (as of 12 May 2026)

1. Finalising method for creating paper-like materials
2. Creating samples of paper-like materials using various vegetables.
3. Focusing on strength and measuring it through physical experiments
4. Examining the causes of strength by analysing the constituent compounds and structure using microscopes and other tools.

Experiment 3 : Creating paper samples

19 May 2026

PLAN

1. Aim

The aim is to create paper-like materials from various vegetables and prepare samples for subsequent strength testing and microscopic observation.

2. Background

Cellulose is considered to be one of the main components responsible for the strength of paper. Therefore, vegetable with different fibre contents were selected to investigate how the source material affects the properties of the final paper sample.

The following vegetables were chosen:

- Celery : High in dietary fibre and readily available
- Potatoes : Contain less dietary fibre than celery and are high in starch
- Sweet potatoes : Contain relatively high levels of both dietary fibre and starch.
- Carrots : A common vegetable
- Onions : A common vegetable

Paper-like materials will be produced from these vegetables to compare differences in strength and structure.

3. Determination of Experimental Method

Based on the results of previous experiments, the following conditions are adopted.

- The concentration of the sodium hydroxide solution is set at 0.1 mol/L.
- The process of redispersing the pulp in water is omitted.
- The pulp obtained after filtration is spread directly into sheets.
- Baking paper is used as a base to prevent sticking during drying.
- All samples are prepared under identical conditions, with only the type of vegetable varying.

19 May 2026

4. Materials and Equipment

- ① vegetable : Celery, potatoes, sweet potatoes, carrots, onions : 30 g each
- ② chemicals
 - 0.1 mol/L sodium hydroxide solution (NaOH aq) (each 150 ml)
 - 0.5 mol/L Hydrochloric acid (HCl aq) (each 30 ml)
 - Distilled water
- ③ Equipment : Same as Experiment 2.

5. Method

Use the same method as in Experiment 2. However, omit the process of dispersing the sample in water described in step ⑥.

6. Prediction

The modifications made to the previous method will reduce problems during sample formation and drying, allowing paper-like samples to be successfully produced from each vegetable.

21 May 2026

Result / Experimental Log

Date : 21 May 2026

Log

Points / Observation

11:03 AM Experiment started (Day 1)

Preparing for the experiment.

11:30 AM Heating of potato sample with NaOH_{aq} was started.

Potatoes : 30.25 g, NaOH_{aq} (0.1 mol/L) : 150 mL

↓ Heating is scheduled to 30 min

Let this be sample 1.

11:35 AM Heating of Carrot sample was started

Carrots : 31.33 g, NaOH_{aq} (0.1 mol/L) : 150 mL
Let this be sample 2.

11:33 AM ★ Problem

As the vegetables in Sample 2 had lost their shape more than expected, the heating time reduced to 25 min.

When crushing sample 1, it felt quite sticky. It was like glue, it smelled of egg.

11:55 AM Stop heating sample 1
Proceed to step ④ and beyond.

The aqueous solution was cloudy white.

Start Heating of onions sample

Onions : 31.05 g, NaOH_{aq} : 150 mL
Let this be sample 3

12:00 PM Stop heating sample 2
Proceed to step ④ and beyond

It had completely lost its shape and was a right mess.

The aqueous solution had turned a deep orange colour.

12:25 PM Stop heating sample 3
Proceed to step ④ and beyond.

Its shape had dissolved and it had become like water. The solution remained colourless and transparent

Strong smell of onions.

12:35 PM Rolled out the sample onto base lined with baking paper and left it to dry

Date : 22 May 2026.

Log

Points / Observation

9:02 AM Experiment started (Day 2)

Preparing for the experiment

9:06 AM Heating of sweet potatoes sample was started

Sweet potatoes : 31.40 g NaOH_{aq} : 150 mL
Let this be sample 4.

9:13 AM Heating of Celery sample was started

Celery : 31.25 g NaOH : 150 mL
Let this be sample 5.

9:31 AM Stop heating sample 4.
Proceed to step ④ and beyond.

As in yesterday's experiment, set the heating time to 25 min.

The aqueous solution turns dark red and has a strong sweet smell.

9:38 AM Stop heating sample 5.
Proceed to step ④ and beyond

The aqueous solution is yellowish-green. It has a smell of celery. After filtration, a large amount of liquid was released during pulping.

★ Points I noticed

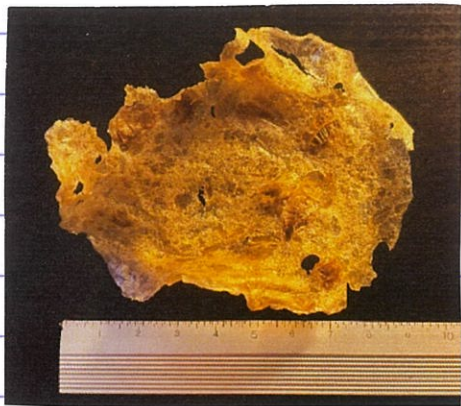
The amount of liquid produced during pulping varied among samples

- Sample 1 (Potato) → Hardly any liquid was produced.
- Sample 2 (Carrot) → A small amount of liquid was found, but it was mixed with pulp.
- Sample 3 (Onion) → A large amount of liquid was produced
- Sample 4 (Sweet potato) → A small amount of liquid was observed
- Sample 5 (Celery) → A large amount of liquid was observed

25 May 2026

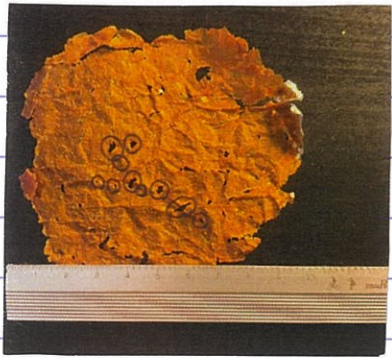
★ Results of the sample after drying (25 May 2026)

- Sample 1 produced a hard material with a plastic-like texture.
- Whilst sample 2, 4 and 5 produced paper-like materials.
- Sample 3 did not produce any material that could be handled.
- Paper-like samples 2 and 4 had numerous holes, and the areas where the paper had thinned and those where it had heated up were distinct, meaning the results were not uniform.



Sample 1 after drying

- It has taken on a texture resembling thin, hard plastic.
- Perhaps because it is so thin, it appears to have numerous tiny holes.



Sample 2 after drying

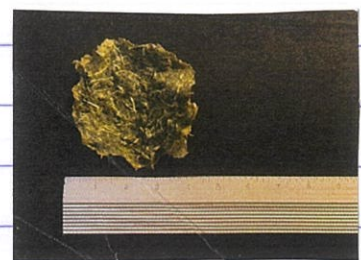
- It had a paper-like texture.
- It had numerous tiny holes and felt brittle.
- It may not be able to withstand the strength test.

★ Sample 3 did not result in a sample with a distinct shape.



Sample 3 after drying

- It had a texture similar to that of Sample 1 and 2.
- This sample also had many holes and may not be suitable for strength test.



Sample 4 after drying

- It had a texture like sturdy paper.
- There were relatively few holes.

27 May 2026

Discussion

① Was the method for creating the paper-like material appropriate?

- By using baking paper, I was able to create the materials without it sticking to the base, even when with vegetables other than celery.

- It was possible to create the material without the vegetables liquefying completely. ★

↳ It appears that proceeding with a sodium hydroxide concentration of 0.1 mol/L presents no issue.

- Although I reduced the heating time by 5 minutes from the planned duration pathway through the experiment, the experiment proceeded without any problems

↳ I intend to continue with a 25-min heating time in future experiment.

② Were the conditions standardised across all samples?

- Because the amount of water and fiber in each vegetable varied, some samples produced watery pulp, whilst others produced almost no water at all.

↓
Samples such as sample 2 (Carrots) and sample 3 (Onions), which produced watery pulp, became thinner and contained more holes after drying than the other samples.

- ↓
- In this condition, these samples would not be able to withstand the subsequent strength testing.

This suggests that the amount of fibre remaining in the pulp may have been lower?

- And it would be difficult to ensure consistent conditions when comparing them with the other samples.

★ ↳ An additional step is required to remove excess water from the pulp....

27 May 2026

③ Improvements for the next Experiment.

An additional step will be added to the procedure to remove excess water from the pulp.

↓
How?

1. Squeeze the pulp by hand to remove excess water?

Pros	• Easy to carry out without additional equipment.
Cons	• The amount of water removed may vary among samples, making it difficult to maintain consist condition.

2. Using a hair dryer

Pros	• Excess moisture can be removed efficiently in a short period of time.
Cons	• The samples may be blown apart by the airflow. • The samples may become overly dry to the heat. • As with had squeezing, it is difficult to maintain consistent conditions.

③ Applying a weight from above

Pros	• Applying the same weight for the same amount of time makes it relatively easy to maintain consistent conditions. • The thickness of the samples may also be standardised.
Cons	• The process is time-consuming.

4. Using a centrifuge

Pros	• Experimental conditions can be controlled accurately by using equipment.
Cons	• A centrifuge is required. • Fine pulp particles may mix the water, making it difficult to recover only the pulp.

★ Method 3, applying a weight from above, will be used in the next experiment.

27 May 2026

④ Considerations for the next Experiment

The onion sample (Sample 3) - became almost completely liquid during processing, making it difficult to produce a suitable paper-like material.

↓
★ Onion will be excluded from the next Experiment.

Experiment 4 Preparation of Final Samples for Strength Testing

27 May 2026

PLAN

1. Aim

To prepare standardised paper-like samples that can be used for subsequent strength testing.

2. Background

In Experiment 3, some samples produced excessive amounts of water, resulting in thin and porous materials after drying. These samples were unsuitable for strength testing because consistent testing conditions could not be maintained. Therefore, an additional step to remove excess water will be introduced to improve sample quality and standardised conditions.

Onion will be excluded because it became almost completely liquid during pressing.

3. Apparatus and Materials

Same as Experiment 3

The following equipment is added to the experiment.

Weight

- 500g chopping board $\times 1$
- 1kg weights $\times 4$

4. Method

Based on the results and observations from the previous experiments, the paper-making procedure was optimized to ensure consistent sample preparation for the final strength testing.

①. Measure 60g of each vegetable and cut them into pieces approximately $1\text{cm} \times 1\text{cm} \times 1\text{cm}$ in size.
 To use in future experiments, increase the amount of vegetable

②. Place each vegetable sample into a beaker and add 150 mL of 0.1 mol/L sodium hydroxide solution.

③. Heat each sample for 40 minutes.
 Increase the heating time since the amount of vegetable is increased.
 Adjust the heating time as needed until it has a similar texture to last time.

27 May 2026

④. Filter the mixture using filter paper and a funnel.

⑤. Transfer the remaining material to mortar and grind it with pestle to make paste-like pulp.

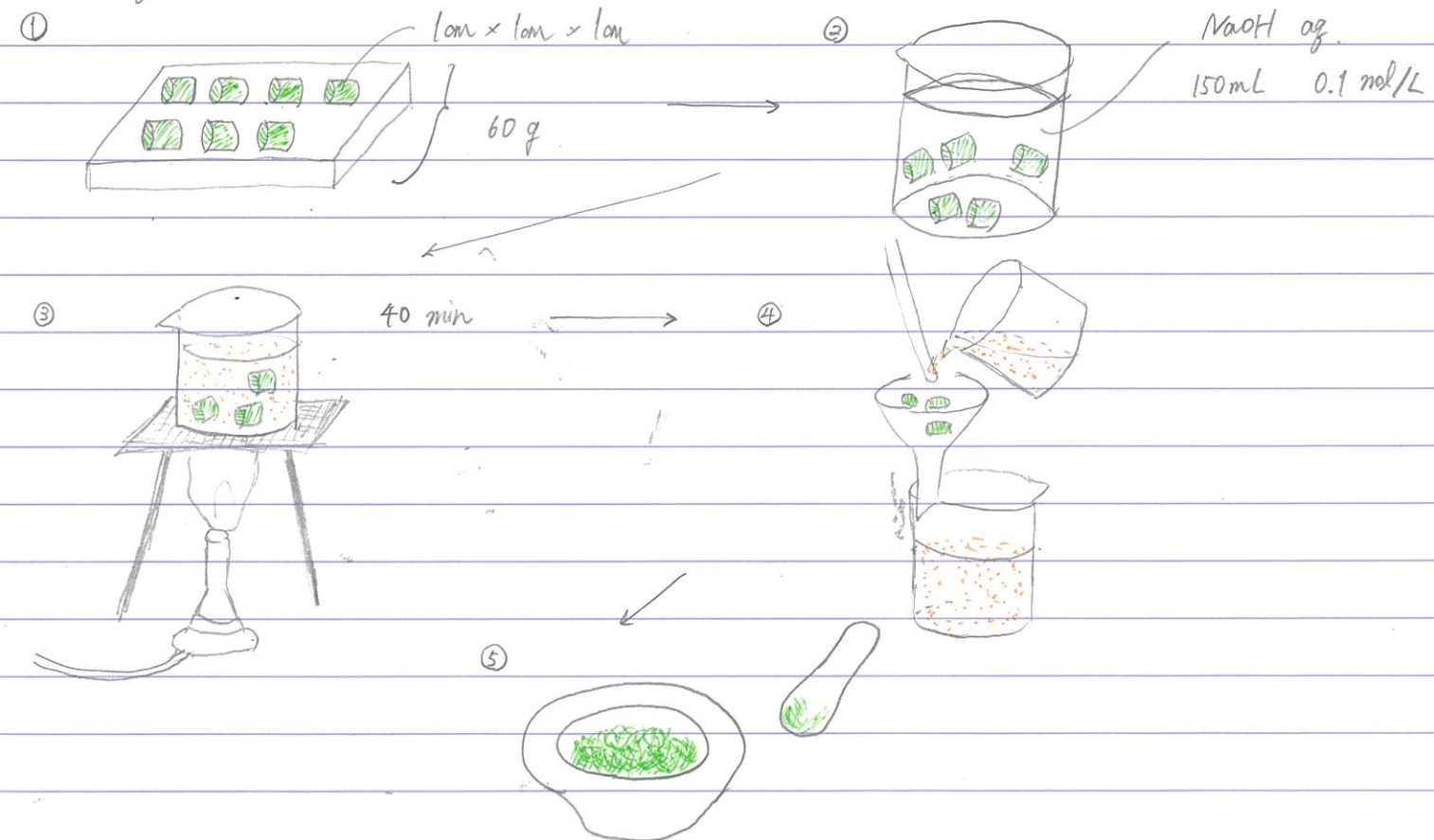
⑥. Spread the pulp onto a base lined with baking paper. Then place a chopping board on top, followed by four separate 1kg weights, so that equal pressure is applied across the entire pulp.

⑦. Apply pressure for 3 minutes and remove any water that is released.

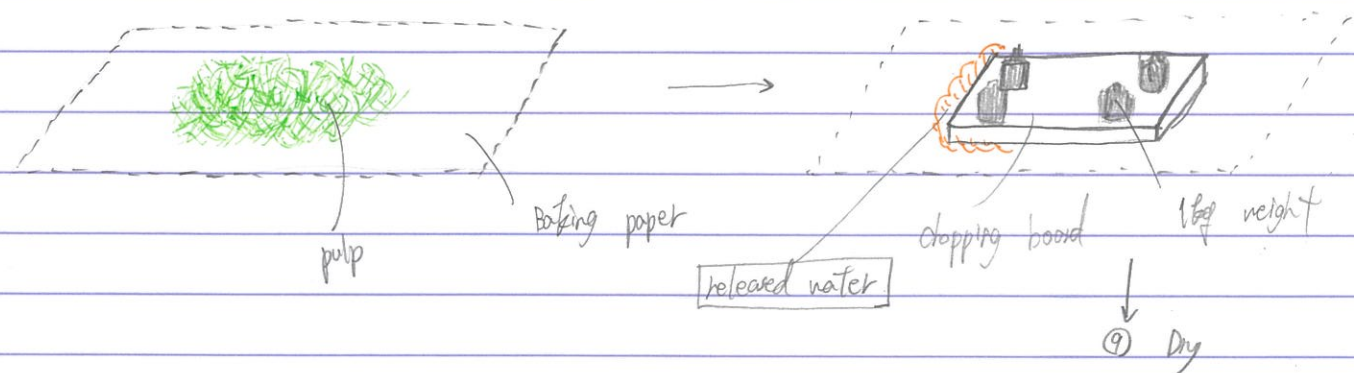
⑧. Repeat the pressing process once more in the same way.

⑨. Leave the pressed samples to dry for several days.

★ Images



⑥



5. Observation Points

- Whether only water is removed during the pressing process.
- Whether the samples had uniform thickness.
- Whether the number of holes in the samples decreased.
- Whether the samples would be strong enough after drying to withstand the strength test.
- Whether the samples could be collected without being damaged.

6. Prediction

- By pressing the pulp twice and removing excess water, the samples are expected to have a more consistent and sufficient thickness. The number of holes is also expected to decrease because the pulp will be compressed more evenly. After drying, the samples are expected to be strong enough to be collected without damage and used for the strength test.

28 May 2026

Results / Experimental Log

Date: 28 May 2026

Log

11:15 AM Experiment started (Day 1)

11:20 AM Heating of Celery and sweet potato sample was started

35 min

11:55 AM Stop heating both sample 1 and sample 2.

The procedures described in step ④, ⑤ and ⑥ were carried out.

12:09 PM The first pressing was carried out on sample 1.

12:12 PM The second pressing was carried out on sample 1.

12:16 PM The first pressing was carried out on sample 2.

12:20 PM The second pressing was carried out on sample 2.

12:30 PM Left these samples to dry.

Points / Observation

- Preparing for the experiment

NaOH sol: 150 mL, 0.1 mol/L (Each)

Sweet potatoes: 60.09 g

Let this be sample 1.

Celery: 59.99 g

Let this be sample 2.

- As sample 1 began to lose its shape, similar to the previous experiment, the heating process was stopped. The total heating time was 35 minutes.

Therefore, the heating time for all subsequent samples will be standardised to 35 minutes.

★

- Due to a shortage of 1 kg weights in the school laboratory, two 1 kg weights and four 250 g weights were used instead.

Points

Only water was successfully removed.

- The pressing time was standardised to 3 minutes.

29 May 2026

Date : 29 May 2026

Log

9:10 AM Experiment started (Day 2)

Points / Observation

Preparing the experiment

9:18 AM Heating of Carrot and potato sample was started

NaOH of : 150 mL , 0.1 mol/L

Carrots : 59.50 g

Let this be sample 3.

Potatoes : 60.90 g

Let this be sample 4.

35 min

9:53 AM Stop heating and step ④, ⑤ and ⑥ were carried out.

Based on yesterday's experiment, the heating time was standardised to 35 minutes.

10:10 AM The first pressing was carried out on Sample 3.

The pressing time was standardised to 3 minutes.

10:14 AM The second pressing was carried out on Sample 3.

10:18 AM The first pressing was carried out on Sample 4.

10:21 AM The first pressing was carried out on Sample 4.

10:28 AM Left these samples to dry.

★ Points I noticed

- Adding the pressing processing process successfully removed only water from the samples.
- The Sodium hydroxide concentration, heating time and pressing time allowed the experiment to be completed without any issues.
- Therefore, the experimental procedure was considered to be appropriate.

1 June 2026

Results of the sample after drying (1 June 2026)

★ After several days of drying, a significant issue was observed.

White spots, which appeared to be mould, were observed on Sample 1 (sweet potato) and Sample 2 (celery).

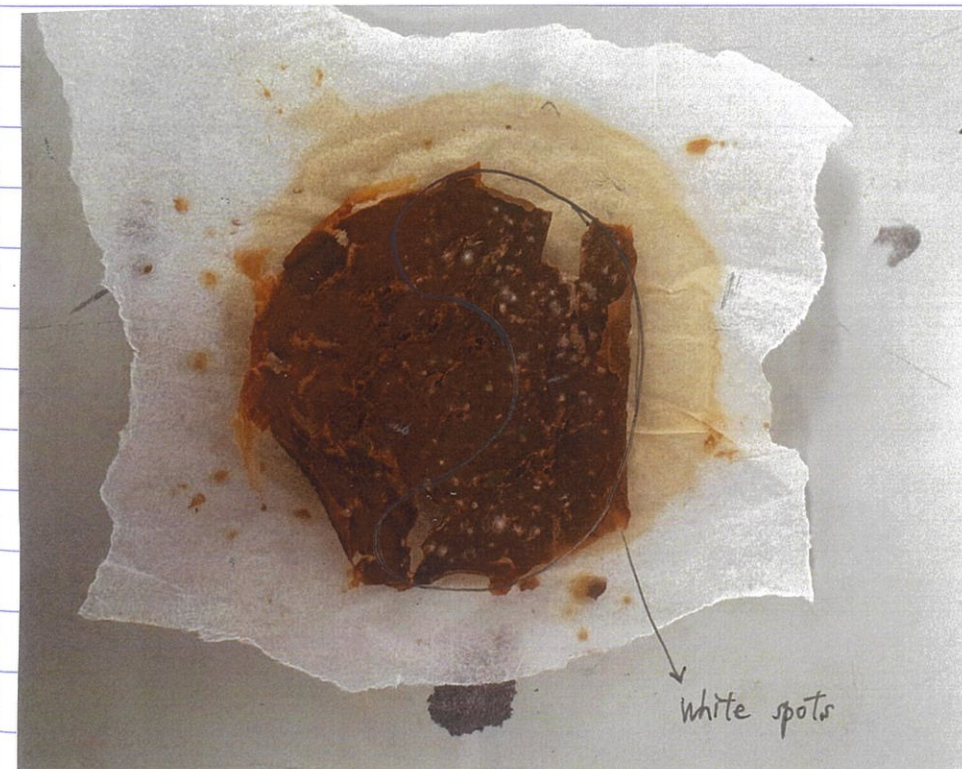
→ There's a possibility that the mould had spread to the other samples during storage, making the condition of the samples inconsistent as an experimental variable.

By adding the pressing process, the texture of the samples appeared to become more uniform.

The number of holes in the dried samples decreased compared with the previous samples.

When handled while wearing gloves, the samples seemed strong enough to be used for the strength test.

The samples could be removed from the baking paper without tearing easily.



The appearance of mould (1, June 2026)

→ Other sample pictures are shown on page 36

1 June 2026

Discussion on the issue

★ The white spots are most likely mould.

• Why did the mould appear?

(mould → page 35)

↳ May have been related to the weather conditions during the drying period.

	Maximum temperatures	Minimum temperatures
30 May 2026	16 °C	12 °C
31 May 2026	17 °C	11 °C (Adelaide)

• In addition the humidity remained above 80 % for long periods of time

• These conditions may have slowed the drying process and allowed moisture to remain inside the samples.

• Since the samples were dried indoors, the air around the samples may also have remained humid.

• As the samples were made from vegetable materials, they contained organic matter that could support mould growth if enough moisture was present.



• The combination of remaining moisture, high humidity, and organic material may have contributed to the growth of mould.

★ To confirm whether the white spots were actually mould, the affected samples should be kept separately and observed later under a microscope. If thread-like structures, such as hyphae, are observed, this would support the possibility that the white spots were mould.

★ Since the samples produced in this experiment may have been contaminated by mould spreading from the affected samples, none of them will be used for the strength testing.

2 June 2026

Background Research 4 : Mould

1. What is mould?

• Mould is a type of fungus. • Fungi are eukaryotic microorganisms.

• Mould grow as long, thread-like filaments called hyphae.

• A mass or network of hyphae is called mycelium.

• Mould can produce spores, which help it spread to new areas.

2. Structure of mould

• Hyphae grow by extending at their tips. • When many hyphae grow together, they form a mycelium.

• Mycelium can look like a white, cotton-like or fuzzy layer on the surface of food or plant material.

• The visible colour of mould can change when spores are produced. Some mould may first appear white and later become green, black, grey or other colours depending on the species and stage of growth.

3. Conditions that support mould growth

• Mould needs moisture to grow.

• Mould is more likely to grow when humidity is high or when the material remains wet for a long time.

• Mould also needs a food source. Plant-based materials can provide organic matter that fungi can use.

• Temperature affects mould growth, although different mould species have different preferred temperature ranges.

• Poor airflow can slow drying and keep surfaces moist, which can support mould growth.

• Food and plant materials with enough available water can support the growth of mould.

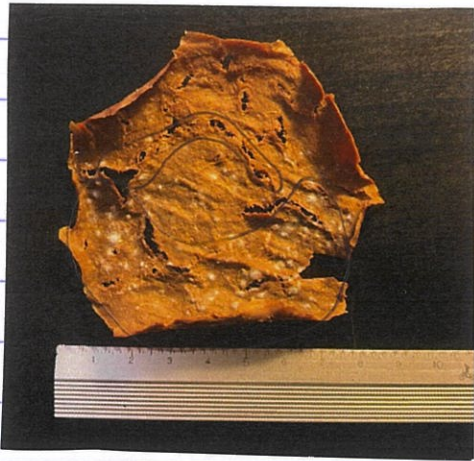
★ Although its white, cottony appearance suggests the presence of fungal hyphae, it's impossible to determine whether it is mould without conducting a detailed microscopic examination.

Bibliography

⑨ Murray, P.R., Rosenthal, K.S., & Tenover M.A (1996). Introduction to mycology. In Medical Microbiology. University of Texas Medical Branch at Galveston. NCBI Bookshelf.

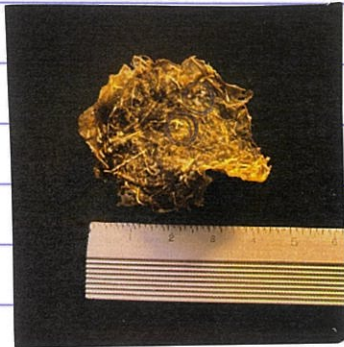
⑩ Cole, G.T (1996). Basic biology of fungi. In Medical Microbiology. University of Texas Medical Branch at Galveston. NCBI Bookshelf.

Pictures of the sample after drying.



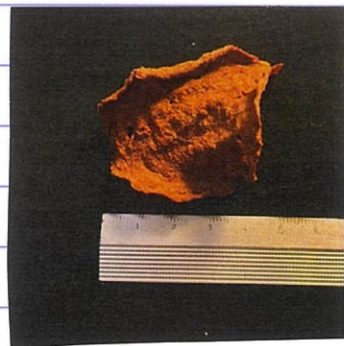
Sample 1 after drying

- Although cracks were observed, the number of small holes decreased.
- The thickness appeared uniform.
- White spots, thought to be mould, were observed.



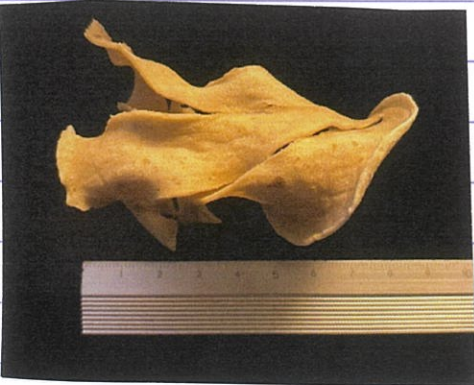
Sample 2 after drying

- The thickness appeared uniform.
- White spots, thought to be mould, were observed.



Sample 3 after drying

- Perhaps because I included a pressurisation process, the texture seemed firmer than last time.



Sample 4 after drying

- The thickness appears to be more uniform than last time.
- Twisting was observed.
- Cracks were observed.

Could it be that the high humidity meant it took longer?

Discussion

Was it possible to remove just the water?

Only excess water, rather than the pulp itself, was removed by applying pressure.

What was the texture of the finished sample like?

The texture of the completed samples was more uniform than in the previous experiment. Compared with the previous results, the samples had a more even thickness overall, and the number of holes was reduced.

When touched, the samples also felt stronger than those made in the previous experiment.



These results suggest that the pressing process was likely appropriate for removing excess water and improving the uniformity of the sample.

Improvement for the next experiment

In order to prepare samples suitable for the strength testing, mould growth needs to be prevented during the drying process.

How?

A fume hood

Drying the samples in a fume hood will create airflow, reduce humidity, and prevent mould spores from settling on the samples.

Was there a problem with the heating time?

Although it was planned to heat the samples for 40 minutes, it was stopped the heating after 35 minutes because, as in the previous experiment, the samples began to lose their shape. Since all samples were formed without any issues, it was concluded that a heating time of 35 minutes was sufficient.



will heat it for 35 minutes in the next experiment as well

Experiment 5 : Preparation of Final Samples for the Strength Test

3 June 2026

PLAN

1. Aim

The aim of this experiment is to prepare final vegetable-based paper samples suitable for the strength test.

2. Background

Experiment 4 also aimed to produce samples for the strength test. In that experiment, the pressing process appeared to be effective because excess water was removed without losing the pulp. The completed samples also had a more uniform thickness and fewer holes than those made in the previous experiments. However, mould-like white spots appeared on some of the dried samples. Therefore, the sample from Experiment 4 could not be used for the strength test.

Based on lessons learned from Experiment 4, it'll be made improvements to the drying process in Experiment 5.

3. Materials and Equipment

The same materials and equipment as in Experiment 4 are used. However, a fume hood is added.

4. Method

① ~ ④ the same as Experiment 4.

However, during the drying process described in ④, the samples are dried inside the fume hood. In addition, the heating time is set at 35 minutes.

5. Observation Points

- whether mould-like white spots appear during or after drying.
- whether the samples dry completely without holes

6. Hypothesis

Drying the samples in a fume hood will prevent mould-like growth by improving airflow. Therefore, samples are expected to dry successfully and be suitable for the strength test.

4 June 2026

Results / Experimental Log

Date : 4 June 2026

Log

11:10 AM Experiment started

11:18 AM Heating of all samples

(Celery, potato, sweet potato, and carrot) were started

35 (min)

11:53 AM Heating was completed
Step ④, ⑤ and ⑥
were carried out.

12:01 PM Began the first pressurisation
process in sample 1.

12:04 PM Began the second pressurisation
process in sample 2.

Points / Observation

Weigh

Celery : 61.10g Let this be Sample 1

Potatoes : 60.73g Let this be Sample 2

Sweet potatoes : 59.74g Let this be Sample 3

Carrots : 61.10g Let this be Sample 4.

NaOH ag (0.1 mol/L) 150 mL (Each).

About 15 minutes after heating, just as in previous experiments, the aqueous solution of Sample 1 turned yellow-green, Sample 2 turned cloudy white, and samples 3 and 4 turned dark orange.

Sample 1 had a strong celery smell; sample 2 had no change in odour; and sample 3 and 4 had a strong sweet smell.

When crushing the potato sample in a mortar, it gave off an egg-like smell.

The duration of each pressure application should be standardised at 3min.

A lot of water came out

4 June 2026

12:09 PM Began the first pressurisation process in Sample 2.

Hardly any water was produced, it had a paste-like texture



12:13 PM Began the second pressurisation process in Sample 2.

12:17 PM Began the first pressurisation process in Sample 3.

A little water appeared



12:20 PM Began the second pressurisation process in Sample 3.

12:25 PM Began the first pressurisation process in Sample 4.

A lot of water came out.



12:29 PM Began the second pressurisation process in Sample 4.

Drying in the same fume hood.

Observation after drying (11 June 2026)

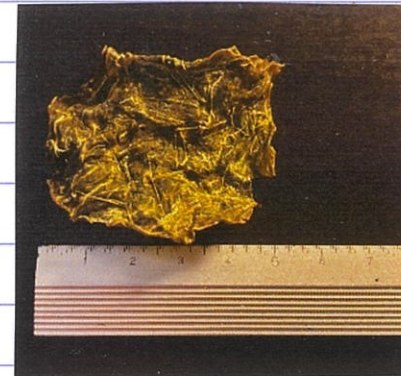
After drying, the sample looked as shown in the pictures on page 41.

No white spots resembling mould were observed, and overall there were few tiny holes and the thickness was uniform.

It was easy to retrieve the samples from the baking paper base, and it was able to do so without damaging them.

11 June 2026

Pictures



Sample 1 after drying (11 June 2026)

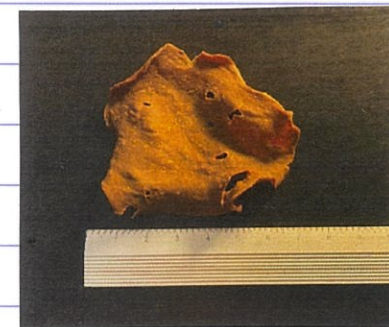
I was able to see the fibres with the naked eye and could feel that it was both sturdy and flexible. The thickness seemed to be consistent throughout.



Sample 2 after drying (11 June 2026)

Although a crack has formed, as there are no longer the numerous tiny holes seen last time, it appears that it can be used for the strength test.

Overall, it felt stiff and looked flexibility.



Sample 3 after drying (11 June 2026)

Although a few holes were found, their number has decreased significantly compared to the previous experiment. This is why it is considered that the sample can withstand the strength testing.



Sample 4 after drying (11 June 2026)

As with Sample 3, although a few holes did appear, the rest of the sample is considered to be sufficiently robust to withstand the strength test.

It is thinner than the other sample.

11 June 2026.

Discussion

- Was it standardised the making process for paper-like materials among vegetables?

It was possible that all the conditions for preparation were standardised.

The sodium hydroxide solution was 0.1 mol/L, 150 ml; the heating time was 35 minutes; all samples weighed 3.5 g; each sample was pressurised for 3 minutes on two occasions; and all samples were dried in the same fume hood.



It's considered that a uniform paper-like material was produced.

- Was it possible to prevent the white spots, which are thought to be caused by mould?

No white spots were observed during the visual inspection. It's thought that the introduction of the fume hood may have improved airflow and prevented the growth of mould.



Examine the sample under a microscope to check whether mould is growing on the inside actually; if no problems are found, proceed to the next stage of the investigation.

Outlook for the Next Experiment.

Having completed the paper-making stage, from the next session onwards, I'll observe the internal structure using a microscope, investigate the nature of the white spots that appeared in Experiment 4, and assess whether it is possible to conduct strength tests on the samples produced in this experiment.

Experiment 6: Microscopic Observation of Vegetable-Based Paper Sample.

11 June 2026.

PLAN

1. Aim

- The aim of this experiment was to observe the internal structures of the vegetable-based paper samples using a light microscope and compare the amount and arrangement of fibre-like structures in each sample.

2. Background

- The samples were made by processing vegetables into paper-like sheet. Since vegetables are plant materials, plant fibres might remain in the sample after processing. These fibres might be visible under a microscope and could differ between samples. Therefore, microscopic observation is carried out before the strength test to check whether fibre-like structures could be seen in each sample and to compare their appearance.

Some dried sample also showed white spots on their surface. Since these spots might have been mould, the white areas are observed under the microscope to check for thread-like structures similar to fungal hyphae.

3. Materials and Equipment

- vegetable-based paper samples (made in Experiment 5)

- Celery sample

- Potato sample

- Sweet potato sample

- Carrot sample

- Sweet potato sample with white spots (made in Experiment 4)

- Light microscope

- Microscope slider

- Cover slips

- Tweezers

- Dropper

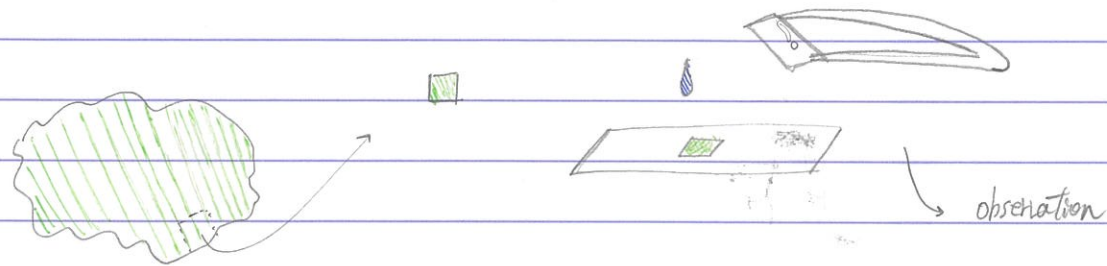
- Water

- Scissors

- Knife

4. Method

- ① A small piece is cut from each dried vegetable-based paper sample.
- ② The piece is placed on a microscope slide.
- ③ A small amount of water is added to make the sample easier to observe.
- ④ A cover slip is placed carefully over the sample.
- ⑤ The sample is observed using a light microscope.
- ⑥ The presence and appearance of fibre-like structures are recorded.
- ⑦ The same procedure is repeated for the celery, potato, sweet potato, and carrot samples.
- ⑧ The surface of each dried sample is checked for mould-like growth.
- ⑨ For samples with white spots, a small part of the white area is placed on a microscope slide and observed.
- ⑩ The white spots are checked for thread-like structures that might indicate mould.
- ⑪ Microscope images are taken for later comparison and discussion.



5. Observation Points

- whether fibre-like structures are visible in each samples
- The appearance of the fibre-like structures
- whether the amount or arrangement of the structures differed between samples.
- whether mould-like growth is visible on the dried sample.
- whether white spots contained thread-like structures
- whether the white areas looked different from the normal parts of the samples.

6. Hypothesis

Fibre-like structures would be visible in all vegetable-based paper samples because the samples are made from plant materials. However, the appearance, amount, and arrangement of these structures might differ depending on the type of vegetable.



If the white spots are caused by mould, thread-like structures similar to fungal hyphae, would be observed in those areas. Samples without visible white spots are expected not to show mould-like structures under the microscope.

12 June 2026

Experimental Log / Results

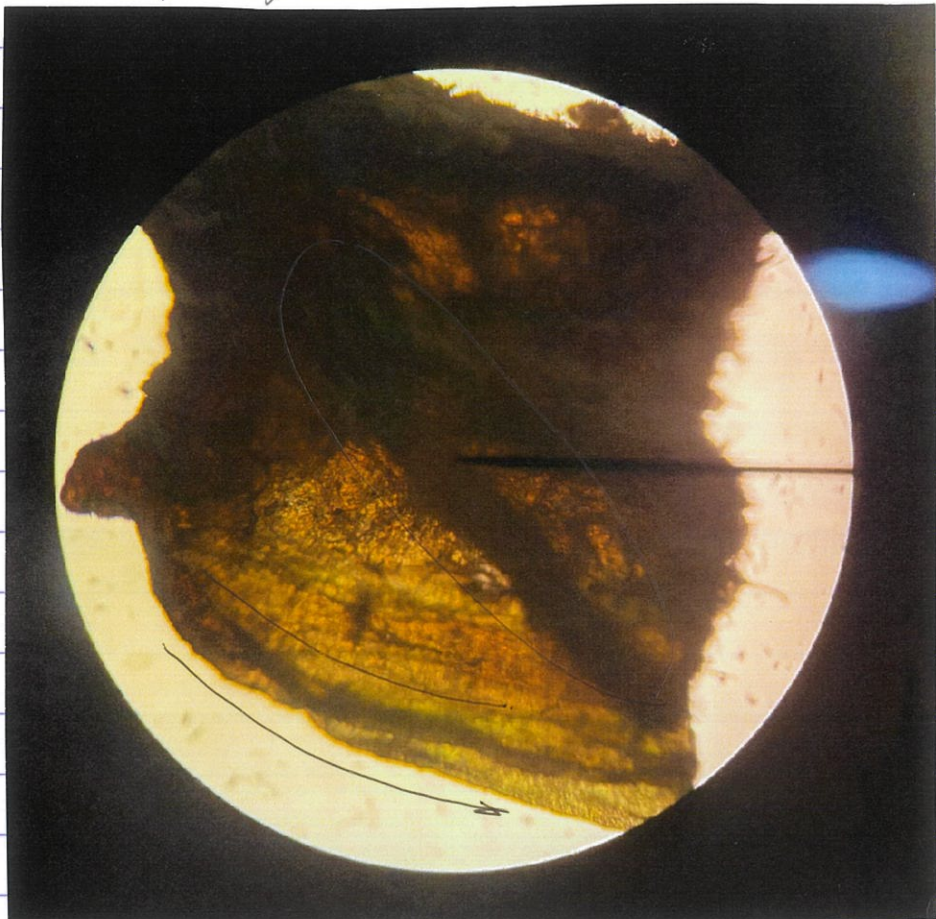
Date: 12 June 2026.

Log

- A small piece was taken from each dried vegetable-based paper sample and observed using a light microscope.
- The celery, potato, sweet potato, and carrots were observed.
- The samples were mainly observed at $40\times$ and $100\times$ magnification.
- The potato sample was observed at $40\times$ magnification, but it could not be clearly observed at $100\times$ magnification because the image could not be focused.
- For each sample, the presence and appearance of fibre-like structures were recorded.
- Microscope images were taken for later comparison.
- Sweet potato sample with white spots were also observed separately at $\times 40$ magnification.
- In the white areas, the presence of thread-like structures was checked to investigate whether the spots might have been mould.

Results

The sample images and observations are recorded below.



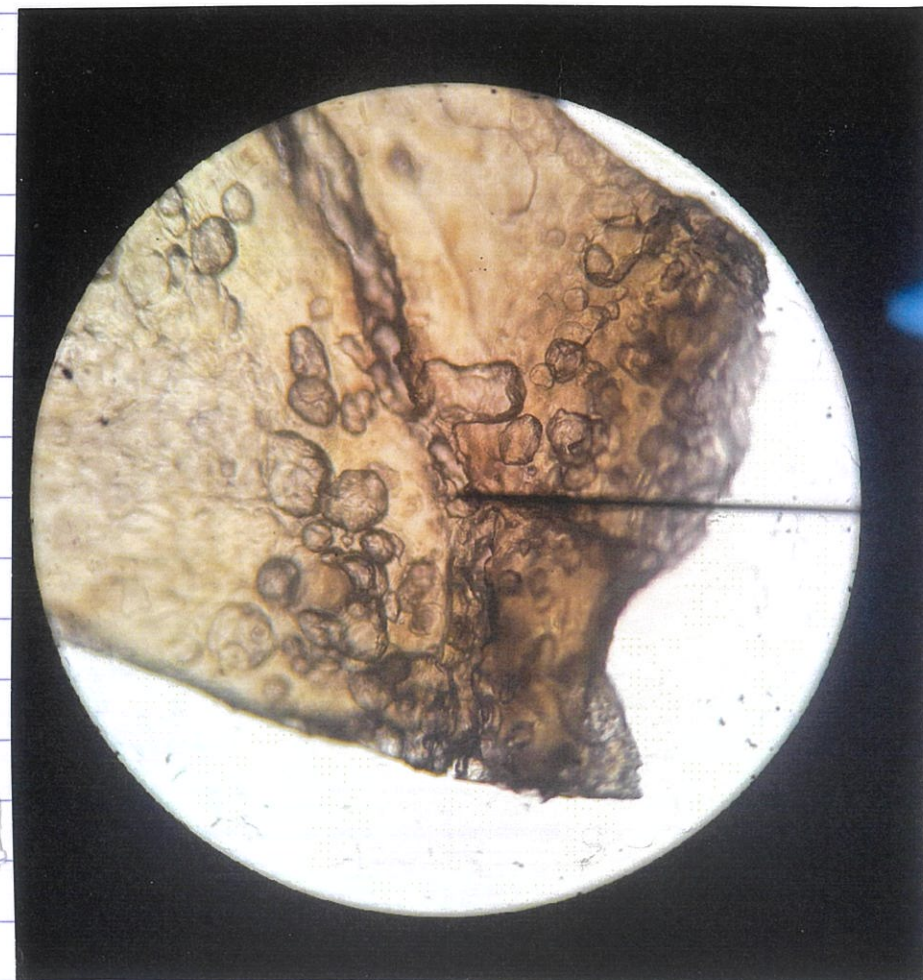
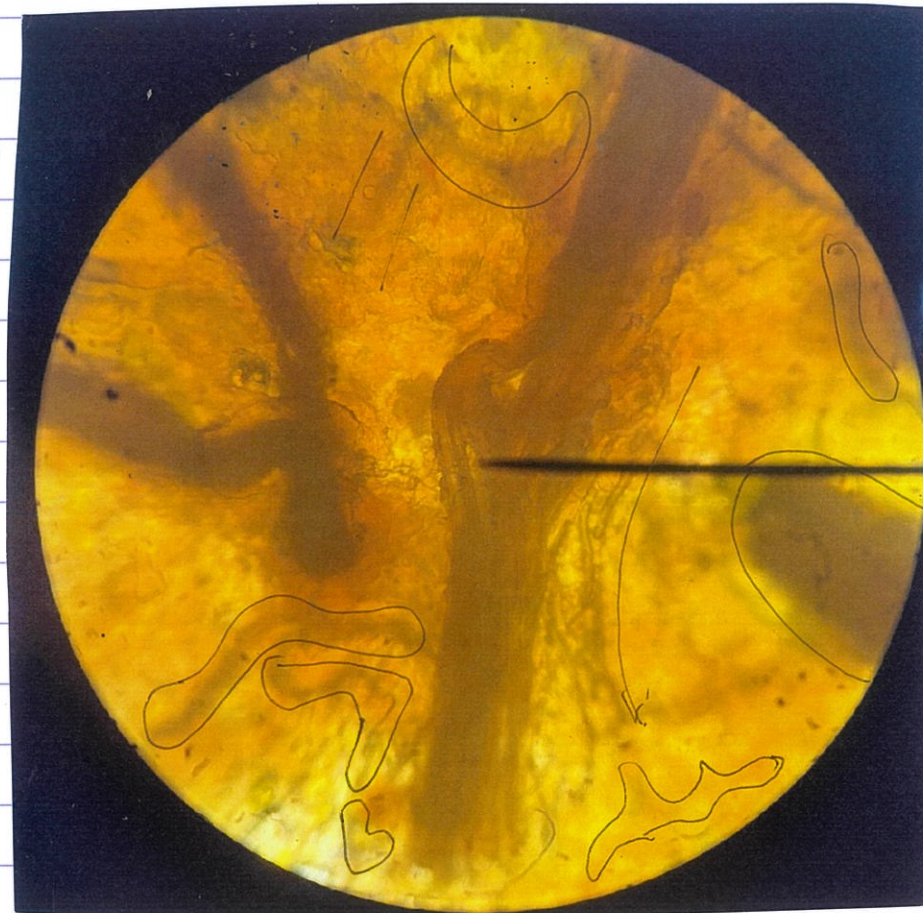
Celery sample at $40\times$

- several line-like structures were observed.
- The fibres appear to be densely packed and intricately intertwined.
- Large fibres were also observed.

12 June 2026

Celery sample at $100\times$

- Fibres ranging from thin to thick were observed.
- It can be seen that the fibres are densely packed and intertwined.

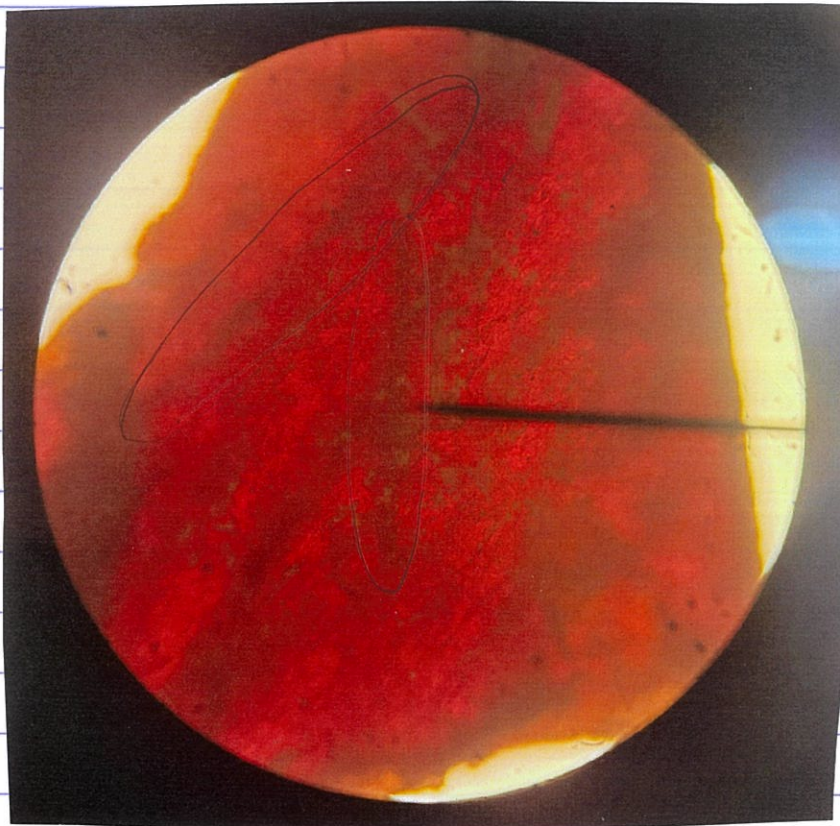


Potato sample at $40\times$

- No fibres were observed.
- Several granular structures were observed.

★ As the image at $100\times$ magnification was out of focus and could not be seen clearly, it could not be recorded.

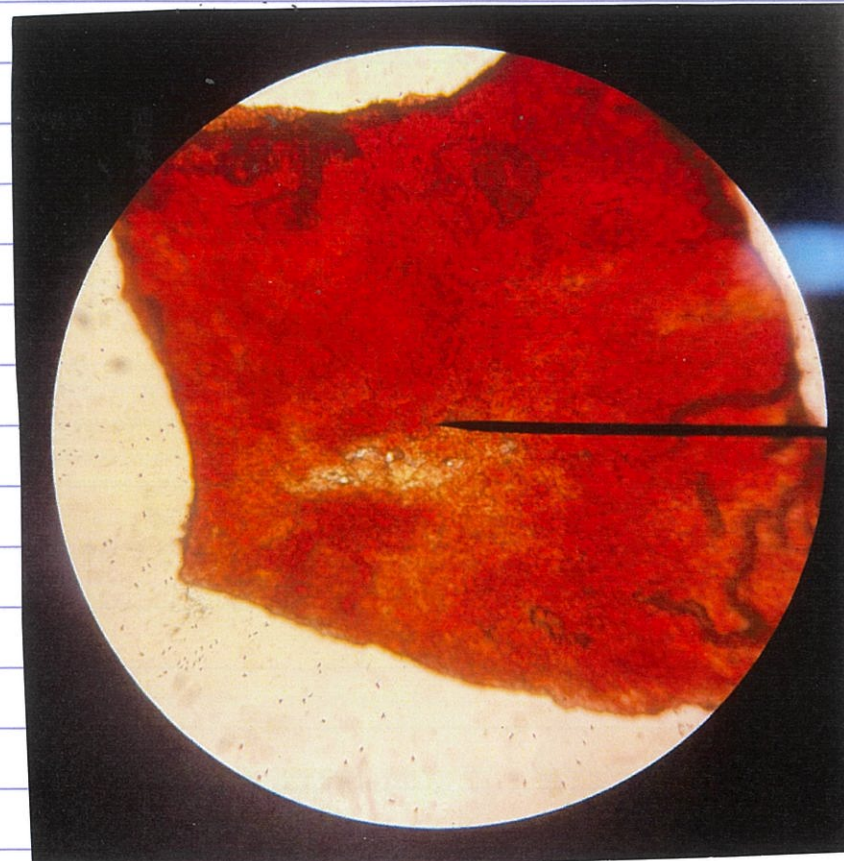
12 June 2026



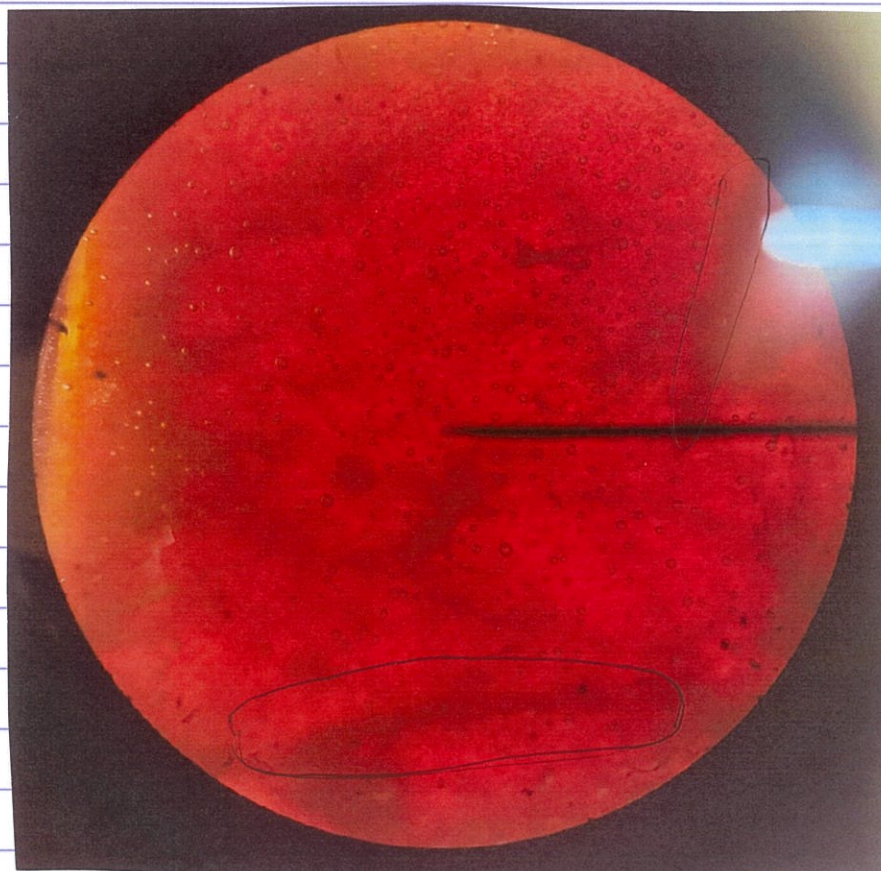
Sweet potato sample at $\times 40$
Parts with fibrous texture were
observed in some areas

The texture of the surface felt
somewhere between that of the potato
sample and the celery sample.

12 June 2026

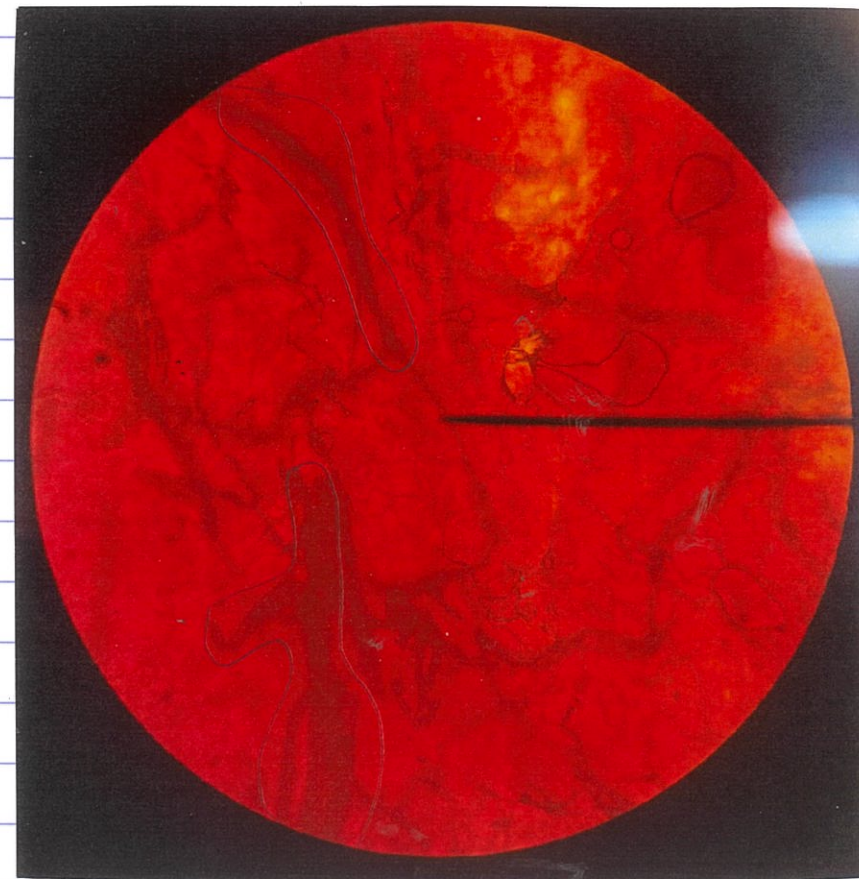


Carrot sample at $\times 40$
Several large fibers were identified



Sweet potato sample at $\times 100$
Fibers were identified.

However, compared to celery,
the number of fibers was clearly
lower, and their density was also
lower.



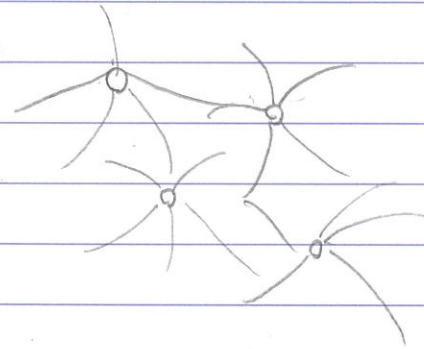
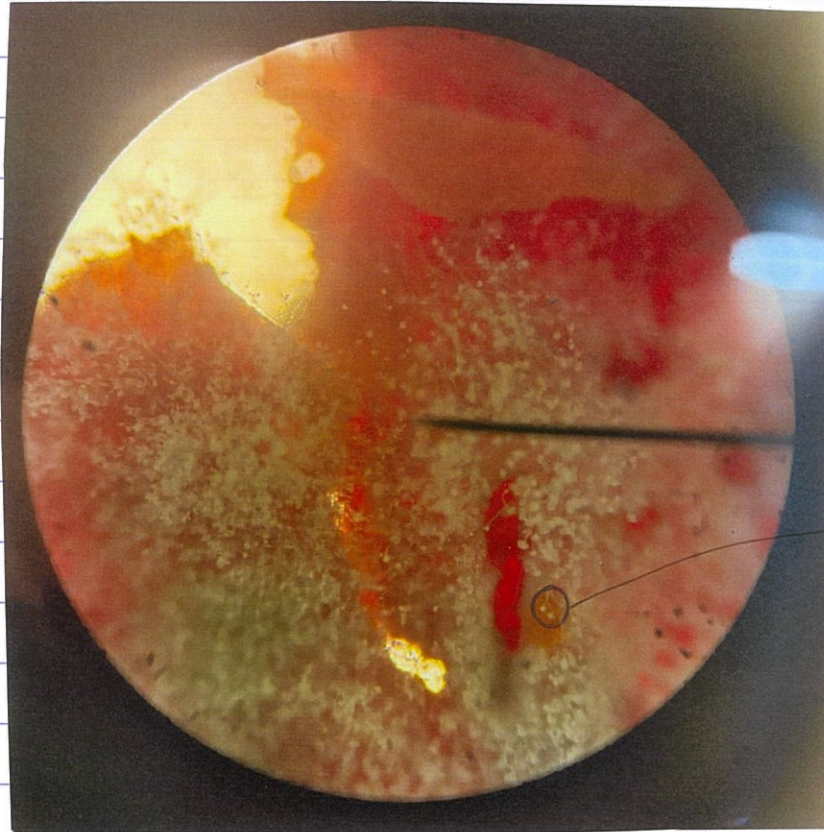
Carrot sample at $\times 100$
Fibers were clearly visible. There
were more fibers than in the sweet
potato sample. They appeared to
be finer than the fibers in the
celery sample.

12 June 2026

Sweet potato sample with white spots.
(at $\times 40$ magnification)

Where white spots were observed, a cotton-like structure had spread out.

The whole thing was connected by thread-like strands.



13 June 2026

Background Research 5 : The constituents of Each Vegetable.

✓ Celery

Edible part : Mainly the petiole, which is part of the leaf structure rather than the stem.

- Celery petioles contain supporting tissues and vascular tissues.
- Celery petiole collenchyma cell walls contain cellulose and pectin as dominant polysaccharides.
- The clear fibrous structures observed in the celery sample may have come from remaining petiole tissues, such as collenchyma or vascular bundles.

✓ Carrot

- Edible part : swollen primary root, also called a taproot.
- The carrot taproot functions as a storage organ.
- Plant cell walls are generally made mainly of cellulose, hemicellulosic polysaccharides, and pectic polysaccharides.
- The fibrous structures observed in the carrot sample may have come from remaining root cell walls or vascular tissue.

✓ Potato

- Edible part : stem tuber, not a root
- A potato tuber is an enlarged underground stem used for storing carbohydrates, nutrients, and water.
- In potato tissue, starch granules are contained inside parenchyma cells.
- The round granular structures observed in the potato sample may be starch granules.

✓ Sweet potato

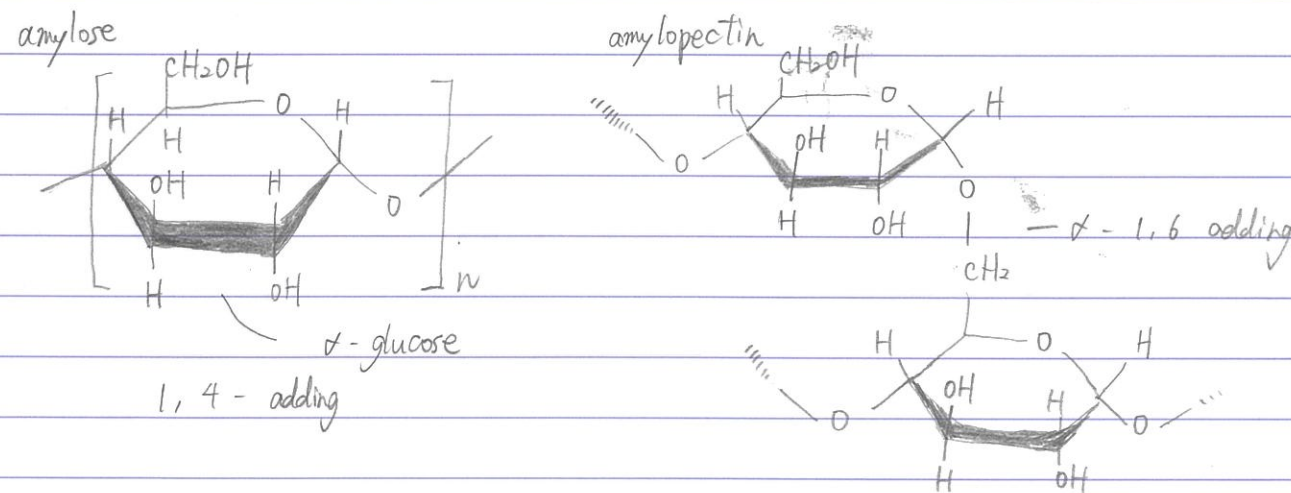
- Edible part : storage root, not a stem tuber.
- Storage roots are enlarged fleshy portions of root tissue used for storage.
- Sweet potato tissue contains starch-storing parenchyma cells.
- Sweet potato cell-wall material also contains polysaccharides related to cell walls, including pectic components.
- The sweet potato sample may show both granular structures related to starch storage and fibrous or sheet-like structures related to root tissues.

Bibliography

- ⑪ University of Minnesota Libraries Publishing. The Science of Plants : 1.3 Plant Parts we Eat.
- ⑫ Holland, C., Ryden, P., Edwards, C.H., & Grundy, M.M.L. (2020)
Plant Cell Walls : Impact on Nutrient Bioaccessibility and Digestibility. Foods, 9 (2), 209.
- ⑬ Chen, D., Harris, P.J., Sims, I.M., Zujovic, Z. & Melton, L. D. (2017)
Polysaccharide compositions of collenchyma cell walls from celery (*Apium graveolens* L.)
BMC Plant Biology, 17, 104.
- ⑭ Choi, J.H. et al. (2024). Flour and parenchyma cells from sweet potato and potato :
a comparative study of their physicochemical properties and digestibility.

Background Research 6 : starch

- starch is a storage polysaccharide in plants.
- starch is Insoluble, nonstructural carbohydrates composed of α -glucose polymers,
and mainly composed of two glucose polymers : amylose and amylopectin.



- Amylopectin forms much of the semi-crystalline framework of starch granules, while amylose is a smaller and mostly linear molecule.
- Starch is stored as insoluble granules inside plastids called amyloplasts.
- In potato tissues, starch granules are contained inside parenchyma cells.
- Potato and sweet potato are therefore likely to show more granular structures than celery or carrot.

- The round granular structures observed in the potato sample may be starch granules.
- When starch is heated in water, it can gelatinize during gelatinisation, starch granules absorb water, swell, and form a paste or gel-like structure.

Bibliography

- ⑮ Pfister, B., & Zeeman, S.C. (2016). Formation of starch in plant cells
Cellular and Molecular Life Sciences, 73 2801-2807.
- ⑯ Gong, Y., et al. (2024). Factors and modification techniques enhancing starch gel properties : A review.

Discussion.

How was the microscopic observation?

① Celery

- clear fibrous structures were observed in the celery sample.
- The amount of visible fibres appeared to be the largest among the four samples.
- These fibres may have come from remaining petiole tissues, such as vascular bundles or supporting tissues.



★ This is consistent with the fact that celery petioles contain supporting tissues and cell-wall polysaccharides.

② Carrot

- Fibrous structures were also observed in the carrot sample.
- The amount of visible appeared to be less than in celery, but fibres were still clearly present.
- These structures may have come from remaining root cell walls or vascular tissue.



★ Because carrot is a swollen taproot, some root tissue may have remained after processing.

③ Potato

- In the potato sample, clear fibrous structures were not observed in the same way as in celery or carrot.
- The amount of visible fibres appeared to be very small.
- Instead, round granular structures were observed.



★ Since potato is a starch-storing stem tuber, these granular structures may be starch granules.

④ Sweet potato

- In the sweet potato sample, some fibrous or tissue like structures were observed.
- The amount of visible fibres appeared to be more than in potato, but less than in celery.

★ Since sweet potato is a storage root that contains starch-storing tissue, both tissue-like structures and possible starch-related granules may remain after processing.

Was mould observed?

- No clear mould-like white spots were observed on the samples made in Experiment 5.
- This suggests that the improved drying method may have reduced visible mould growth.



The sample made in Experiment 5 appeared to be acceptable for the strength test.

How was white spots in the sample made in Experiment 4.?

- White spots were observed on some samples made in Experiment 4.
- Under the microscope, thread-like structures were observed in the white spotted area.
- These structures looked similar to fungal hyphae.



The white spots were likely to be mould.

★ Cannot say for certain what type of mould it is.

Experiment 7 : strength Test of Vegetable - Based Paper Sample

14 June 2026

PLAN

1. Aim

To measure the tensile strength of the vegetable-based paper samples using the Vernier Structures & Materials Tester.

2. Background

No mould-like growth was observed on the vegetable-derived paper-like samples prepared in Experiment 5 during the previous experiment.

Therefore, it was determined that they could be used for strength testing.

* Tensile strength is generally calculated by dividing the maximum load by the original cross-sectional area of the test specimen.

3. Equipment

- Vegetable-based paper samples
- Vernier Structures & Materials Tester
- Clamp stand
- Clamp
- Ruler
- Scissors
- Cutter
- Vernier data recording system



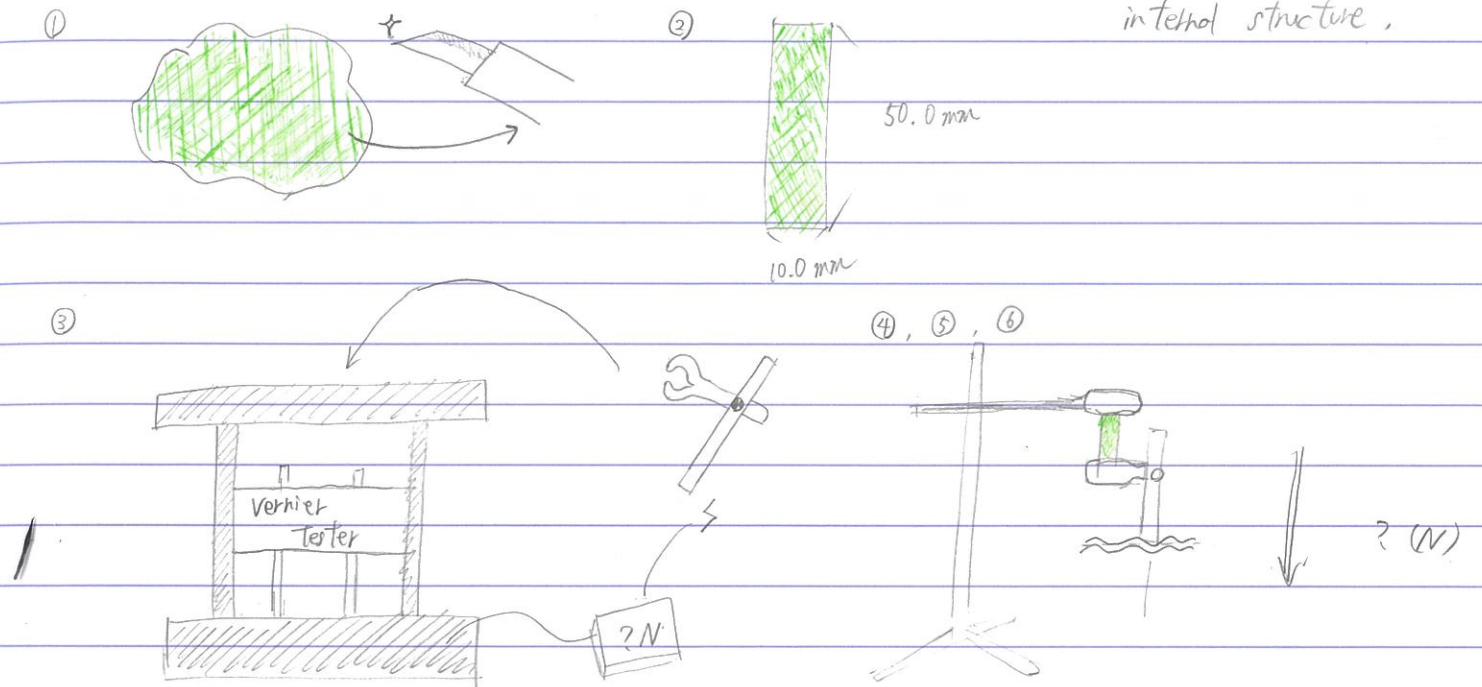
↳ Vernier Structures & Materials Tester

4. Method

- Cut the vegetable-based paper samples into strip-shaped test pieces
- Standardize the size to $10.0 \text{ mm} \times 50.0 \text{ mm}$, measuring the thickness of a sample
- Connect the clamp to the vernier tester.
- Use a clamp stand with a clamp to hold the upper end of the sample.
- Attach the lower end of the sample to the vernier tester.

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- Pull the sample using the testing equipment.
- Record the maximum force if the sample breaks during the test.
- Repeat the same procedure for the different vegetable-based paper samples.
- Based on the results obtained, it will be examined the relationship between strength and internal structure.

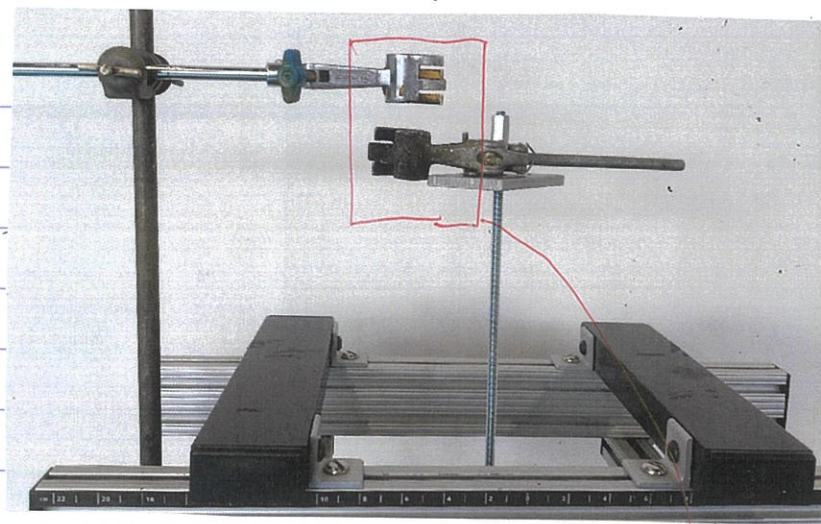


5. Observation Points

- whether the sample could be held firmly by the clamp.
- whether the sample broke in the middle or slipped out from the clamp before breaking.
- whether the clamped part of the sample was damaged during the test.
- whether the maximum force could be recorded correctly.
- Compared to observations under a microscope, what trends can be observed.

6. Hypothesis

- Based on the amount of fibre observed through microscope observation, the tensile strength is expected to be highest in the order of celery, carrot, sweet potato, and potato.



Experimental Log

Date: 15 June 2026 (Day 1)

1:20 PM Experiment started

1:35 PM Device setting was completed

★ Problem

- When attempting the experiment, the sample slipped between the clamps and it was impossible to secure it.

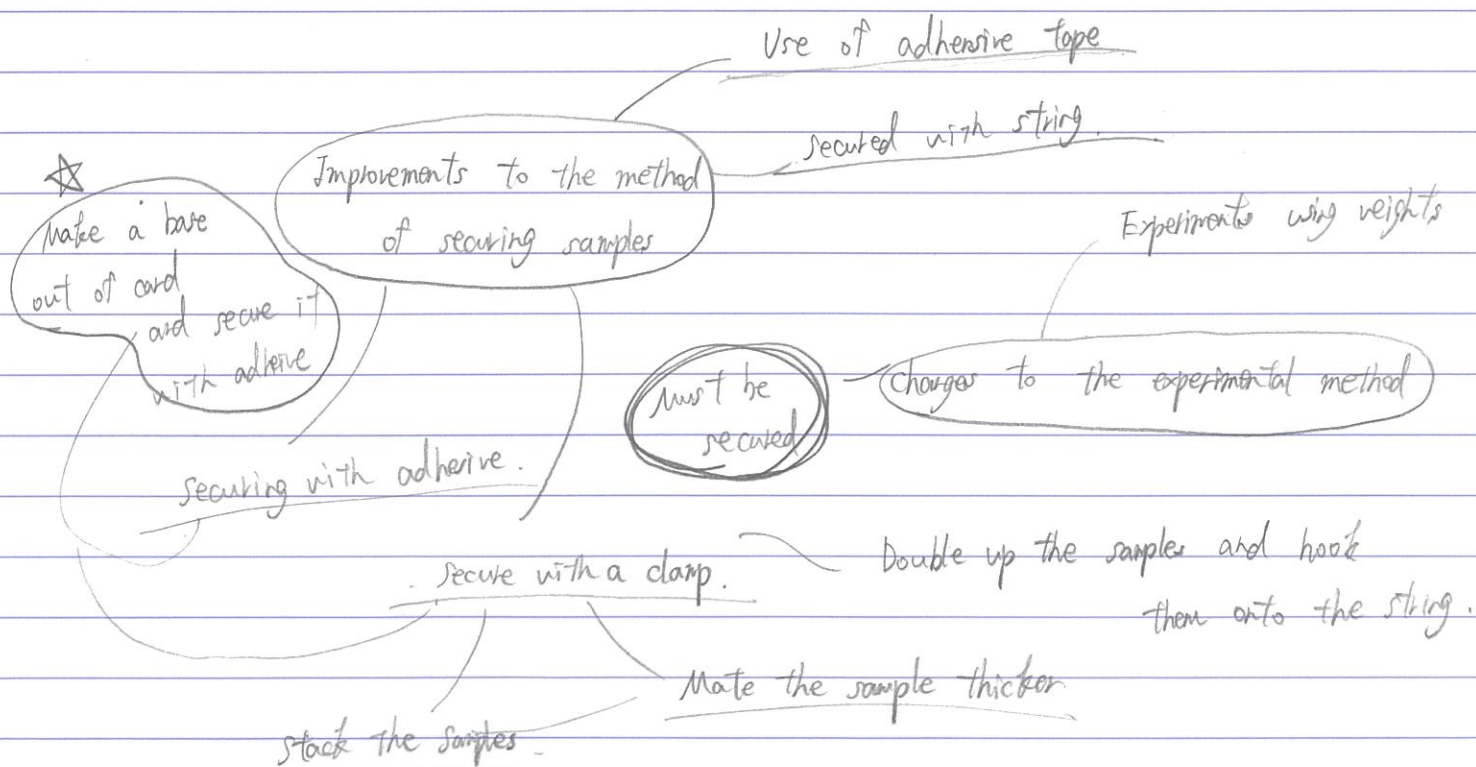
↓

The experiment was halted

Experimental Note

- The sample was too thin to secure.
- To measure the strength accurately, it must be securely fixed at both the top and bottom.

Idea for improvements brainstorming



Improvement for the next experiment.

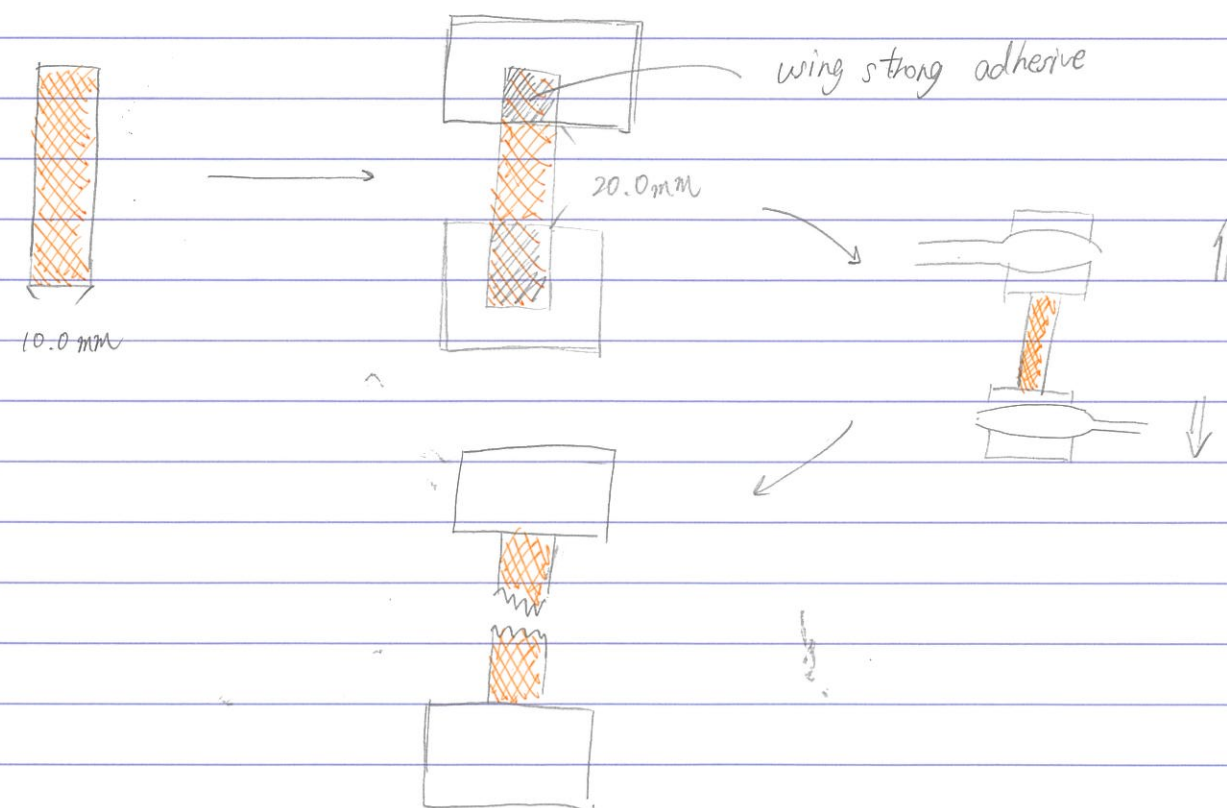
- In the next experiment, a base will be added to secure the samples more reliably during the strength tests. The base will be made from thick cardboard, and a strong adhesive will be used at the points of attachment to the sample.

This will prevent the sample from slipping out of the clamps or tearing at the points of attachment during the strength tests, ensuring that it breaks at its centre.

The length of the section not banded will be standardised to 20.0 mm for all samples.

It is anticipated that this method will enable us to measure the tensile strength of the samples accurately.

★ Images



Experimental Log / Results

Date: 16 June 2026 (Day 2)

Log

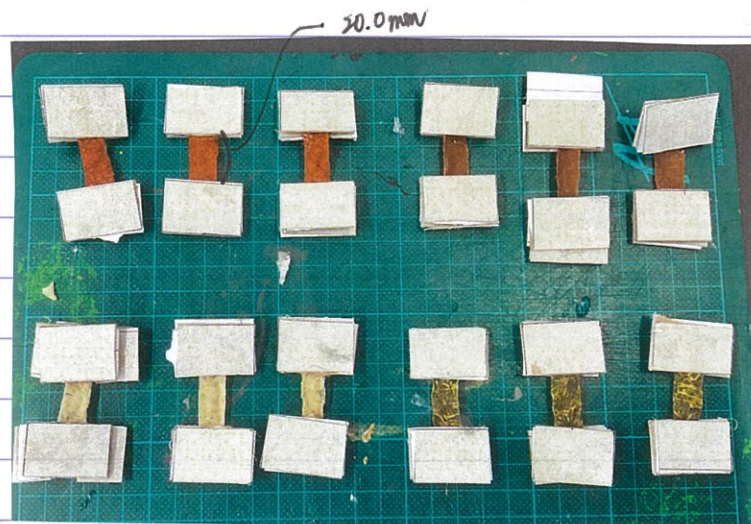
Points / Results

9:21 AM Preparation for the experiment started

measured the thickness of the sample

- I made base out of card.
- When doing so, I took the above points regarding the adhesive into account and ensured that the length of the unadhered section was uniformly 20.0 mm.

- Three test specimens were prepared from each of the four types of vegetable samples.



10:36 AM Preparations for the experiment were completed

11:07 AM Experiment started

- The experiment was carried out using the method described on Pages 56 and 57.

11:09 AM carried out an experiment in celery sample

- ① 18.7 N
 - ② 31.3 N
 - ③ 32.2 N
- It was reversed at the centre of the sample.

11:26 AM carried out the experiment with potato sample

- ① X
 - ② 24.5 N
 - ③ 22.8 N
- was reversed at the centre of the sample.

11:41 AM carried out the experiment using sweet potato sample

- ① 26.1 N
- ② X
- ③ 27.0 N

12:03 PM carried out the experiment using carrot sample

- ① 23.4 N
- ② 24.2 N
- ③ X

12:24 PM Experiments completed.

- Using the improved fixation method, the samples could be held more firmly during the strength test, and the breaking force could be measured.

The experimental measurement results are shown below table.

Sample	Thickness (mm)	Breaking force 1 (N)	Breaking force 2 (N)	Breaking force 3 (N)
Celery	0.6	X (1)	31.3	32.7
Potato	1.3	X (2)	24.5	22.8
Sweet potato	1.0	26.1	X (3)	27.0
Carrot	0.5	23.4	24.2	X (4)

- (1) The first trial for the celery failed. A force of 18.7 N was recorded, but the sample already had a crack before the test. During the test, the sample tore easily from this crack. Therefore, this result has not considered reliable and was excluded from the valid data.

- (2) The first trial for the potato sample could not be measured because the sample broke while it was being set up in the testing equipment. Therefore, no reliable breaking force was recorded for this trial, and it was excluded from the valid data.

(3) The second trial for the sweet potato sample failed because the adhesion between the sample and the support base was not strong enough. The sample slipped out of the support base before the sample itself broke. Therefore, the breaking force could not be measured correctly, and this trial was excluded from the valid data.

(4) The third trial for the carrot sample failed for the same reason as the sweet potato sample. The adhesion between the sample and the support base was not strong enough, so the sample slipped out of the support base before breaking. Therefore, this trial was not used as valid data.

The other samples broke in the exposed central section, as shown in the photo.



Appearance of the Samples After the Experiment

Calculation

Only valid trials were used for the calculation. The sample either slipped out of the support base, broke before testing, or already had a crack before the test.

First, the average breaking was calculated from the valid trials:

$$(\text{Average breaking force}) = \frac{(\text{Valid Trial 1}) + (\text{Valid Trial 2})}{2}$$

Next, the cross-sectional area of each sample was calculated using the width and thickness of the sample:

$$(\text{Cross-sectional area}) = \frac{(\text{width}) + (\text{thickness})}{2}$$

In this experiment, the width of each sample was 10.0 mm.

Finally, tensile strength was calculated by dividing the average breaking force by the cross-sectional area:

$$(\text{Tensile strength}) = \frac{(\text{Average breaking force})}{(\text{Cross-sectional area})}$$

The calculated values are shown in the table below.

Sample	Valid breaking force (N)	Average breaking force (N)	Thickness (mm)	Cross-sectional area (mm ²)	Tensile strength (N/mm ²)
Celery	31.3, 32.2	31.75	0.6	6.0	5.29
Carrot	23.4, 24.2	23.80	0.5	5.0	4.76
Sweet potato	26.1, 27.0	26.65	1.0	10.0	2.66
Potato	24.5, 22.8	23.65	1.3	13.0	1.82

Discussion

1. Was the experiment carried out appropriately?

- On day 1, the samples slipped out of the clamp before breaking, so no valid data for analysis could be obtained.
- On day 2, a support base was added as an improvement. Many sample broke in the exposed central section and valid data could be obtained.



The improved experimental method was considered more suitable.

2. Was the calculation method appropriate?

- In the experiment, the thickness of each sample and the maximum load at breaking point were measured.

Because the thickness of each sample was different, the strength could not be evaluated fairly using only the load at breaking point. However, by calculating the maximum load per unit cross-sectional area, the strength of the of the sample could be compared.

- As a result, the potato sample showed a relatively high load at breaking point, but its maximum load per unit cross-sectional area was low. This showed that its tensile strength was low.



This calculation method allowed samples with different thickness to be compared more fairly.

3. What can be said from the result?

- The order of tensile strength was:

Celery > Carrot > Sweet potato > Potato

- Celery showed the clearest fibre-like structures and had the highest tensile strength.
- Carrot also showed visible fibre-like structures and had the second highest tensile strength.
- Sweet potato and potato had lower tensile strength, and their fibre-like structures were less clear.



These results suggest that samples with more visible fibre-like structures tended to have higher tensile strength.

4. Limitation

- Only two valid trials were used for each vegetable sample because one trial failed for each sample.
- Some samples had cracks or broke during setup, which may have affected the reliability of the results.
- The adhesion between the sample and the support base was not always strong enough.
- The microscope observation was qualitative, so the amount of fibre was not measured numerically.
- The cellulose content was not chemically measured, so it cannot be concluded that cellulose amount directly caused the difference in tensile strength.



The result show a trend, but more repeated trials and more controlled sample preparation would be needed to confirm the relationship more strongly.

Risk Assessment Summary

During this investigation, I considered possible risks related to chemicals, heating, glassware, cutting tools, the pressing process, mould-like sample, and the tensile strength testing equipment. The main risks and control measures are summarised below.

Risk factor	Risk	Control measures taken
0.5 mol/L and 0.1 mol/L sodium hydrochloric	It could irritate the skin and eyes	Wore Safety glasses, gloves and a laboratory apron, and avoided contact with the skin or eyes
0.5 mol/L hydrochloric acid	It could irritate or damage the skin and eyes.	If the solution is spilled or comes into contact with body, rinsed with plenty of water and report the incident to the supervisor.
Heating process	Burns, fire risk, or hot glassware could cause injury	Used a heat-resistant mat, and did not touch equipment directly during or immediately after heating. Did not leave the area while heating was in progress
Knives Cutters scissors	Injuries caused by the use of knives	Used them on a stable cutting board, and did not place hands in the direction of the blade. After use, placed them in a safe location.
Glassware	Injury caused by broken glassware	Handled glassware carefully and avoided strong impacts. If glassware broke, did not touch it with bare hands, and reported it to the supervisor
Weights	Bruises caused by the use of weights	Used weights on a flat surface, and did not place hands under the weights, Placed the weights slowly and carefully.
Mould or Unpleasant odours	Possible fungal material could be contacted or inhaled.	If any abnormalities were observed in the sample, reported them to the supervisor and avoided touching directly. Washed my hands after observation

Risk factor	Risks	Control measures taken
Vernier structures & Materials Tester	Finger injuries	Kept hands and face away from the moving part and the piece during measurement. Operated the device according to the supervisor's instruction.
Adhesives	skin contact and inhalation of vapour	Used only the minimum necessary amount of adhesive and handled it in a well-ventilated area. If it came into contact skin, did not rub it vigorously; consulted the supervisor.

Assistance Received

During this investigation, I received support from Mr. Mihelios, Mr. Noack, Mr. Lewis, and Mr. Fisher at Hamilton Secondary College. They provided me with the opportunity to conduct the experiments and allowed me to use the necessary experimental equipment.

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In developing this research project, I used ChatGPT and DeepL to support the organisation of my writing and English translation. The final content, interpretation, and conclusions are my own responsibility.